STANDARDISATION AND EVALUATION OF THERMAL AND NON-THERMAL PROCESSING OF RIPE JACKFRUIT

by

SARANYA S

(2019 - 28 - 022)

DEPARTMENT OF PROCESSING AND FOOD ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND FOOD TECHNOLOGY

TAVANUR, MALAPPURAM- 679573

KERALA, INDIA

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THESIS

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND FOOD TECHNOLOGY

TAVANUR, MALAPPURAM- 679573

KERALA, INDIA

2025

DECLARATION

I hereby declare that this thesis entitled **"Standardisation and evaluation of thermal and non-thermal processing of ripe jackfruit"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Dedicated to

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SYMBOLS AND ABBREVIATIONS

et al.	:	and others
%	:	per cent
&	:	and
/	:	per
<	:	less than
>	:	greater than
±	:	Plus or minus sign
ΔE	:	Total colour difference
°	:	degree
°Brix	:	Degree brix
°C	:	degree celsius
a*	:	Greenness or redness
AA	:	Ascorbic Acid
Al	:	Aluminium
ALPE	:	Aluminium laminated polyethylene
AOAC	:	Association of analytical chemist
b*	:	Blueness or yellowness
BI	:	Browning Index
C.V.	:	Coefficient of variation
Ca	:	Calcium
CCD	:	Central Composite Design

CFU	:	Colony Forming Unit
CRD	:	Completely randomized design
Cu	:	Copper
df	:	Degree of freedom
DPPH	:	2,2-diphenyl-1-picrylhydrazyl
etc.	:	etcetera
F	:	F value
Fe	:	Iron
Fig.	:	Figure
g	:	gram
g/mL	:	Gram per mililiters
GAE	:	Gallic acid Equivalent
h	:	Hour
HPP	:	High Pressure Processed
J/cm^2	:	Joules per centimeter square
kg	:	kilogram
Kg/cm^2	:	Kilogram per square centimetre
L*	:	Lightness or darkness
mg	:	milli gram
min	:	minute
mL	:	milliliter
Mn	:	Manganese
MPa	:	Mega Pascal
Na	:	Sodium

NaOH	:	Sodium hydroxide
No.	:	Number
p	:	probability
pH	:	percentage of H+ ions
PL	:	Pulsed light
PP	:	Poly propylene
RE	:	Rutin equivalents
RJB	:	Ripe jackfruit bulb
RJP	:	Ripe jackfruit pulp
RSM	:	Response Surface Methadology
s	:	second
SD	:	Standard deviation
Sl.	:	Serial
T	:	treatment
TA	:	Titrable acidity
TAM	:	Total aerobic mesophiles
TFC	:	Total Flavanoid Compound
TPC	:	Total Phenolic Compound
TSS	:	Total Soluble Solids
viz	:	namely
w/w	:	weight by weight
YI	:	Yellowness Index
µm	:	micro meter

Introduction

CHAPTER I

INTRODUCTION

India is a tropical country, and summers here can be very health excruciating. With over 45ºC outside, one needs to be well hydrated and take precautions to stay energised to beat the heat. The best way to do that and cool your taste buds is to be a seasonal fruit and vegetable lover. Seasonal fruits and vegetables consist of rich ingredients and essential nutrients that are required to stay healthy. Alongside water content, these also provide the body with lot of vitamins and minerals, keeping several health hazards at bay.

Jackfruit (*Artocarpus heterophyllus Lam*.) is one of the largest tree-borne spiky seasonal fruits, characterized by strong, sweet scents and aroma and distinctive taste. In 2022, global jackfruit production was estimated at approximately 3.7 million tonnes, with India contributing over 1.4 million tonnes, making it the largest producer worldwide (Pathak *et al.,* 2022). Jackfruit is a fruit packed with minerals such as sodium, potassium, calcium, phosphorous, and iron (Amadi *et al.*, 2018). Fruit provides essential dietary fiber, vitamins, and sugars to the diet. Studies showed that phytochemicals such as carotenoids, polyphenols, and flavonoids have different levels in jackfruit according to different stages of development (Chandra and Bharati, 2020). The high-profile phytochemicals found in jackfruit may contribute to its health-promoting properties. It is eaten fresh or made into cakes, juices, ice creams, and crisps when ripe. It was officially declared the state fruit by the Government of Kerala in 2018 (Anon., 2018). This announcement comes at a time when the Kerala Government is looking into the possibility of branding ‘Kerala Jackfruit’ as a brand to bring attention to its organic and nutrient-dense qualities throughout the country and abroad. By positioning the Kerala Jackfruit as a brand, the state government can leverage its unique characteristics and capture the interest of consumers both domestically and internationally. The jackfruit was once considered a humble crop without any commercial status before it was declared the official fruit of Kerala. Despite its composition and texture, the fruit is perishable and cannot be stored for a long time. There were rotten yellow puddles under every tree in rural homesteads, since this fruit has no market value. Due to insufficient postharvest knowledge during harvest, transportation, and storage, a considerable amount of jackfruit in particular is wasted

throughout the glut season every year. The major constraint to the marketability of jackfruit is its limited shelf-life due to rapid microbial growth and colour loss. A standardised process protocol for the minimally processed jackfruit can reduce post-harvest losses and boost the production sector. This will provide better returns to the farmers, various stakeholders of the supply chain, and ultimately improving the self-sufficiency of the country.

The fruit and vegetable processing market are expected to experience significant growth in the coming years. According to the data, the market is estimated to have reached approximately INR 714 million in 2022. Furthermore, it is projected to expand at a compound annual growth rate (CAGR) of 6.4% from 2022 to reach a value of nearly INR 96,85,14,500 by 2027 (Markets and Markets, n.d). The processed fruit and vegetables market is specifically driven by the ever-increasing needs of busy consumers due to the fast pace of modern life. As people's incomes increase, they have more discretionary income to spend on convenience foods that require minimal preparation. This has led to an increase in the demand for ready-to-eat and on-the-go foods such as pre-packaged snacks, and beverages. As a result of the high growth in the industry, the outlook for the fruit and vegetable processing market appears positive. This is due to the increasing demand for processed fruits and vegetables from consumers, the technological advancements in the processing industry, and the growing number of food processing companies that are entering the market.

Processing of fruits and vegetables will check microbial growth, improve their preservability and enhance sensorial characteristics. Nowadays, consumers are increasingly looking for food products that are as close to their natural taste and flavour as possible, with minimal processing and few added ingredients or minimum preservatives and there is, therefore, a strong tendency towards consumption of premium quality products. The conventional practice of inactivating microbial population by thermal processing helps to extend the product storability and inactivate heat-stable enzymes. In spite of its advantages, thermal processes do have some downsides, such as slow convection and conduction heat transfer. It is also possible to overcook food, resulting of desirable taste, texture, aroma, or appearance, while also being deficient in essential nutrients (Petruzzi *et al*., 2017). It means that the food not only fails to provide adequate nourishment but also fails to meet the expectations of

sensory enjoyment. According to Chen *et al.* (2013), thermal treatments' efficacy can also be affected by several factors, such as the complexity of the product and the microorganisms that reside in it. In the case of minimally processed fruits and vegetables, many methods have been tested and successfully proposed, but thermal processing remains the most cost-effective solution. Contrary to thermal processing, non-thermal processing can preserve quality characteristics in minimally processed fruits and vegetables. Non-thermal preservation techniques such as high pressure and pulsed light processing are believed to be more effective at preserving the original nutrients and flavour of the food, while also reducing the risk of contamination from pathogens. Additionally, these techniques are more energy-efficient than traditional thermal processing methods.

High-pressure processing (HPP) is a non-thermal way to produce high-quality food that maintains the freshness of the product and extends its shelf life. HPP works by applying a high level of hydrostatic pressure to food products, which kills microorganisms and other spoilage agents responsible for food spoilage without the need for high temperatures. This makes it ideal for preserving freshness and extending shelf life without compromising the quality and nutritional value of the food. The process includes using high levels of pressure on packaged or bulk food products. This pressure can range from 100 to 600 megapascals (MPa) and lasts for a specific amount of time (Abera, 2019). The high pressure is evenly distributed all over the product package or container. Contrary to thermal processing, HPP primarily affects the non-covalent bonds. This ensures the highest product quality while minimizing changes in taste and nutrition. Previous studies have already reported the potential ability of HPP in retaining the bioactive compounds, enzyme inactivation, and microbial destruction in fruits and vegetables. HPP processed mango pulp was shown to retain up to 129% of ascorbic acid (AA) after a single 600 MPa pulse (Kaushik *et al*., 2014). As the world population is becoming increasingly urbanized, there is an increase in the number of young people and changes in lifestyles. Increasing disposable incomes and more nuclear families create demand for HPP foods. It is estimated that HPP is worth USD 15,523.36 million in 2019, indicating its economic significance and growth potential in the food industry, since it offers a safe and longer-lasting alternative to preserving perishable food (Anon, 2020).

Pulsed light (PL) technology is another environmentally friendly short-time non-thermal decontamination technique for fruit juices. In PL an intense pulse of light with 100-1100 nm wavelengths is used on the target within a short time. The pulse covers ultraviolet, visible, and near-infrared wavelengths. The major application of PL is in surface decontamination of food and packaging materials. Upon absorption of the high intensity PL by the microbial DNA, genetic information is impaired. This process is also known as photodamage or photochemical damage, which is caused by the absorption of light energy within the microbial cells. This energy is then converted into heat, resulting in the denaturation of proteins and nucleic acid molecules, and ultimately cell death (Chen *et al*., 2013). Pataro *et al*. (2011) found that membrane damage played a crucial role in bacterial inactivation by PL in apple and orange juice. In addition to the photochemical effect, the photothermal effect can also play a significant role in the destruction of microbes during PL processing. A number of fruit juices have been studied using PL technology to kill food microbes and inactivate enzymes over the course of the past year. The effects of PL treatment on the microbial load of lactic acid fermented Mulberry juice have been reported to be acceptable without affecting the biochemical properties (Kwaw *et al*., 2018). Food and Drug Administration, 2015, approved PL applications for food processing and handling with a UV dosage of 12 J/cm^2 and pulse duration ≤ 2 ms. Food treatment with PL has been attempted on a small scale, but there is no evidence that it is useful on a large scale.

In a few studies, temperature control was demonstrated to be an effective method for safely storing ripe jackfruit. However, nonthermal methods such as HPP and PL have yet to be investigated. This study attempted to standardise thermal and non-thermal processing of ripe jackfruit and evaluate the quality and storage of ripe jackfruit processed with retort pouches, high pressure, and PL techniques. The major objective of the study consists of:-

- Standardisation of thermal process protocols for ripe jackfruit and its pulp using retort pouch packaging
- Standardization of non-thermal processing protocols for ripe jackfruit and its pulp using HPP, and for pulp using PL technology
- Safety and quality evaluation of thermal and non- thermal processed ripe jackfruit

Review of literature

CHAPTER II

REVIEW OF LITERATURE

This research project aims to standardise and evaluate ripe jackfruit's thermal and non-thermal processing, specifically its bulb and pulp. To achieve this, a thorough literature review was conducted to gather relevant information that aligns with the project's objectives.

2.1 Jackfruit (*Artocarpus heterophyllus L.)*

Jackfruit (*Artocarpus heterophyllus Lam*.), a member of the Moraceae family and the Rosales order, is believed to have originated in the rainforests of southwestern India, specifically the Western Ghats (Swetha and Ranganna, 2016). Today, it is cultivated extensively in various tropical regions around the world, including Southeast Asia, West Africa's evergreen forests, northern Australia, and southern Florida (Shyamalamma *et al*., 2016). Countries in Southeast Asia and the Caribbean are significant producers of jackfruit, with India being a major contributor. In India, jackfruit cultivation is prominent in both southern and northeastern states such as Kerala, Karnataka, Andhra Pradesh, Tamil Nadu, Assam, Tripura, Bihar, Uttar Pradesh, and the Himalayan foothills. It is commonly referred to as "poor man's food" in eastern and southern India due to its affordability and nutritional value (Srivastava *et al*., 2017). Kerala stands out as one of the primary region for jackfruit cultivation in India, with approximately 156,000 hectares dedicated to this fruit. The annual production in Kerala reaches around 1.826 million metric tons, resulting in an impressive productivity rate of 12 metric tons per hectare (Anon, 2022). This significant yield highlights jackfruit's importance as a staple agricultural product in the state, contributing to local consumption and potential export markets. Jackfruit is renowned for being the world's largest fruit, capable of growing over ten inches long and reaching up to forty inches in size. The ripe fruit features yellow flesh with a sweet flavour that distinguishes it from other tropical fruits. Nutritionally, jackfruit is rich in starch and protein and serves as an excellent source of essential vitamins and minerals such as vitamins A and C, calcium, potassium, sodium, thiamin, iron, and zinc (Dey and Baruah, 2021). Its high carotene content and substantial vitamin C levels play a crucial role in protecting against

free radicals, enhancing immune function, and promoting gum health. Compared to other tropical fruits, jackfruit is particularly notable for its elevated levels of protein, calcium, iron, and thiamine (Dey and Baruah, 2021).

India ranks among the top producers of jackfruit, a tropical fruit that thrives in warm and humid conditions, particularly on hilly terrains and in hot plains. This versatile fruit serves multiple roles, with immature jackfruits often prepared as vegetables and ripe ones enjoyed as fresh fruit. Traditionally, jackfruit trees produce fruit once a year, with flowering occurring between November and February, depending on the location and variety (Fathin *et al*., 2021 and Mandave *et al*., 2022). The tender fruits become available in the market from March to August, with ripening taking place in June. However, the fruit's high water content and soft texture make it highly perishable, resulting in significant wastage (around 30-34%) during the peak season (June-July) due to inadequate post-harvest handling practices (Shinde *et al*., 2021). To address this issue, processing and preservation techniques are essential to extend the fruit's shelf life, create diverse and appealing food products, and generate income and employment opportunities.

2.2 Nutritional benefits of jackfruit

Jackfruit (*Artocarpus heterophyllus*) is a tropical fruit renowned for its rich nutritional profile and potential health benefits. The edible pulp of jackfruit is a significant source of carbohydrates, providing approximately 18.9 grams per 100 grams, along with 1.9 grams of protein, 0.1 grams of fat, and 1.1 grams of fiber, making it an energy-dense food (Rahman and Nahar, 1990). Additionally, it is rich in essential minerals such as calcium (20 mg), phosphorus (30 mg), and iron (500 µg) per 100 grams, which play a crucial role in bone health, muscle function, and oxygen transport (Bobbio *et al*., 1978). The nutritional composition of ripe jackfruit in 100 g edible portion-fresh weight basis recorded from previous researches is listed in Table 2.1 below

Table 2.1 Nutritional composition of ripe jackfruit (100 g edible portion-fresh weight basis)

Proximate composition	Water (g)	72.0–94.0	
	Protein (g)	1.2−1.9	
	Fat (g)	0.1−0.4	
	Carbohydrate (g)	16.0–25.4	
	Fiber (g)	1.0–1.5	
	Energy (kJ)	88−410	
Elemental profile	Calcium (mg)	24	source:
	Iron (mg)	0.23	Swami *et al*.,
	Magnesium (mg)	29	2012,
	Manganese (mg)	0.043	Waghmare *et*
	Phosphorous (mg)	21	*al*.,2019 and
	Potassium (mg)	448	Villacís-
	Sodium (mg)	2	Chiriboga *et*
	Zinc (mg)	0.13	*al*., 2020
Vitamin profile	Thiamine (mg)	0.105	
	Riboflavin (mg)	0.055	
	Niacin (mg)	0.92	
	Pantothenic acid	0.235	
	(mg)	0.329	
	Vitamin B6 (mg)	24	
	Folate (µg)	13.8	
	Vitamin C (mg)		
	Phenolics (mg	0.18 to 0.46	
	GAE/g)		
	Carotenoids content	1.32	
	(µg/g FW)[2]		

FW: Fresh Weight

Jackfruit is notably high in vitamins, particularly vitamin C, with 13.7 mg per 100 grams, which plays a role in immune support and antioxidant protection (Swami *et al*., 2012).

It is also a good vitamin A (540 IU) source, contributing to vision health and skin maintenance (Hossain *et al*., 2020). Additionally, it provides B-complex vitamins such as thiamine, riboflavin, and niacin, which are essential for energy metabolism and nervous system function (Nansereko and Muyonga, 2021). Furthermore, jackfruit's low-fat and high-fiber nature makes it a suitable dietary choice for weight management and cardiovascular health (Healthline, 2022). The high antioxidant content in jackfruit, derived from carotenoids, flavonoids, and phenolic compounds, contributes to its anti-inflammatory and disease-preventing properties (Brahma and Ray, 2023).

2.3 The challenges and opportunities of jackfruit processing and preservation

Jackfruit, a tropical fruit renowned for its unique aroma and crunchy, sweet flesh, is a versatile ingredient that can be consumed raw or cooked in a variety of dishes. It is a promising crop for addressing food security and poverty in rural and urban areas, offering a wealth of opportunities for value-added products. The fruit's various parts, including the pulp, peel, and seed, can be utilized to create a range of products. Ripe jackfruit bulbs can be canned in syrup or mixed with dehydrated bulbs to make chutney, preserves, candy, concentrates, and powder. Ripe jackfruit pulp is used to make various products such as juice, biscuits, jam, jelly, leather, RTS products etc. making it a valuable resource for sustainable development. However, its massive size, often exceeding 45 kg, and handling difficulties have hindered its marketing (Jagadeesh *et al*., 2007). Since only one-third of the fruit is edible, jackfruit is a prime candidate for minimal processing, allowing for efficient use of its edible parts.

The demand for fresh cut fruits has experienced rapid growth in recent years. According to Bansal *et al.* (2015) minimal processing is gaining popularity over traditional preservation methods due to its superiority in terms of sensory quality and nutritional value. Furthermore, the food service industry is shifting towards using pre-prepared ingredients to reduce handling and operating costs, thereby increasing efficiency. However, the fruit's high perishability and susceptibility to mechanical

injuries result in significant wastage, with an estimated loss of Rs 2,000 crore in India alone (Anaya-Esparza *et al*., 2018). Given the short shelf life of fresh jackfruit, preserving it as fresh-cut pieces or pulp is crucial to extend its availability and stabilize prices during peak seasons. Modern consumers increasingly favour diets high in natural antioxidants, dietary fibres, natural colourants, minerals, vitamins, low calories, low cholesterol, low sugar, and free from chemicals (Shinde *et al*., 2021). To address the significant postharvest losses of jackfruit, it is essential to research innovative technologies for better preservation quality of safe jackfruit bulbs and pulp, enhancing its value and utilization.

Thermal and non-thermal preservation methods play a major role in preserving ripe jackfruit and extending its shelf life. The choice of preservation method depends on various factors, including the type of jackfruit, its intended use, and the desired shelf life. Thermal preservation methods are often preferred for commercial-scale applications due to their ease of implementation and cost-effectiveness. However, non-thermal preservation methods offer a promising alternative for small-scale producers and consumers who prioritize natural and minimally processed products (Nelluri *et al*.,2022).

2.4 Thermal preservation of fruits

The preservation of ripe jackfruit through thermal methods has gained significant attention due to its potential to prolong shelf life. Thermal processes can be categorized based on the intensity of heat treatment applied (Miller and Silva, 2012). The high temperature long time method, which involves temperatures around 80°C with holding times exceeding 30 seconds, is frequently utilized in processing juices and beverages. This method can be further classified into pasteurisation (below 100°C), canning (approximately 100°C), or sterilisation (above 100°C) (Miller and Silva, 2012). The goal of thermal preservation is to reduce the most resistant microorganisms by 5 logs. This process uses external heat, which is then transferred to the food through conduction and convection. Prolonged exposure to high temperatures can lead to cell death by causing gradual changes in membrane permeability, including lipid phase transitions and protein conformation alterations. The degree of membrane fluidity changes depends on the type of thermal stress applied (Chen *et al*., 2013). Thermal

processing has been shown to effectively reduce microbial growth and enzymatic activity, thereby enhancing shelf stability with a significant effect on the physicochemical properties (Saxena *et al*., 2012 and Chen *et al*., 2013).

A study by Rathod *et al*. (2014) investigated the effects of thermal processing on the nutritional quality of amla and bael blend juice processed at 80°C to 90°C for a duration of 25 seconds. The findings revealed that treating the blend at 90°C yielded the best results in terms of nutritional quality. This optimal temperature treatment helped in retaining the essential nutrients and bioactive compounds present in both amla and bael juice, which are known for their high vitamin C content, antioxidants, and other beneficial phytochemicals. The treatment also ensured microbial safety and extended shelf life, making the juice blend more suitable for consumption while maintaining its nutritional integrity.

The total sugars content was significantly higher when the carrot and grape blended nectar was subjected to a thermal treatment of 80°C for 5 min. According to Yadav *et al*. (2015), this specific temperature and duration not only helped in retaining the sugars present in the blend but also potentially enhanced their extraction and concentration. This finding underscores the importance of optimizing thermal processing conditions to maximize the retention of desirable nutritional components in fruit and vegetable nectars.

As per the study conducted by Thomas *et al*. (2015), black mulberry juice processed at 107°C for 3 min. exhibited significantly higher total phenolic content, total flavonoid content, monomeric anthocyanin content, and total antioxidant capacities compared to the raw fruit. However, during in vitro simulated gastrointestinal digestion, the monomeric anthocyanins were more bioavailable in the raw fruit matrix than in the juice matrix. The impact of thermal preservation on the physical and chemical properties of fruits and vegetable beverages has also been extensively studied, with thermal treatment found to influence the physico-chemical properties, which are critical quality indicators (Petruzzi *et al*., 2017). The high heat can lead to the degradation of heat-sensitive nutrients, alter the texture and consistency of food, and affect its sensory properties (Allai *et al*.,2023). These changes can significantly impact the overall quality and nutritional value of the food. Although pasteurisation ensured and prolonged

microbial safety of watermelon and pineapple juice, it had affected adversely on the colour, ascorbic acid and enzyme activities of pasteurized juices. Treatment time of 10 min significantly reduced the ascorbic acid content of both juices (Mandha *et al*., 2023).

Yıkmış *et al*. (2023) analyzed the thermosonicated and thermal pasteurized black grape juice for its bioactive components, nutritional content, and aroma profile. Thermal pasteurisation resulted in low sensory as well as lower retention of bioactive components, nutritional content, and aroma profile compared to thermosensation process. The study suggests thermosonication as a promising alternative to thermal pasteurisation, potentially improving the juice's taste and bioactive properties. Future research should focus on the amino acid content, phenolic compounds, and health benefits such as anticancer and antimicrobial properties.

Zhang *et al*. (2024) conducted studies on ultra-high pressure, thermal pasteurisation, and ultra-high temperature sterilisation of freshly-squeezed lettuce juice. The study revealed that thermal pasteurisation and treatments significantly affected the physico-chemical characteristics of lettuce juice. The chlorophyll content and total soluble content of juice were reduced significantly with these treatments and it amplified the loss of fat-soluble vitamins.

Despite some disadvantages, thermal processing methods like retort pouch packaging remain commercially viable due to their numerous advantages in preserving food products. Retort pouches offer a lightweight, flexible, and shelf-stable packaging solution, eliminating the need for refrigeration or cold chain logistics, which is particularly beneficial in regions with limited access to these resources. The extended shelf life of thermally processed foods also reduces food waste and allows for broader market distribution, making it attractive for both manufacturers and consumers. Although there are challenges such as potential nutrient loss and higher initial equipment costs, the overall cost savings in transportation, storage, and reduced spoilage make this technology a profitable option for large-scale food production. Moreover, the growing demand for convenient, ready-to-eat meals further supports the adoption of retort pouch packaging in the food industry.

2.4.1 Retort pouch processing

Retort thermal processing, commonly referred to as retort pouch processing, ensures commercially sterile food products by eliminating pathogenic and spoilage-causing organisms while allowing for some heat-resistant bacterial spores that cannot grow under normal storage conditions. These products typically have a shelf life of 2 to 5 years, constrained by quality degradation rather than bacterial spoilage (Clark, 2009). The retorting process involves placing food in sealed containers/flexible pouches and heating them in a large pressure cooker called a retort, where specific temperatures above the boiling point of water are maintained for precise durations depending on the nature of fruit and several other parameters. The processing time and temperature must be sufficient to render the product commercially sterile. After cooking, the container is cooled to room temperature for further study. Key factors such as decimal reduction time (D), thermal resistance constant (z), and thermal death time (F) values are used to determine appropriate processing times and temperatures to achieve commercial sterility while minimizing nutrient loss and sensory degradation.

Establishing an effective thermal processing schedule requires determining the appropriate heating duration at a specific temperature. This process involves assessing the thermal destruction rate of a target microorganism or enzyme under actual processing conditions. Additionally, understanding how microbial destruction or enzyme inactivation varies with temperature is crucial, particularly during the come-up time, when the product reaches the desired processing temperature.

The microbial destruction rate is quantified by the decimal reduction time (D value), which represents the time in min. needed at a given temperature to reduce the microbial population by 90%. Higher temperatures generally result in lower D values, indicating faster microbial reduction. By plotting the logarithm of D values against temperature, a thermal resistance curve is generated, revealing the temperature sensitivity indicator, or Z value. The Z value signifies the temperature range required to alter D values by a factor of ten.

The effectiveness of thermal processing in eliminating microorganisms is measured using the F value or lethality. This metric assesses the overall sterilisation

impact of heat treatment. To compare different sterilisation processes, a standard lethality unit corresponds to 1 minute of heating at a reference temperature—commonly 121.1°C for sterilisation and 82.2°C for pasteurisation (Singh and Heldman, 2009).

For thermal processes involving a food product's exposure to a time–temperature profile, the cumulative lethal effects are calculated using the following equation:

$$Fo = \int 10^{(T-T_o)/Z}\, dt \qquad \ldots.(2.1)$$

where, T = Product temperature

To = Reference Processing temperature

Z = Temperature range required for a one-log cycle change in D value

The resulting lethality, denoted as process lethality, represents the overall effectiveness of the heat treatment (F_0). In acidic foods, such as fruits, processing aims primarily at reducing spoilage-causing bacteria and deactivating heat-resistant enzymes rather than achieving complete sterilisation.

The primary concern in canned/retort processed foods is anaerobic bacteria, particularly *Clostridium botulinum*, which can produce a deadly toxin under favorable conditions. The industry employs the 12-D concept to ensure that the thermal process effectively reduces the survival probability of these spores to one in a billion containers. Additional heat treatments are often applied to account for other heat-resistant spoilage bacteria, with *Bacillus stearothermophilus* frequently used as a non-pathogenic surrogate for testing process effectiveness (Clark, 2009).

2.4.2 Retort pouch processing system

Various types of retorts have been developed to meet the diverse needs of packaging and manufacturing in thermal food processing, and they are primarily classified by the method of heating, batch vs. continuous operation, and the mode of agitation. Common heating methods include saturated steam, water immersion, water spray, and steam-air systems (Al-Baali, and Farid, 2007). Saturated steam retorts, typically used for metal cans, are energy-intensive but cost-effective. They require

steam saturation to prevent air pockets that could insulate containers and reduce efficiency, with overpressure sometimes applied during cooling to avoid container deformation. Water immersion and water spray retorts enable overpressure processes, making them suitable for more fragile containers like glass or flexible pouches. Steam-air retorts use fans to mix air and steam, ensuring even heating without cold spots, thus accommodating various container types.

Steam air retorts are typically configured in either a vertical or horizontal (Figure 2.1) orientation. These metal pressure vessels are equipped with several key features, including a steam inlet (A), water inlet (B), venting outlets for releasing air during the retort's heat-up phase and for draining (D), outlets for venting at the end of the cycle (C), and a safety pressure relief valve (F). Additionally, the vessel is outfitted with a pocket for instruments such as a thermometer, a temperature-recording probe, and a pressure gauge.

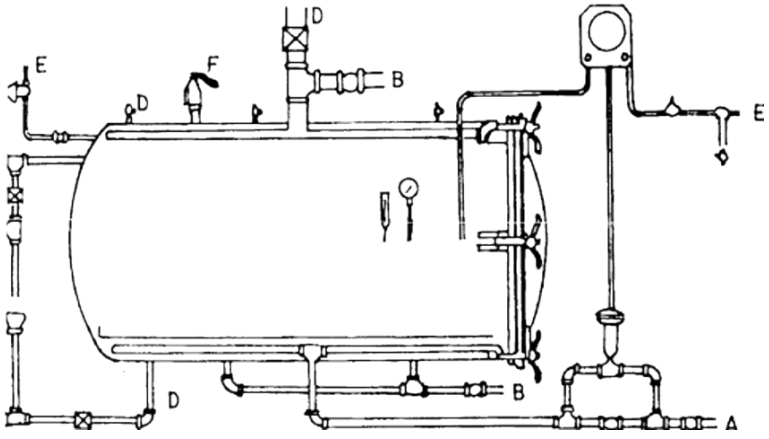


Figure 2.1 Horizontal retort machine

(*Source: Al-Baali, and Farid, 2007*)

The operation of this retort begins by heating it to approximately 121°C. Steam is introduced to remove all air from the retort and the spaces between containers (venting), after which the retort reaches the target pressure and processing temperature (Al-Baali, and Farid, 2007). Once processing is complete, the steam is turned off and a combination of cooling water and air is introduced to cool the containers. The air helps maintain pressure as the remaining steam condenses; without this, containers could deform due to pressure imbalances between the interior and exterior. Current efforts in

thermal sterilization aim to enhance heating rates, thereby boosting production efficiency while minimizing quality degradation in the product (Caufield, 2014).

Retorts are also categorized as batch or continuous systems. Batch retorts require manual loading and unloading, with each batch undergoing separate heating and cooling phases, adding time and labour to the process. In contrast, continuous retorts streamline production by allowing containers to enter and exit without temperature and pressure fluctuations, reducing processing time and labour costs. Continuous systems, such as rotary and hydrostatic retorts, rely on conveyors for automated container movement, where the residence time depends on conveyor speed. Retorts can further be divided based on agitation: static retorts hold containers stationary, while rotary and oscillating systems agitate the containers to improve heat distribution. Rotary retorts are widely used for metal cans, while oscillating retorts, a newer innovation, can handle a variety of container types, including flexible pouches and semi-rigid trays (Ramesh, 2020).

2.4.3 Retort pouches

Retort pouches are a type of flexible packaging designed for shelf-stable and sterilized food products, such as soups, stews, and sauces. Made from layers of nylon, polyethylene film, and aluminum foil, these pouches create an oxygen-free environment that prevents spoilage. They are hermetically sealed to withstand high temperatures during thermal processing, resulting in an extended shelf life without the need for refrigeration. This convenience has led to their growing popularity among both manufacturers and consumers, as they are easy to transport and store.

The concept of retort pouches originated in the 1950s, promoted by the US Army and later developed by the United States Army Natick R&D Command in collaboration with Reynolds Metals Company and Continental Flexible Packaging (Primepac., 2020). Their introduction marked a significant innovation in food packaging, leading to a shift away from traditional canning methods. Although there was initial resistance to this new packaging format, its advantages—such as improved nutrient retention and customization options—have been recognized over time. The internal structure of retort pouches consists of four layers: propylene for heat sealing,

nylon for abrasion protection, aluminum for light and gas barrier properties, and polyester for strength and printability, all made from FDA-approved materials that enhance durability through thermal processes (plate 2.1) (Caufield, 2014).

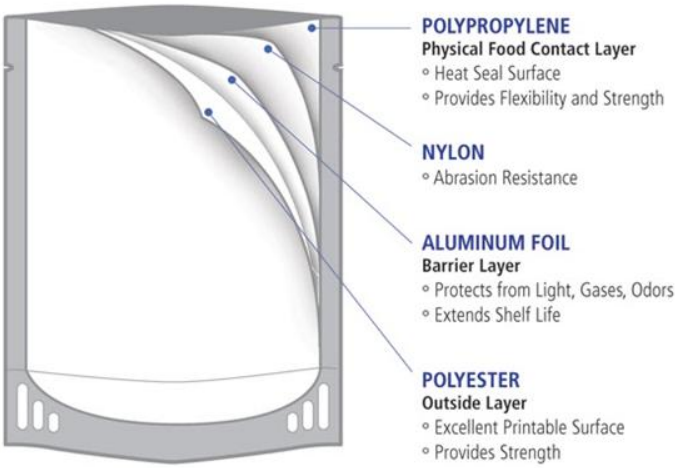


Plate.2.1 Laminate film layers in a retort pouch (Primepac. 2020)

Retort pouch technology is rapidly becoming a popular packaging solution in today's consumer market. In a country like India, where maintaining refrigeration and cold storage can be challenging, retort foods present a significant opportunity to boost the consumption of ready-to-eat (RTE) processed foods. This opens up a promising avenue for entrepreneurs to explore and capitalize on the potential of this innovative technology (Varalakshmi *et al*., 2014).

2.4.4 Effect of retort pouch processing on food products

Retort pouch processing has been widely utilized for various food products to extend shelf life while maintaining safety and sensory attributes. The process involves sealing the food in heat-resistant, flexible pouches and subjecting them to thermal sterilization. This technology is especially advantageous for RTE foods, as it ensures long-term storage at ambient temperatures. In a study by Sreelakshmi *et al*. (2015), retort pouch processing was applied to a ready-to-serve sandwich spread made from mud crab (*Scylla serrata*), processed at different temperatures and F0 values. The optimized process, with conditions of 116°C for 6 min., achieved the best results in terms of texture, colour, and commercial sterility. The total processing time was 42.59

min., with a cook value of 84.29, making it the most favourable combination for maintaining product quality.

Shah *et al.* (2017) explored the retort processing of Rogan josh, a traditional Kashmiri meat dish, and demonstrated that thermal processing at 121°C with F0 values between 7 and 11 min. effectively preserved the product's quality for up to 12 months at ambient temperature. Despite a decline in pH, shear force, and sensory attributes during storage, the product remained microbiologically safe. The study indicated that the samples processed with an F0 value of 9 min. showed the highest overall acceptability in terms of sensory characteristics, suggesting that this method could increase the market demand for such traditional products due to their convenience and long-term storability.

In another study, Pal *et al*. (2019) investigated the effect of retort processing on the Indian dessert, chhenapoda. Using a Response Surface Methodology (RSM), it was found that adding 18.5% sugar and 7.5% semolina to cottage cheese resulted in an optimal formulation. Retort processing at 120°C for 30 min. significantly reduced the total plate count from 110 × 107 to 4 × 104 and eliminated yeast and mold counts. This method produced a microbiologically safe product with acceptable sensory qualities that could be stored for up to 30 days under refrigerated conditions, highlighting the potential for improving the shelf life of dairy-based products through thermal processing.

According to previous research, a study on the development of a RTE thermally processed rice pulav using retort processing revealed that optimal processing parameters of 117.67°C for 22.4 min. resulted in a product with high overall acceptability and desirability (Thakur and Rai, 2018). The study further investigated the product's stability during 180 days of storage at ambient temperature, subjecting it to various chemical, microbial, and sensory analyses. The findings indicated that while the product exhibited an increase in certain chemical parameters, such as free fatty acid, thiobarbituric acid, and peroxide values, over the 180-day storage period, it maintained a satisfactory sensory and microbiological profile.

Research conducted by Krishnaprabha *et al*. (2019) has shown that retort pouch processing is effective in extending the shelf life of traditional Indian foods like Ramasseri idli. For instance, the study indicated that retort-processed idli can be safely stored for up to three weeks without microbial contamination or significant quality degradation, based on physico-chemical assessment. Additionally, the study determined that the ideal thermal processing conditions for retort-pouched idli were 100°C for an F value of 6 min., which maintained physico-chemical, microbiological, and sensory qualities similar to the control sample when refrigerated.

Most recently, Jeyapriya *et al.* (2024) optimized the process schedule for retort pouch processing of chevon patties, finding that the third treatment (retort temperature of 114°C and product core temperature of 90°C) required 15 min. of heating and 7 min. of cooling, achieving a total lethality (F0) of 11.093. The heating lag factor was 1.10, while the cook value was 73.26 min.. This treatment also had the highest heating rate index and sterilization efficiency. Patties processed with an F0 of 11.093 received better sensory scores, reinforcing the efficacy of retort processing in maintaining product quality.

These studies collectively demonstrate that retort pouch processing, despite being a thermal method, can be optimized for different food products to retain sensory attributes, achieve commercial sterility, and significantly extend shelf life. However, optimizing thermal processing parameters to balance microbial safety and quality preservation remains a challenge, requiring further research to refine these techniques for industrial applications. Overall, while thermal preservation offers a viable approach to extending the shelf life of products, ongoing innovations, and rigorous quality assessments are necessary to enhance its effectiveness and consumer acceptance.

Non thermal preservation is an alternative processing technology for quality preservation and shelf-life extension of these products. These technologies are designed to maintain the benefits of conventional heat treatment methods while addressing their inherent drawbacks

2.5 Non thermal preservation of food

The growing consumer preference for fresh and natural foods, devoid of artificial additives, has prompted researchers to explore innovative technologies that minimize the use of chemicals while preserving the natural flavours and quality of food products. In response, novel non-thermal techniques are being developed to ensure food safety without compromising nutritional value, as they have been shown to be less effect on food products compared to traditional methods (Koutchma *et al*., 2016). Non-thermal processing technologies offer a gentler approach to food processing by primarily targeting non-covalent bonds. These bonds include hydrophobic, hydrogen, electrovalent, and ionic bonds, which are crucial in maintaining the structure and functionality of food molecules (Bevilacqua *et al*., 2018). By focusing on these bonds, non-thermal methods allow for the denaturation, inhibition, and gelatinization of proteins, enzymes, and starches. Additionally, these technologies are effective in destroying microorganisms and pathogenic bacteria. The key advantage is that this process preserves the molecular structure of the food, maintaining its nutritional and sensory qualities.

According to researchers, the aroma and exotic flavour of ripe jackfruit are vital quality attributes that significantly impact consumer acceptance. They have noted that thermal preservation methods negatively affect these qualities in fruit juices (An *et al*., 2019, Wang *et al*., 2019). Consequently, there is a demand for preservation techniques to better preserve jackfruit's flavour compounds. Advanced non-thermal preservation methods, such as high-pressure processing and PL technology, are highly effective in maintaining the quality characteristics of fruits and vegetables (Fernandez *et al*., 2019; Mandal *et al*., 2020).

This research work is emphasis on the effect of thermal and non thermal preservation technique to optimize the preservation conditions for ripe jackfruit bulbs and pulp.

2.5.1 High pressure processing

HPP is a cutting-edge technology that has significant attention in the food industry for its ability to preserve fruits and vegetables while maintaining their

nutritional and sensory qualities (Chakraborty *et al.*, 2014). In high-pressure processing, the food products are typically subjected to extremely high pressures (typically 100-1000 MPa or 100 MPa or higher) to kill enzymes, microbes, and other components that contribute to spoilage reactions in food products (Elamin *et al*., 2015). This process is effective in extending the shelf life of fruits and vegetables by inactivating enzymes responsible for spoilage and quality degradation

The behaviour of foods under HPP follows three key principles: Le Chatelier's Principle, Isostatic Pressing, and the Microscopic Ordering Principle. Le Chatelier's Principle states that high-pressure shifts equilibrium, reducing volume and altering food components like proteins and enzymes. Isostatic Pressing (Pascal's Principle) ensures uniform pressure distribution, allowing food to retain its shape after decompression. The Microscopic Ordering Principle explains that increasing pressure enhances molecular organization, while heat disrupts it, highlighting their opposing effects. These principles collectively explain how HPP modifies food while preserving its quality (Gopal *et al*., 2017). Gopal *et al*. (2017) reported that pressure severely affects non-covalent bonds, causing low molecular weight food components to remain intact under such conditions. They also noted that since HPP operates independently of the sample's size and geometry, processing time can be minimized.

In a typical HPP procedure, the prepacked product is placed in a flexible container and loaded into a high-pressure chamber filled with a hydraulic fluid, usually water. The fluid is pressurized, transmitting the pressure through the packaging into the food (Plate 2.3), and maintained for a few min. This HPP technique allows for uniform and instantaneous transmission of pressure throughout the product, regardless of its size or shape (Plate 2.2). As a result, HPP can effectively inactivate microorganisms and enzymes, extending the shelf life of food while preserving its nutritional and sensory qualities. After processing, the product is removed and stored or distributed using conventional methods (Daher *et al*., 2017).

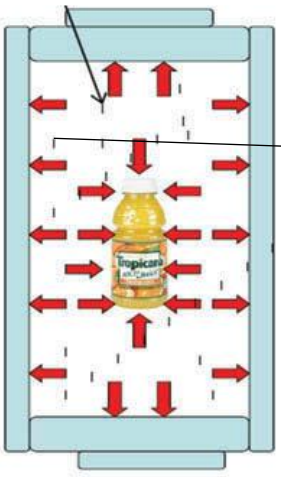


Plate.2.2 Isostatic principle in HPP unit (*Source: Abera, 2019***)**

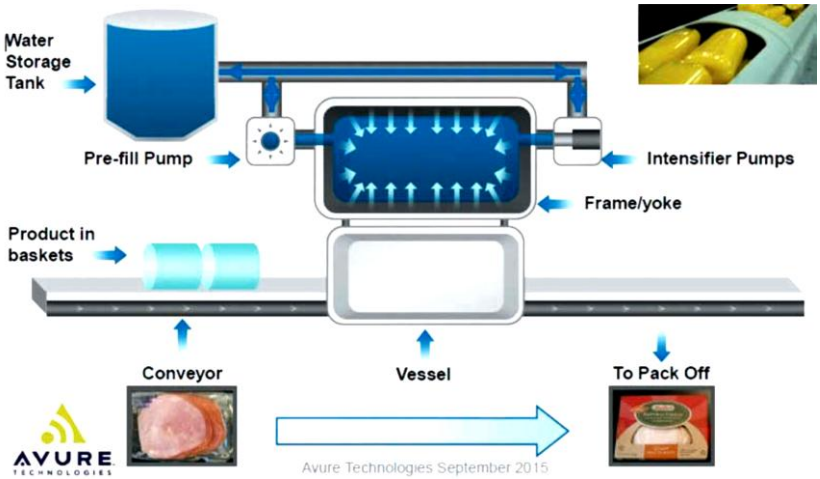


Plate 2.3 Working of HPP unit (*Source: Abera, 2019*)

Industrial HPP systems are classified into batch, continuous, and semi-continuous modes. Both batch and continuous systems are suitable for high-pressure pasteurization. The batch system offers versatility, handling both liquid and solid products, typically pre-packaged before processing. In contrast, continuous and semi-continuous systems are designed exclusively for liquid or pumpable products (Sharma *et al*., 2020).

During HPP, food products undergo volume reduction as pressure increases. In the compression phase (Ts–Tm), both pure water and food products subjected to 600 MPa at ambient temperature experience approximately a 15% volume decrease (Sharma *et al*., 2020). The product remains at high pressure for a set duration (Tm–T2) before decompression (T2–Tf), where it generally returns to its original volume. However, due to heat dissipation during compression, the final temperature (Tf) is often slightly lower than the initial temperature (Ts). The temperature rise in food products under pressure varies based on factors such as final pressure, product composition, and initial temperature. These principles align with Le Chatelier's Principle, which explains volume reduction under pressure, and Isostatic Pressing, ensuring uniform compression and expansion. Understanding these effects is crucial for optimizing batch, continuous, and semi-continuous HPP systems used for liquid and solid food processing. Figure 2.2 illustrates key variables—pressure, temperature, and time—used to define HPP testing conditions. The ambient pressures before (Ps) and after (Pf) processing are typically 0.1 MPa. Tm represents the maximum temperature reached at process pressure. The temperature difference between the initial (Ts) and final (Tf) ambient states reflects the heat loss during processing, assuming depressurization occurs within a few seconds.

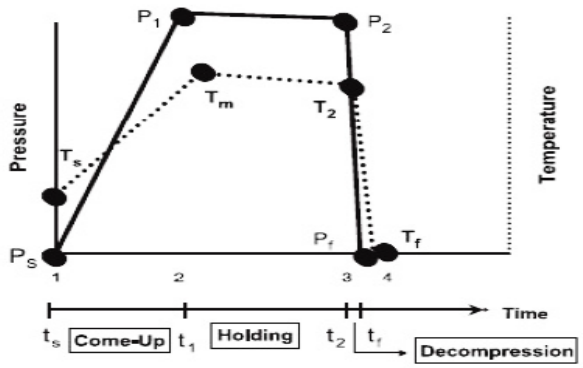


Figure 2.2 Pressure temperature effect in HPP

2.5.1.1 Effects of HPP on fruits and vegetables

The effects of HPP on fruits and vegetables depend on various factors, including pressure level, treatment duration, and temperature. Previous studies revealed that HPP

had a positive effect on fruit and vegetable quality. HPP can preserve the colour of fruits and vegetables, including green, yellow, and red colours (Keenaz *et al*., 2011, González-Cebrino *et al*., 2012). HPP has been found to have a positive impact on the preservation and extraction of carotenoids in various fruits and vegetables.

HPP is an advanced technology that ensures microbiological safety in food while preserving its nutritional and sensory attributes (Chopde *et al*., 2014). This process works by modifying the functional characteristics of proteins and polysaccharides, as well as influencing biochemical reactions. According to Chopde *et al*. (2014), HPP effectively maintains the colour, texture, and flavour of fruits and vegetables, helping to retain their overall quality. Additionally, HPP has been recognized as an efficient method for microbial inactivation, targeting bacteria, yeast, and mold, thereby extending the shelf life of fruits and vegetables (Chakraborty *et al*., 2014).

The study by Denoya *et al*. (2015) suggested that HPP of fresh cut peaches at 500 MPa for 5 min. under vacuum packaging had a synergistic effect on colour preservation for 21 days. During HPP of minimally processed peach pieces and observed that HPP effectively inactivated the enzymes and retained the colour characteristics of peaches at higher pressures of 600 MPa/5 min. (Denoya *et al*., 2016).

Paciulli *et al*. (2016) observed that beetroot slices subjected to HPP at 650 MPa retained their textural properties, such as hardness and chewiness, better than those that underwent thermal treatment. In terms of inactivating foodborne pathogens, a pressure range of 100-1200 MPa has been shown to be effective, as demonstrated by Dhineshkumar *et al*. (2016).

Yi *et al*. (2017) conducted a study to investigate the effects of HPP on the quality of apple juice. Specifically, they compared the colour retention of apple juice treated with HPP at 600 MPa for 3 min. with thermally treated juice. The results showed that the HPP-treated juice retained its colour better than the thermally treated juice. This is likely due to the fact that HPP is a non-thermal preservation method that helps to inactivate enzymes and microorganisms without affecting the juice's natural colour and flavour compounds.

Aabya *et al*. (2018) reported that their study on the effects of HPP and thermal treatment on strawberry purée and juice suggested that HPP was more effective in preserving quality. They observed that HPP-treated samples retained a higher anthocyanin content, with 67% retention, compared to those subjected to thermal treatment after 35 days of storage at 6˚C.

According to Saikaew *et al*. (2018), the anthocyanin content in purple waxy corn treated with HPP was found to be higher at 700 MPa compared to 550 MPa. They conducted the treatment over a duration of 30 to 45 min. The results indicate that higher pressure levels are more effective in preserving or enhancing anthocyanin content in the corn under these conditions.

Scheidt and Silva (2018) found that for blueberries processed at 200 and 600 MPa, hardness remained unchanged immediately after HPP. Storage tests revealed that processed blueberries maintained their hardness for at least 28 days, whereas fresh, non-processed blueberries lacked resistance to water storage, breaking down within a week due to metabolic activity.

Fernandez *et al*. (2019) conducted a comprehensive study on the effects of HPP on mixed fruit and vegetable smoothies, focusing on enzyme inactivation and quality retention. Their research determined that the optimal HPP treatment conditions were 627.5 MPa at 20°C for 6.4 min., which effectively reduced pectin methylesterase (PME) activity by 85%. By significantly reducing PME activity, HPP helps maintain the viscosity and consistency of the smoothie while preserving its fresh-like sensory characteristics. Additionally, HPP processing at these conditions minimizes thermal damage, allowing for better retention of vitamins, colour, and flavour compared to traditional heat treatments. This study highlights the advantages of HPP in producing high-quality, microbiologically safe smoothies with an extended shelf life while maintaining the natural attributes of fruits and vegetables.

Stinco *et al*. (2019) reported that their assessment of HPP on the carotenoid profile of cloudy carrot juice revealed that applying 600 MPa in three cycles led to the lowest degradation of 26% while Al-Ghamdi *et al.,* 2020 reported that pressure assisted thermal sterilisation had no effect on the carotenoid pigments in purees of beetroot and

purple potato puree. Additionally, De Ancos *et al*. (2020) found that HPP at 400 MPa/40°C/1 minute as a pretreatment before juicing increased the carotenoid concentration in orange juice.

Sun *et al*. (2019) reported that applying HPP at 400 MPa to carrots resulted in a significant reduction in their textural properties, specifically a decrease in hardness by 71.0% and in chewiness by 73.8%. Notably, they also observed that increasing the pressure beyond 400 MPa did not lead to any further loss in these textural attributes.

Hu *et al*. (2020) studied fresh-cut pumpkins and discovered that their hardness decreased as the pressure increased. HPP caused a significantly smaller reduction in colorimetric and textural properties, such as hardness and chewiness, compared to heat treatment. Immunofluorescence analysis indicated that HPP led to a decrease in the esterification degree of pectin within pumpkin cells. When applied to fresh-cut pumpkin slices, moderate pressure levels (300–400 MPa) proved to be more effective than higher pressures, preserving quality attributes more efficiently. Similarly, Tao *et al*. (2020) investigated the effects of HPP on Laba garlic and identified 200 MPa as the optimal pressure for maintaining its textural quality. This retention of texture in Laba garlic was mainly attributed to the compacted cells and the increased Ca^{2+} cross-linked cell-cell adhesion. These findings suggest that while higher pressures may negatively impact the hardness of some vegetables like pumpkins, there are specific optimal pressures, as demonstrated with Laba garlic, that can effectively preserve textural properties. Furthermore, Fernandez *et al*. (2019) reported a 70.7% PME inactivation in a vegetable smoothie processed at 630 MPa for a holding time of 6 min..

The effects of HPP on fruits and vegetables are influenced by various factors, including pressure level, treatment duration, and temperature. A study by Raghubeer *et al*. (2020) found that HPP of coconut water at 593 MPa for 3 min. was effective in eliminating *E. coli, Salmonella, and L.monocytogenes*. Additionally, HPP has been shown to improve the texture of fruits and vegetables, making them firmer and crisper.

A recent study demonstrated that the microbiological safety of pineapple fruit juice can be ensured for a minimum of 21 days through the application of either individual HPP at 500 MPa for 10 min. or thermal processing at 95°C for 3 min.. The

findings revealed that both HPP and thermal processing treatments were effective in inactivating Total Aerobic Bacteria, Yeast and Mold, and coliform in pineapple fruit juice. Notably, the HPP treatment did not significantly impact the physicochemical properties of the juice, although a noticeable change in colour was observed, as reported by Wu *et al*. (2021).

The potential of HPP to preserve fruits and vegetables is vast, particularly in countries like India, which is the second-largest producer of fruits and vegetables in the world. According to the National Horticulture Board's 2nd advance estimates for 2023-24, India's annual fruit output totalled 112.62 million metric tonnes, with vegetable production reaching a substantial 204.96 million metric tonnes (Chandrasekhar, 2024). The adoption of HPP technology could significantly reduce post-harvest losses and improve the quality of fruits and vegetables in India.

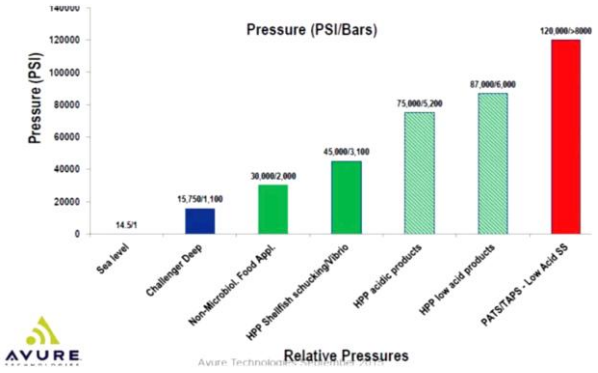


Fig. 2.3 Relative pressure levels in HPP and its applications

(Source: Raghubeer *et al*., 2020)

The figure 2.3 illustrates the range of pressure levels utilized in various HPP applications, highlighting its advancements and benefits in food preservation. As pressure increases, HPP effectively inactivates microorganisms while maintaining the nutritional, sensory, and functional properties of food products. Lower pressures (30,000–45,000 PSI) are used for applications such as shellfish shucking and pathogen reduction, whereas higher pressures (75,000–87,000 PSI) are required for acidic and low-acid food products to ensure extended shelf life and microbial safety. The latest advancements, such as pressure-assisted thermal sterilization/supercritical assisted pressure sterilization (PAT/SAPS) technology, apply ultra-high pressures exceeding

120,000 PSI, enabling the production of low-acid shelf-stable (SS) foods without heat-induced degradation. These innovations demonstrate the growing potential of HPP as a non-thermal, eco-friendly, and effective food processing method, offering an alternative to traditional thermal pasteurization while preserving food quality and extending storage stability.

In conclusion, HPP is a promising technology that has the potential to revolutionize the food industry by providing a safe and effective method for preserving fruits and vegetables. Further research is needed to fully understand the mechanisms of HPP and to develop optimal processing conditions for different fruits and vegetables (Song *et al*., 2023). However, the existing evidence suggests that HPP is a valuable tool for improving the quality and safety of fruits and vegetables, and its adoption could have significant economic and social benefits for the food industry.

2.5.2 PL technology in food industry

In recent years, the food industry has seen significant advancements in non-thermal technologies designed to inactivate microorganisms without the use of heat. PL technology has emerged as a promising non-thermal method for food preservation, leveraging the power of intense, short-duration pulses of broad-spectrum light to achieve microbial decontamination on the surface of foods and packaging materials. The PL spectrum spans a broad wavelength range from 200 to 1100 nm, encompassing the ultraviolet (UV) region (200–400 nm), the visible (VIS) spectrum (400–700 nm), and the near-infrared (NIR) range (700–1100 nm) (Palgan *et al*., 2011).

PL technology, an advanced form of ultraviolet-C (UV-C) treatment discovered in the 1930s, uses xenon lamps to produce high-intensity flashes for food preservation. The ultraviolet spectrum consists of three wavelength ranges: long-wave UV-A (320–400 nm), medium-wave UV-B (280–320 nm), and short-wave UV-C (200–280 nm). PL is highly effective in microbial destruction due to its broad-spectrum UV content, short pulse duration, and high peak power. Research highlights photochemical and photothermal effects as key mechanisms behind its antimicrobial action (Abida *et al*., 2014).

The photochemical effect arises from UV light, which disrupts microbial DNA by altering its double bond alignment, preventing replication. This leads to electronic and photochemical reactions, forming pyrimidine and thymine dimers. The photothermal effect occurs as PL is absorbed and converted into heat, rapidly increasing microbial cell temperatures, sometimes reaching 130°C, causing destruction. While various methods extend fruit juice shelf life, they can alter sensory qualities and consumer acceptability (Ramos-Villarroel *et al.*, 2014).

The efficacy of PL inactivation is directly tied to the intensity of the light, measured in J/cm², and the number of pulses delivered (Ortega-Rivas and Salmeron-Ochoa, 2014).

Notably, PL treatments have demonstrated exceptional results in maintaining the quality features of fresh-cut fruits and vegetables, as well as in juice processing. Furthermore, this technology has shown potential as an alternative method for liberating bioactive compounds from vegetable sources, which can be utilized as ingredients in the food industry.

PL technology offers several advantages over traditional thermal processing methods, including significant microbial reduction in a short treatment time, minimal environmental impact, and high flexibility. One of its key benefits is its ability to preserve essential food quality attributes such as colour, texture, and nutritional value (Huang and Chen, 2014). Furthermore, PL technology has been recognized as an energy-efficient and environmentally sustainable approach to food preservation (Abida *et al*., 2014).

PL treatments utilise xenon gas lamps to generate high-intensity pulses ranging from 1 to 20 flashes per second, with pulse durations between 1 μs and 1 s. The fluence (ϕ) varies between 0.01 and 50 J/cm² (Ramos-Villarroel *et al*., 2014). Key parameters include fluence rate (W/m²), pulse width (ms), exposure time (s), and pulse repetition rate (Hz) (Abida *et al*., 2014). The temperature inside the chamber is monitored using thermocouples, and a cooling system prevents overheating. Processing efficiency depends on fluence, lamp distance, light propagation medium, and applied wavelengths (Gomez-Lopez and Bolton, 2016). Additionally, the chemical composition and

structure of the food matrix, along with microbial characteristics, influence microbial inactivation (Valdivia-Najar *et al*., 2017). Batch and continuous system of PL equipment are used to process foods. Pumpable liquids or juices can be processed in a continuous system as presented in Plate.2.4.

A batch type PL system (Plate 2.5) consists of a chamber with xenon lamps emitting high-intensity light through a quartz window. It includes a cooling blower, shelves for sample placement, and a controller for operation. The power supply ensures energy input, while the chamber door allows secure sample handling, enhancing microbial inactivation efficiency (Bhavya and Hebbar, 2017).

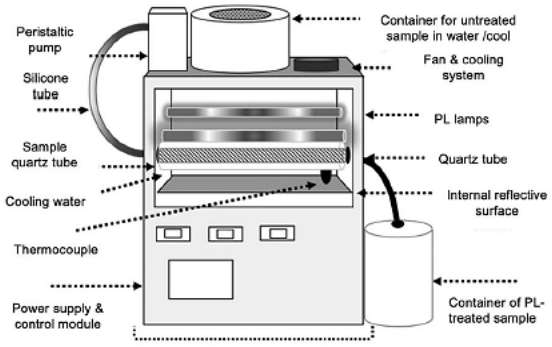


Fig 2.4 Continuous PL processing system

(*Source: Salazar-Zuniga et al.,2023*)

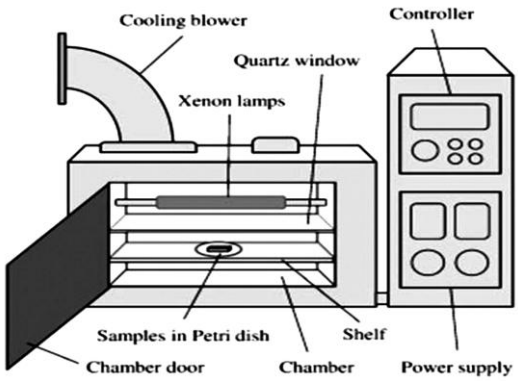


Fig 2.5 Batch-type PL unit

(*Source: John and Ramaswamy, 2018*).

PL technology effectively decontaminates packaged and unpackaged food and contact surfaces without harmful residues. Using mercury-free xenon flash lamps eliminates the need for chemical disinfectants. Cost-effective and versatile, PL preserves food quality and operates in both continuous and batch modes. Its high-energy pulses enable faster microbial inactivation than continuous UV light (Huang *et al*., 2018).

2.5.2.1 Effect of PL on foods

PL technology has emerged as an innovative, non-thermal decontamination method with significant potential for enhancing food safety and extending shelf life.

Research has demonstrated the effectiveness of PL technology in reducing microbial populations across various food products. Studies have successfully utilized PL systems for non-thermal sterilization of infant foods (Choi *et al*., 2010). Krishnamurthy *et al.* (2010) reported that *Staphylococcus aureus* treated with Pulsed UV (PUV) exhibited severe cellular damage, including cell wall disintegration, membrane shrinkage, and internal structural collapse. Furthermore, xenon lamp-generated intense PL has proven effective in inactivating pathogens like *Listeria monocytogenes* on solid surfaces and seafood (Cheigh *et al*., 2013). Levy *et al*. (2012) demonstrated that PL was more effective than continuous UV treatment in inactivating *Aspergillus niger* spores. Similarly, Orlowska *et al*. (2013) reported a 5-log reduction of *E. coli* in water, achieved at half the energy dose required for continuous mercury lamps, reinforcing the superior efficiency of pulsed lamps in microbial inactivation. These findings highlight PL technology's potential as a reliable method for microbial reduction in food processing.

The study by Teja *et al*., 2017 showed that UV treatment had no significant effect on pH and total soluble solids (TSS) of apple and pineapple juices. The treatment conditions included varying treatment times (5-15 min) and distances from the lamp source (8.6-22.8 cm). Overall, UV treatment had a minimal impact on the quality parameters of both juices, with changes being less pronounced compared to thermal treatments.

In a study conducted by Chakraborty *et al*. (2020), the pasteurisation of gooseberry juice was examined using both thermal processing and PL technology. The research found that the PL pasteurisation method was significantly more effective in preserving the nutritional content of the juice. Specifically, the PL-treated samples retained 45% more phenolics, 54% more antioxidants, and 61% more vitamin C compared to the juice that underwent traditional thermal pasteurisation. This indicates that PL technology not only effectively pasteurizes the juice but also better preserves its beneficial compounds. Vollmer *et al*., 2020 studied the effect of PL technology and thermal pasteurisation on pineapple juices and observed a 5 log reduction of microbes and the bromelanin activity was retained in treatment 2.4Kv/94 or 187 pulses than the thermal pasteurisation.

According to Chakraborty *et al*. (2022), a mixed fruit beverage was formulated from apple ber, carambola, and black table grape juices in a specific ratio. The authors reported that this optimized blend was then subjected to thermal treatment at 90 °C for 5 min. and PL treatment at 30 W cm^2 for 167 seconds, resulting in a total energy dose of 5000 J cm^2. They found that this treatment resulted in complete inactivation of natural microbiota, including aerobic mesophiles, yeasts, and molds, as well as spoilage enzymes such as polyphenol oxidase and peroxidase. Furthermore, Chakraborty *et al*. (2022) noted that the PL pasteurised sample retained significantly higher amounts of vitamin C, antioxidants, and phenolic compounds, with increases of 25%, 27%, and 19%, respectively, compared to the thermally pasteurised beverage.

However, the use of PL technology to decontaminate food still requires more efforts to achieve industrial-scale direct food decontamination. At the current level, few pilot scale studies have been carried out and revealed important considerations. To maximize the effectiveness of the treatment, it is crucial to optimize the conditions and consider the interplay between the time of contamination, PL treatment parameters, and the food matrix. Some authors have addressed the existing limitations by combining PL treatments with complementary techniques, thereby achieving food conservation with minimal compromise on quality. Large-scale studies are now necessary to pave the way for the introduction of this disinfection technique at the industrial level.

From the above discussion, it is evident that food processing methods play a crucial role in improving the safety, shelf life, and quality of food products. Thermal and non-thermal techniques offer distinct advantages, such as microbial inactivation, nutrient retention, and enhanced sensory attributes. Table 2.2 highlights the key benefits of these processing methods, showcasing their positive impact on various food products. The advantages of thermal and non-thermal processing methods demonstrate their significance in food preservation and quality enhancement. While thermal processing effectively ensures food safety, non-thermal techniques help retain nutritional and sensory properties. These benefits contribute to the development of high-quality food products that meet consumer demands for both safety and freshness.

Table 2.2 Effects of thermal and non-thermal processing on food products

Food product	Treatment	Effect	Reference
THERMAL PROCESSING			
Mandarin Juice	65°C/15 to 35 min and 75°C/10 to 30 min	• Juice treated at 65°C for 15 min. preserved quality over six months of refrigeration. • Maintained TSS, acidity, and ascorbic acid. • Retained sugar content and minimized nonenzymatic browning.	Pareek *et al*. (2011)
Tomato Juice	100°C/2 to 10 min	• Increased lethality observed against *B. coagulans* (ATCC 8038).	Peng *et al.* (2012)
Grape juice	65°C/30 min	• No microbial growth up to 2 yr storage. Detection of HMF	Mert *et al*. (2013)
Apple, orange Juice blend	70°C/60 and 90 s	• A 60-second thermal treatment had no impact on *S. cerevisiae* SPA growth. • A 90-second treatment resulted in only a 0.49 log CFU/mL reduction. • After 8 days at room temperature, microbial presence remained significant.	Tyagi *et al.* (2014)
Bottle gourd Juice	63°C/30 min and 75°C/10 min	• Ascorbic acid decreased by 35.27% at 63°C. • Higher pasteurization temperatures increased total phenolic content significant	Bhat *et al.* (2016)
Ready to eat rice pulav	117.6°C/22.4 min	• Maintained good sensory and microbiological quality for up to 180 days.	Thakur and Rai (2018)

Mixed formulas of fruits and vegetables pulps (pineapple, beetroot, strawberry and lemon juice)	90°C/5 min and 98°C/2.5 min	• Treatments under 5 min. effectively inactivated POD. • Reduced microbial load by over 2 log_{10} cycles. • Preserved optimal sensory attributes.	Gonçalves *et al.* (2020)
HPP			
Apple juice	430 MPa; 7 min	• Complete inactivation of PME and indigenous microbiota. • No significant impact on physicochemical properties, nutrition, or sensory quality.	Juarez-Enriquez *et al*. (2015)
Banana Smoothie	350 to 550 MPa; 2 to 10 min; 20 °C	• Significant microbial reduction observed. • Total aerobic bacteria inactivation increased with higher pressure and treatment time. • PPO and PME remained active after HPP at 550 MPa/10 min, showing pressure resistance.	Li *et al.* (2015)
Jucara, mango juice blend	600 MPa; 5 min; 25 °C	• HHP preserved anthocyanin content. • Maintained high sensory acceptance.	Moreira *et al.* (2017)
Mandarin (*Citrus unshiu*) juice	600 MPa, 4 °C and 300 s)	• Total aerobic bacteria content remained <2 log CFU/mL across all processing methods. • Sugar and acid composition remained stable in all treated mandarin juices.	Cheng *et al.* (2020)
Jackfruit shreds	600 MPa; 8 min	• Increased biochemical compounds	Saranya *et al.* (2024)

		• 31% maximum extraction of total flavonoid content (TFC)	
PL PROCESSING			
Orange juice	Frequency (Hz): 3; Total fluence (J/cm^2): 5.10; Peak power (J/cm2/pulse): 1.213; Pulse width (μs): 360; Exposure time (s): 2.81; Distance from the lamp (cm): 1.9	• *Escherichia coli* reduced by 2.42 log CFU/mL.	Muñoz *et al*. (2011)
Tomato fruit	2.68 J cm−2; 2.5 k/20 °C; 15 day (n=2).	• PL reduced natural and inoculated microbial contamination on tomatoes by ~1 $\log_{10}$. • Nutritional quality remained unchanged, while carotenoid levels slightly increased.	Aguiló-Aguayo *et al*. (2013)
Green onions	5 and 14.3 J/cm^2 (dry PL) 56.1 J/cm^2 (wet PL) *	• *E. coli* O157:H7 reduced by >4 log.	Xu *et al.* (2013)
Spinach	180 to 1100 nm with 17% of UV light. duration− 0.3 μ s and fluence−8 J/cm2	• *L. innocua* reduced by 1.85 log CFU/g. • *E. coli* reduced by 1.72 log CFU/g.	Agüero *et al.* (2016)
Persimmons (*Diospyros kaki* L. cv. Vanilla)	Fluence: 20 kJ m^{-2} Exposure times: 1.2s	• Increased total phenolic content (TPC)	Denoya *et al*. (2020)

	Distance from the sample: 22 cm		
Fresh-cut mangoes	(1.5 and 3.0 × 104 J/m^2	• Minimal effects in their quality parameters, biochemistry and physiology.	Sousa *et al.* (2023)

2.6 Optimization of technologies

The optimization of thermal processing, high pressure processing, and PL processing technologies has shown promising results in enhancing the quality and safety of fruit pulps. Each technology has specific optimized conditions that contribute to effectively preserving nutritional and sensory properties, thereby extending the shelf life of fruit products. As research continues to evolve, these technologies may offer even greater benefits for fruit pulp processing in the future.

Kaushik *et al*. (2016) conducted a study on optimizing thermal-assisted high-pressure processing of mango (*Mangifera indica L*.) pulp using response surface methodology. They investigated the effects of pressure, temperature, and holding time on the pulp's physicochemical and nutritional properties. The study provided valuable insights into optimizing HPP parameters for mango pulp processing.

Vargas-Ramella *et al*. (2021) reviewed the impact of PL processing technology on the phenolic compounds of fruits and vegetables. They found that PL can improve the phytochemical content in fresh fruits and vegetables. The review highlighted the potential of PL as a promising non-thermal technology for enhancing the quality of fruit pulps.

Vargas-Ramella *et al*. (2021) also studied the impact of PL processing on the phenolic compounds of fruits and vegetables. They found that PL treatments can stimulate colouration and anthocyanin accumulation in fig fruit (*Ficus carica L*.). The study demonstrated the potential of PL for improving the quality attributes of fresh-cut mango.

Gavahian and Khoshtaghaza (2021) investigated the effect of PL treatments on the texture quality of fresh-cut mangoes. They found that PL can be used to maintain the physical and nutritional quality of fresh-cut mangoes. Guerrero-Sánchez *et al*. (2021) evaluated the effect of PL treatments on the inactivation of Salmonella on blueberries and its impact on shelf-life and quality parameters. The study provided insights into the optimization of PL parameters for ensuring the safety and quality of fruit pulps.

2.7 Physico-chemical properties

Physico-chemical properties are essential indicators of food quality, influencing its stability, safety, and consumer acceptance. These properties, including pH, moisture content, texture, colour, and nutrient composition, help assess the impact of processing, packaging, and storage on food products. Understanding these factors ensures better quality control and product optimization.

2.7.1 Physicochemical properties of thermal processed fruits and beverages

Thermal processing, such as retort processing, has been widely used to preserve food commodities and extend its shelf life. However, this method can have significant impacts on the physicochemical properties of the product. A study by Smith *et al*. (2014) explored the impact of thermal processing on the sensory and nutritional quality of fruit pulp. It emphasized that retort processing effectively inactivates enzymes and microorganisms, but excessive heat can lead to loss of colour and texture, affecting consumer acceptance**.**

A study conducted by Sharma *et al*. (2015) investigated the changes in physicochemical properties of mango pulp after pasteurisation. The researchers found

that pasteurisation led to a decrease in moisture content from 88.2% to 85.1% and a reduction in pH from 4.1 to 3.9. Additionally, the acidity increased from 0.6 to 0.8 g citric acid per 100 mL, while the total dietary fiber content decreased by approximately 30%.

Research by Johnson and Lee (2018) investigated the optimal conditions for retort processing of mango pulp. The findings indicated that specific temperature and time combinations could enhance the retention of vitamins and improve the overall quality of the pulp while minimizing undesirable changes in texture and flavour.

A comparative study by Patel and Zhang (2020) analyzed the effects of different retort methods (static vs. agitation) on the heat penetration and quality of canned fruit pulp. Results showed that agitation improved heat distribution, leading to better microbial inactivation and retention of sensory attributes.

In a comparative study conducted by Verma and Singh (2021), the effects of thermal processing, HPP, and PL technology on the physicochemical properties of papaya pulp were evaluated. The researchers found that thermal processing led to a 25% decrease in vitamin C content, while HPP and PL treatment-maintained vitamin C levels at 90% and 95% of the initial value, respectively. Furthermore, the study reported that HPP and PL-treated pulp had higher levels of total carotenoids and better colour retention compared to thermally processed pulp.

Research by Zhu *et al*. (2022) focused on the nutritional retention in retorted fruit pulps, revealing that while retort processing effectively preserves essential nutrients, certain vitamins, particularly vitamin C, were significantly reduced. The study recommended optimizing processing parameters to enhance nutrient retention.

A review by Garcia and Thompson (2023) highlighted recent advancements in retort technology, including the use of flexible pouches that enhance heat transfer. This innovation has been shown to improve the quality of retorted pulp by minimizing the thermal degradation of sensitive compounds. Below is a Table 2.3 summarizing the effects of thermal processing on various products including the methods of analysis, observed outcomes, and references.

Table 2.3 Effects of thermal processing on physicochemical properties

Product	Parameter	Methods of Analysis	Observed Effects of Thermal Processing	References
Fruit-Based Products	Rheological Properties	Rheometer	Thermal processing affects the viscosity and flow behaviour of fruit-based products, influencing texture and mouthfeel.	Vidigal *et al*. (2023)
Tomato Fruits	Colour	Colorimeter, HPLC	Superheated steam treatment at 100°C for 7 min. negatively affected colour but enhanced certain nutraceutical contents.	Narra *et al.* (2024)
Fruit Juices	Sensory Properties	Sensory Evaluation Panels	Thermal treatments can lead to the formation of flavour compounds, altering the sensory profile of fruit juices.	Zia *et al*. (2024)
Tree Nuts	Physical and Chemical Properties	Various Analytical Techniques	Thermal processing methods like drying and roasting significantly impact the quality and nutritional value of nuts.	Ogundipe *et al*. (2024)

2.7.2 Physicochemical properties of HPP processed fruits and beverages

In contrast to thermal processing, non-thermal preservation methods, such as HPP, have gained attention due to their ability to maintain the quality of food products while minimizing the impact on physicochemical properties. Recent studies have investigated the impact of HPP on various physicochemical properties of different fruits and beverages. An early study by Martinez *et al*. (2014) indicated that HPP preserves the nutritional quality of fruit pulp better than traditional thermal methods. The study noted that HPP maintained higher levels of vitamins and antioxidants in the pulp.

Research published by Wang and Zhang (2016) examined the physico-chemical changes in apple pulp subjected to HPP. The results demonstrated that HPP effectively reduced microbial load without significantly altering the pulp's colour or texture, making it a promising alternative to thermal processing. A study conducted by Patel and Rao (2018) evaluated the effects of HPP on the physicochemical properties of pomegranate pulp. The researchers reported that HPP-treated pulp retained higher levels of total phenolic compounds and antioxidant activity compared to thermally processed pulp. Additionally, the colour parameters (L*, a*, and b*) were better preserved in HPP-treated samples, indicating a more natural appearance (Patel and Rao, 2018).

In a study by Agcam *et al*. (2021), the effects of HPP on the physicochemical properties of black carrot pomace were analyzed. The results indicated that HPP preserved the colour and nutritional quality of the pulp better than traditional thermal methods. Specifically, the total phenolic content was found to be higher in HPP-treated samples, which retained more antioxidant properties compared to their thermally processed counterparts. The study reported a significant retention of ascorbic acid levels post-processing, demonstrating the advantages of HPP in maintaining the bioactive compounds of fruit pulp.

Research by Liu *et al*. (2021) focused on the effects of HPP on enzyme activity in fruit pulp. It was found that HPP effectively inactivated enzymes responsible for browning and spoilage, thus maintaining the visual and sensory quality of the pulp over extended storage periods. More recently, a review by Gupta *et al*. 2023 highlighted the advancements in non-thermal preservation technologies and their impact on the physicochemical properties of fruit pulp.

The review emphasized that HPP and PL treatment can effectively preserve the sensory attributes, nutritional value, and microbial safety of fruit pulp while minimizing the negative effects associated with thermal processing. The authors also discussed the potential of combining non-thermal technologies with other preservation methods, such as the use of natural antimicrobials, to further enhance the quality and shelf life of fruit pulp.

The following Table 2.4 summarizes the effects of HPP, along with the methods of analysis, and observed outcomes of different physicochemical properties of fruits and beverages.

Table 2.4 Effects of HPP on physicochemical properties of specific fruits and beverages

Product	Parameter	Methods of Analysis	Observed Effects of HPP	References
Mango Pulp	Rheological Properties (Pa.s)	Rheometer	HPP treatment influenced the viscosity and flow behavior of mango pulp, affecting its texture and mouthfeel.	Ahmed *et al*. (2005)
Cashew apple juice	Vitamin C Content (mg/100g)	Titration method	Maximum reduction is 0.9% Retention at 250 MPa	Queiroz *et al*. (2010)
Strawberry Purée	Microbial Load Reduction (log CFU/mg)	Plate Count Method	Reduced microbial load -extending its shelf life while preserving quality attributes.	Marszałek et al., 2017
Purple Waxy Corn Kernels	Colour Parameters (L*, a*, b*)	Colorimeter	Preserved the colour attributes	Saikaew *et al.* (2018)
Blueberries	Firmness	Texture Analyzer	Better texture retention during storage.	Scheidt and Silva, (2018)
Sugarcane Juice	Antioxidant Activity (%)	DPPH Assays	10% increase in the TAC of sugarcane juice processed at 600 MPa/30 °C 31% increase in TFC	Sreedevi *et al*. (2018)
Jackfruit Shreds	TFC (REg/100mg) TSS (°Brix) Firmness (N)	Spectrophotometric Assays Refractometry Texture Analyzer	No significant alterations in °Brix levels after HPP. Higher levels of pressure and time increased the firmness of the shreds.	Saranya *et al*. (2024)

2.7.3 Physicochemical properties of PL processed fruits and beverages

PL technology has emerged as a promising non-thermal preservation method for maintaining the quality of fruits and beverages while minimizing nutrient loss and microbial contamination. Over the years, researchers have explored its effectiveness in preserving the physicochemical properties of various fruit pulps. One of the earliest studies in this field was conducted by Nguyen and Patel (2017), who examined the effects of PL on the colour and flavour of strawberry pulp. Their findings indicated that PL treatment effectively retained the vibrant colour and fresh flavour of the pulp, outperforming traditional thermal methods in sensory evaluations. This early success sparked further interest in the potential of PL for preserving fruit-based products.

Building on this foundation, Kaushik *et al*. (2020) investigated the impact of PL on the physicochemical properties of guava pulp. Their study revealed that PL treatment led to a 12% increase in TSS while maintaining a stable pH of around 4.2. Additionally, the microbial load was significantly reduced, highlighting PL technology's potential to extend the shelf life of fruit pulps without compromising their physicochemical attributes. These findings reinforced the idea that PL could serve as an effective alternative to conventional preservation methods, ensuring product quality while improving safety.

Further expanding the scope of research, Ali and Smith (2022) assessed the nutritional impact of PL on orange pulp. While some vitamins experienced slight degradation, the study confirmed that the overall nutrient profile remained stable, demonstrating that PL technology is a viable method for preserving the nutritional integrity of fruit pulps. The Table 2.5 illustrate the analysis and effect of physicochemical properties after PL treatment in fruit and beverages.

Table 2.5 Physicochemical properties of PL processed fruits and beverages

Product	Parameter	Methods of Analysis and effect	References
Mango Peel and Pulp	Phytochemical content & Antioxidant potential	HPLC, DPPH & ABTS Assays • Enhanced phytochemical content and antioxidant potential with low fluence PL	Lopes *et al*. (2016)
Blueberries	Microbial Survival & Quality	Microbiological Analysis & Texture analyser • Reduced microbial load while maintaining quality and nutritional characteristics	Jin *et al*. (2017)
Pomegranate Juice	Microbial Safety, Enzyme Inactivation, and Phytochemical Retention	Plate Count Method, Enzyme Assays, HPLC • Effective pasteurization with microbial reduction, enzyme inactivation, and phytochemical retention	Bhagat and Chakraborty, (2022)
Tender coconut water	Enzyme Activity	Enzyme Assays (Polyphenol Oxidase & Peroxidase Activity) • Maintained quality while reducing enzymatic activity	Reddy *et al*. (2024)

The cumulative findings of these studies illustrate the progressive understanding of PL's benefits, from enhancing sensory qualities to maintaining physicochemical stability and nutritional content. As research in this area continues to evolve, PL technology holds significant promise for the food industry, offering a non-thermal, effective approach to fruit and beverage preservation.

2.8 Packaging and Storage Study

The journey of food preservation has always been intertwined with the evolution of packaging and storage techniques. As the demand for high-quality, nutrient-rich, and long-lasting food products grows, researchers have explored various methods to enhance food safety, extend shelf life, and retain essential nutrients. Among these, HPP, PL treatment, and retort processing have gained significant attention for their ability to preserve food quality while minimizing degradation over time.

Patras *et al.* (2014) delved into the effects of HPP and thermal processing on strawberry puree stored in polyethylene terephthalate (PET) bottles at 4°C for six months. Their findings highlighted that HPP-treated samples exhibited superior retention of vitamin C, total phenolic content, and antioxidant activity compared to thermally processed ones. In the same year, Gómez-López *et al*. (2014) investigated the impact of PL treatment on apple juice packaged in PET bottles and stored at 4°C for 28 days. The results demonstrated that PL-treated juice maintained higher levels of vitamin C and total phenolic content compared to untreated samples.

Continuing this exploration, Aguiló-Aguayo *et al.* (2015) examined the effects of PL treatment on tomato juice stored in PET bottles at 4°C for 42 days. Their research revealed that PL-treated juice retained higher lycopene and total phenolic content than untreated controls. Around the same time, Devi *et al.* (2015) investigated retort processing's impact on mango pulp stored in flexible retort pouches at ambient temperature for 12 months. Their study confirmed that the processed pulp maintained its physicochemical properties, colour, and sensory attributes throughout the storage period.

Huang *et al.* (2017) evaluated blueberry puree processed with HPP and stored in PET bottles at 4°C for 60 days. Their findings emphasized HPP's effectiveness in retaining anthocyanins and total phenolic content, boosting antioxidant properties. Similarly, Oms-Oliu *et al*. (2017) studied PL treatment on watermelon juice stored in PET bottles at 4°C for 35 days, concluding that PL-treated samples exhibited higher vitamin C and total carotenoid content compared to untreated samples.

Two years later, Vieira *et al*. (2018) assessed the impact of HPP on orange juice stored in PET bottles at 4°C for 28 days. The study highlighted that HPP-treated juice maintained superior levels of vitamin C and total phenolic content. Around the same time, Kaushik *et al.* (2018) analyzed retort processing on pomegranate arils stored in flexible retort pouches at 37°C for six months. Their research demonstrated that the arils retained acceptable quality in terms of physicochemical properties, colour, and sensory attributes.

The study by Keenan *et al.* (2019) explored the effects of HPP on carrot juice packaged in PET bottles and stored at 4°C for 42 days. Their results confirmed that HPP-treated juice preserved higher carotenoids and total phenolic content compared to untreated samples. Following this, Sharma *et al*. (2020) examined the quality and shelf life of guava pulp processed through retort methods and stored in flexible retort pouches at 37°C for 12 months. Their findings demonstrated that the pulp retained its quality with only minimal changes in physicochemical properties, colour, and sensory characteristics.

The most recent study by Rao *et al*. (2021) focused on pomegranate juice processed with HPP and stored in PET bottles at 4°C for 56 days. Their research concluded that HPP-treated juice maintained higher anthocyanins and total phenolic content, thereby enhancing its antioxidant properties.

The collective findings of these studies illustrate the significant advancements in packaging and storage methods over the years. From HPP to PL treatment and retort processing, each technique plays a vital role in ensuring food safety, extending shelf life, and preserving nutritional integrity. As research continues, these innovations pave the way for a future where food waste is minimized, and consumers can enjoy fresh, high-quality products for extended periods.

2.9 Cost estimation

Beyond ensuring quality and safety, the economics of food processing plays a crucial role in determining the feasibility and adoption of various preservation

techniques. As researchers and industries seek to balance costs and benefits, several studies have explored the financial aspects of different processing methods.

Sampedro *et al*. (2014) examined the commercial pasteurization of orange juice using pulsed electric fields (PEF). Their study revealed that while PEF processing cost approximately $0.037 per liter, surpassing the $0.015 per liter cost of thermal pasteurization, its advantages in nutrient retention and reduced processing time made it an attractive alternative in premium market segments.

The following year, Reddy *et al.* (2015) analyzed the economic feasibility of HPP)for fruit pulp, estimating production costs at approximately $0.045 per kg. Despite the substantial capital investment required for HPP equipment, the method's ability to significantly extend shelf life and preserve sensory quality made it a promising option for high-end markets.

Zhang *et al*. (2019) conducted a comparative study of thermal and non-thermal preservation methods, estimating that thermal processing had the lowest cost per kg at $0.020, while non-thermal alternatives such as HPP and PEF ranged from $0.030 to $0.050 per kg. Although more expensive, these advanced techniques offered improved product quality, allowing for premium pricing strategies that could justify the additional costs.

Barcelos *et al*. (2022) investigated the cost implications of continuous pasteurization of açai pulp using plate heat exchangers. Their study found that operational expenses, driven by energy consumption and equipment maintenance, amounted to approximately $0.025 per kg. The authors emphasized that continuous pasteurization provided both an efficient and economically viable approach to pulp processing, ensuring long-term sustainability.

Most recently, Lee *et al*. (2023) assessed the economic viability of PL technology for pasteurizing fruit pulp. They determined that processing costs were around $0.040 per kg, placing it competitively alongside PEF but at a higher cost than traditional thermal methods. Their findings underscored that while PL minimized thermal degradation of sensitive compounds, its cost-effectiveness largely depended on production scale and consumer demand for high-quality products.

As these studies illustrate, the economics of food preservation is as dynamic as the technologies themselves. While some methods demand higher initial investments, their potential to enhance shelf life, maintain nutritional integrity, and appeal to premium markets makes them viable in the long run. The continued exploration of cost-effective and efficient processing techniques paves the way for a future where food remains safe, nutritious, and accessible, while ensuring financial sustainability for producers and industries alike.

2.10 Conclusion and knowledge gap of the study

The study of thermal and non-thermal preservation methods for fruit pulp, particularly through retort processing, HPP, and PL technology, provides a comprehensive understanding of how these techniques can enhance the quality and safety of fruit products. Recent literature highlights the effectiveness of retort processing, which employs high temperatures and pressures to eliminate microorganisms and enzymes responsible for spoilage. This method significantly extends shelf life while preserving sensory and nutritional qualities when heat treatment parameters are optimized to minimize adverse effects (Kuffman and Pacheo, 2020; Kailas Engineering, 2024).

In parallel, HPP has gained recognition as a promising non-thermal preservation method that maintains the integrity of bioactive compounds in fruit pulp. Research indicates that HPP effectively reduces microbial loads while preserving flavor, color, and nutritional content, making it particularly suitable for high-acid fruit products where maintaining organoleptic qualities is crucial (Barbhuiya *et al*., 2021). Similarly, PL technology has shown potential for enhancing microbial safety without the use of heat. Recent findings suggest that PL can effectively inactivate pathogens while retaining the nutritional and sensory attributes of fruit, though its commercial application remains in developmental stages (Barbhuiya *et al*., 2021).

Despite these advancements, there remains a significant knowledge gap regarding the comparative efficacy of thermal and non-thermal processing techniques specifically for ripe jackfruit. Most existing studies focus on other fruit types, leaving a lack of standardized information on optimal preservation methods for jackfruit. Given

the fruit's short shelf life and susceptibility to microbial spoilage, addressing this gap is essential for ensuring its quality, safety, and commercial viability.

Future research should focus on systematically evaluating and standardizing these processing approaches, particularly in terms of their impact on the physicochemical, microbiological, and sensory attributes of ripe jackfruit. Exploring the synergistic effects of thermal and non-thermal methods, optimizing processing conditions, and assessing consumer acceptance will be critical for advancing fruit pulp preservation. By establishing an optimized approach, this research will contribute to the sustainable utilization of jackfruit, enhance its market potential, and reduce post-harvest losses.

Materials and methods

CHAPTER III

MATERIALS AND METHODS

This chapter explains the materials and approved methodologies followed for the standardisation and evaluation of thermal and non-thermal processing of ripe jackfruit bulb (RJB) and ripe jackfruit pulp (RJP). The session comprises the detailed procedures followed for the thermal process standardisation of ripe jackfruit by retort pouch processing, non-thermal standardisation via HPP and PL technology. For a better understanding and elucidation, this session is subdivided as:-

Experiment I: Thermal process standardisation of RJB and RJP utilizing retort pouch processing

Experiment II: Standardisation of HPP parameters for RJB and RJP

Experiment III: Standardisation of PL for RJP

3.1 Raw material collection and sample preparation

Jackfruit (variety: *Varikka*) was sourced from the Fruits and Vegetables Research Station at Kerala Agricultural University, Vellanikkara, Thrissur, Kerala. The external impurities over the jackfruits were removed by washing them properly in tap water and surface sanitisation was carried out by dipping washed jackfruits in 1% (120 ppm) sodium hypochlorite solution for 10 min. (Saranya *et al*., 2024). The surface-sanitised jackfruits were cut into four pieces vertically, and the central core was removed to separate the RJB (Plate 3.1). The jackfruit bulbs, thus separated and de-seeded were used for further processing. RJP for thermal and non-thermal processing was prepared with the aid of an industrial mixer (Plate 3.2) (Make: Sarahas Techno, Kerala).

Plate.3.1 Cutting and deseeding and packing of RJB

Plate. 3.2 Jackfruit pulping using industrial mixer

EXPERIMENT I:

3.2 THERMAL PROCESS STANDARDISATION OF RJB AND RJP UTILIZING RETORT POUCH PROCESSING

Thermal process standardisation of ripe jackfruit was carried out in a steam-air retort (Plate 3.3c) following the method given by Gobikrishnan *et al*. (2019). The retort was equipped with a high-pressure water circulation pump for cooling and compressed air for overriding pressure. Retort pouches of 250 g capacity were selected as the packaging material during the experimental trials. Treatment samples were prepared by filling 200 g bulbs in each packet with 35˚Brix sugar syrup as a filling solution (Fig.3.1). Concomitantly, the jackfruit pulp in each packet was 150 g. Excess air inside the packets was exhausted via, high-pressure steam from a steamer (Plate 3.3 a) and immediately packed in a pneumatic sealer (Make: Sevana, India; Model: QS300PNI) prior to processing. The sealed jackfruit samples were placed in the retort trays and loaded inside the machine for processing. The thermal processing was initiated after achieving a steam boiler pressure of 2 bars and closing the retort door and pressure valves in the process chamber, so that the internal pressure can be maintained within the chamber. Immediately after thermal processing, the cooling process was carried out two times by passing normal water to the process chamber along with a blast of compressed air to

avoid the rapid pressure difference. Upon the completion of the cooling cycle, processed samples were unloaded and preserved for storage. The retort pouch pasteurisation and sterilisation conditions applied for the safe preservation of RJB and RJP are detailed in Table. 3.1

Table 3.1 Thermal processing of ripe jackfruit samples

Sl. No.	Retort pouch Processing	Process variables	Range
1.	Pasteurisation	Pasteurisation Temperature	75-95ºC
		Pasteurisation Time	5-15 min
2.	Sterilisation	Sterilisation Temperature	105-120ºC
		Sterilisation Time	5-15 min

(a) **(b)** **(c)**

Plate 3.3 Air exhausting, thermocouple insertion and retorting in steam air retort

Copper-constantan thermocouples were used for monitoring the internal temperature and external temperature of the pouch during heat processing Plate 3.3 b). Thermal process conditions of ripe jackfruit were fixed by conducting preliminary study. The processed samples were analysed for their quality characteristics and shelf life for standardisation and better preservation of ripe jackfruit samples. The detailed flow chart for retort pouch processing of ripe jackfruit is given below in Fig.3.1

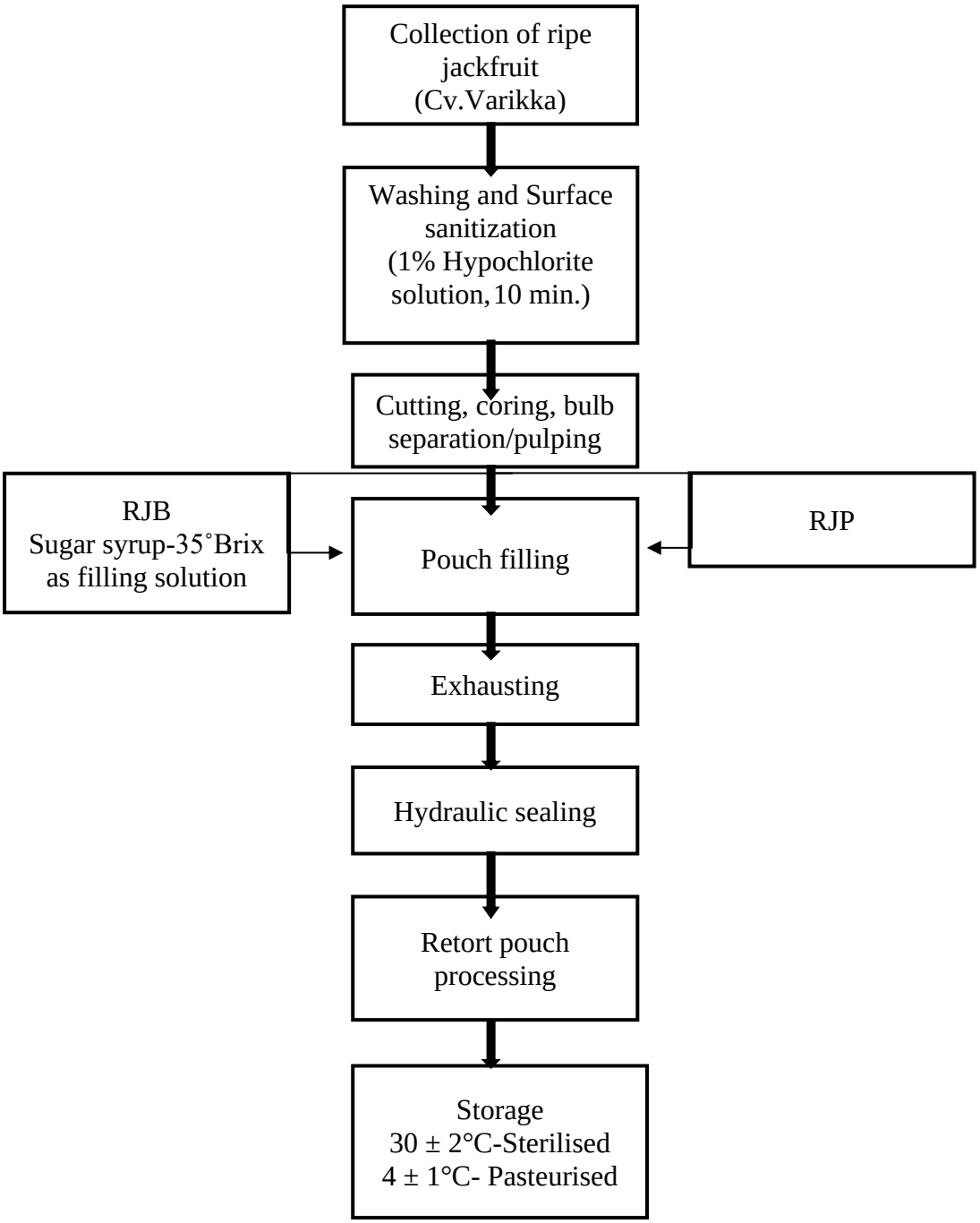


Fig.3.1 Flow chart for retort pouch processing of ripe jackfruit

3.2.1 Experiment design

In this study, the effect of time (min.) and process temperature (ºC) were investigated in relation to the quality and shelf-life extension of ripe jackfruit using a face-centered central composite response surface analysis. The Central Composite

Design (CCD) is an experimental approach used to fit a second-order response surface, drawing inspiration from the structure of balanced incomplete block designs. For the experimental plan, two independent variables: temperature and process time were encoded. Each independent parameter was set at a level based on limitations associated with the sample and the equipment. The experimental data were adjusted to fit a polynomial response surface.

Table 3.2 Coded and un-coded values of process factors in CCD design for retort pouch processed ripe jackfruit

Retort pouch processing	Independent variables	Levels in coded form				
		-1	0	+1	-1.414	+1.414
Pasteurisation	Temperature (°C)	75	85	95	70.85	99.14
	Time (min.)	5	15	25	0.86	29.14
Sterilisation	Temperature (°C)	105	112.50	120	101.89	123.19
	Time (min.)	5	10	15	2.92	17.07

3.2.2 Quality analysis of retort pouch processed ripe jackfruit

The physicochemical characteristics like pH, TSS, titrable acidity (TA), colour characteristics, Ascorbic acid content (AA), Total Phenolic compounds (TPC), Total Flavanoid Compound (TFC), DPPH radical scavenging activity, total sugar, texture, rheological characteristics, microbial activity and sensory analysis were analysed for ripe jackfruit after retort pouch processing are detailed below.

3.2.2.1 pH

A digital pH meter (Model: ECPHTUTOR-S; Make: R-Initiative Enterprises, Faridabad, Haryana) was used to determine the pH of the processed jackfruit samples (AOAC, 2000). The equipment was calibrated with distilled water and buffer solutions of pH 4, 7, and 9. The sensor probe was immersed in the samples to measure the pH values. Prior to testing, RJB samples were ground into a paste using a pestle and mortar.

Each experiment was conducted in triplicate, and the average pH along with the standard deviation value was recorded.

3.2.2.2 Titrable acidity (TA)

The total acidity of treated jackfruit samples was assessed following the AOAC (2000). To prepare the sample, 5 g of treated ripe jackfruit bulbs were ground into a fine paste and mixed with 100 mL of distilled water. After adding a few drops of phenolphthalein indicator, the mixture was shaken thoroughly. A burette was then filled with 0.1 N NaOH, and the sample solution was titrated against the NaOH until the colour changed to pale pink, which was maintained for 30 seconds. The calculation for TA is provided in Eq 3.1:

TA (% malic acid) =

$$\frac{\text{Volume of titrant (ml)x Normality of titrant}\times 0.067 \text{ x } 100}{\text{Sample weight(ml)}} \quad \ldots (3.1)$$

Where 0.067 is the milliequivalent of malic acid.

3.2.2.3 TSS

The TSS content of ripe jackfruit samples was measured using a digital handheld refractometer (model: BX-1, KEM, Japan), with results expressed in ºBrix at room temperature, following the Abrol and Joshi (2011). To conduct the TSS measurement, jackfruit pulp was placed in the measuring port of the refractometer, and the displayed value was recorded, as referenced by Saranya *et al*. (2024). For improved accuracy, the readings were taken three times.

3.2.2.4 Texture

Two-cycle texture profile analysis (TPA) tests were performed using the EZ-SX500N model from Stable Micro Systems Ltd., UK on jackfruit bulbs that had undergone thermal and non-thermal processing. In this analysis, the firmness of the RJB was measured at a constant speed of 0.5 mm/s, utilizing a 60 mm cutting probe, as outlined by Wu *et al*. (2021). During the compression process, the maximum force exerted (Newtons) was recorded, which served as an indicator of the firmness of the

samples. This method provides a quantitative assessment of the textural properties of jackfruit, allowing for a better understanding of how retort pouch processing conditions affect the firmness and overall texture of the fruit.

3.2.2.5 Colour characteristics

Visual colour characteristics were measured using a Hunter lab colour flux meter (MiniScan EZ 4510 LAV, Hunter Associates Laboratory, USA) which provides colour values in the terms of L*, a*, and b* values, where L* indicates whiteness to darkness, a* (+) redness, a* (-) greenness, b* (+) yellowness and b* (-) blueness. The working principle of the instrument is to focus the light on the samples and measure the energy reflected from the samples across the entire spectrum. The instrument was initially calibrated and the ripe jackfruit samples were placed in the transparent cup with as minimum void space as possible. Based on the colour co-ordinates, the Yellowness Index (YI) which indicates the degree of yellowness of the sample was calculated (Pathare *et al.*, 2013).

The colour of the RJB and RJP may vary from its fresh colour after processing due to the enzymatic or non-enzymatic process. According to Eq. (3.2), the deviation of colour from the fresh control sample to the processed jackfruit was analysed and indicated as the total colour difference (ΔE) of the samples.

$$\Delta E = \sqrt{(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2} \quad \text{... (3.2)}$$

where, L^*, a^* and b^* represents the colour value of the analysed sample and L_0, a_0, and b_0 indicates the colour value of fresh RJB/RJP

The yellowness index (YI) represents the variation of colour to yellow and is given by the Eq. (3.3) (Kaushik *et al.*, 2014)

$$YI = 142.86\ b^*/L^* \quad \text{... (3.3)}$$

The Browning index (BI) of the jackfruit was studied and calculated as per Eq. (3.4) given below (Sreedevi *et al.*, 2021).

$$BI = \frac{180.232(a^* + 1.75L)}{(5.645L^* + a^* + 3.012b^*)} \quad \text{… (3.4)}$$

3.2.2.6 Ascorbic acid content (AA)

The AA of the sample was measured using a titration of the 2,6-dichlorophenolindophenol dye with AA according to its ability to reduce the dye to colourless leuco-base using the titration method described earlier by Lu *et al*. (2018) and AOAC (1990).

Treated ripe jackfruit bulbs were ground to fine pulp and 10 mL of the homogenized pulp was made up to 100 mL with 4% oxalic acid solution. After 15 min., the extract was filtered out using a Whatman filter paper No.1 for further studies.

The dye solution used for titration was a mixture of sodium bicarbonate and 2, 6 dichlorophenol indophenols. During the analysis, 42 mg of sodium bicarbonate and 52 mg of 2, 6 dichlorophenol indophenols were diluted with distilled water and made up to 200 mL. A stock standard solution is prepared by dissolving 100 mg of ascorbic acid in 100 mL of a 4% oxalic acid solution. The 10 mL of the standard solution was taken in the standard flask and made up to 100 mL using 4% oxalic acid to make a working standard solution. The 10 mL of working standard solution was pipetted out into a 50 mL conical flask and 10 mL of 4% oxalic acid was added to it and titrated against the dye, to find out the dye factor. The endpoint is the appearance of pink colour which lasts for a few mins. The titration is repeated to obtain concordant values. The amount of AA present in the working standard solution is given by the amount of dye consumed (V_1). The 5 mL of extracted jackfruit sample was taken in a standard flask along with 10 ml of 4% oxalic acid and titrated against dye. Take 5 mL of this sample and add 10 ml of 4% oxalic acid to it. Titrate this against dye to find out the AA content in the sample. The following Eq 3.5 is used for calculation.

$$\text{AA content (mg/100 ml)} = \frac{0.5\text{ mg}}{\text{V1 mL}} \text{ x } \frac{\text{V2}}{5\text{ mL}} \text{ x } \frac{100\text{ mL}}{\text{Volume of sample}} \text{ x100} \qquad \ldots (3.5)$$

V1 - Amount of dye consumed by AA in the working standard ml.

V2 - Amount of dye used up by the jackfruit sample, ml.

3.2.2.7 Total sugar

The total sugar content of processed RJB and RJP was quantified using the method outlined by Ranganna (1986). To begin, a 5 g portion of the processed jackfruit

sample, encompassing both the RJB and RJP, was measured and transferred into a 250 mL standard flask. The sample was then diluted to the 250 ml mark by adding 45% neutral lead acetate and 22% potassium oxalate (2 mL of each). After allowing the mixture to stand for 10 min. to facilitate the precipitation of impurities, the solution was filtered to obtain a clear filtrate. Next, 50 ml of the filtrate was combined with a solution of 5 g of citric acid dissolved in 50 ml of water and brought to a boil. Once the boiling was complete, the mixture was cooled, and a drop of phenolphthalein indicator was added. The solution was then neutralized with 1 N sodium hydroxide until a light pink colour appeared, and the volume was adjusted to 250 mL using distilled water, resulting in the prepared titration solution. To determine the total sugar content, the prepared solution was transferred to a burette, and 5 ml each of Fehling's solution A and Fehling's solution B were pipetted into a conical flask. The burette solution was titrated against Fehling's solution in the flask, using methylene blue as an indicator, until a brick red colour persisted. The total sugar content was then calculated and expressed as a percentage of the original sample weight from Eq 3.6.

$$\text{Total sugar (\%)} = \frac{\text{Fehling's factor x 250 x dilution x 100}}{\text{Titer value x 50 x weight of the sample}} \quad \ldots (3.6)$$

3.2.2.8 Total Phenolic Compounds (TPC) and Total Flavonoid Compounds (TFC)

The treated jackfruit samples were tested for TPC with the Folin-Ciocalteu reagent (FCR) proposed by Kaushik *et al*. (2014). In 1.5 mL microcentrifuge tubes, 100 µL of methanolic extract from ripe jackfruit, 100 µL of MeOH, 100 µL of Folin-Ciocalteu reagent (FC), and 700 µL of Na_2CO_3 were mixed together and vortexed. The tubes were then kept in the dark for 20 min. at room temperature. Following this, the samples were centrifuged at 13,000 rpm for 3 min. using an Eppendorf Centrifuge 5417R (Germany). The absorbance was measured at 760 nm, with aqueous gallic acid (10–400 mg/L) used as a standard reference. The results were reported as mg of gallic acid equivalents per 100 g of dry sample weight, determined by constructing a gallic acid calibration curve.

A colourimetric assay method similar to that described by Saranya *et al*. (2024) was used to estimate flavonoids in retort pouch processed jackfruit samples. As per the procedure, sodium nitrate solution (0.3 mL) was added to the crude extract of retort pouch processed ripe jackfruit samples (10 mL) and allowed to stand for 5 min. Aluminium chloride solution (0.3 mL) was added to this mixture and it was then left for six mins before adding sodium hydroxide (2 mL) to it. The solution thus formed was made up to 10 ml with distilled water and was used to measure the absorbance at 510 nm. The TFC of processed ripe jackfruit samples thus obtained was expressed in mg rutin equivalents/g of fresh sample.

3.2.2.9 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity

The antioxidant capacity of processed ripe jackfruits was assessed using the DPPH assay in terms of DPPH radical scavenging activity. To assess the DPPH radical scavenging activity of retort-pouch-processed ripe jackfruit samples, a 0.1 mM DPPH solution was created using methanol, and an extract of the ripe jackfruit pulp was prepared by homogenizing the pulp in methanol at a concentration of 10 mg/mL, followed by filtration to remove any solid particles. The resulting extract was then diluted to various concentrations ranging from 1 to 10 mg/mL. For the assay, 1 mL of each dilution was combined with 1 mL of the DPPH solution, alongside control samples that contained only DPPH and a known antioxidant for reference. The mixtures were allowed to incubate in the dark at room temperature for 30 min. After incubation, the absorbance was measured at 517 nm using a spectrophotometer (Jayachandran *et al*., 2015). All measurements were conducted in triplicate to ensure accuracy. The percentage of DPPH scavenging activity was calculated using the following formula:

$$\% \text{ DPPH radical scavenging activity} = (A_{control} - A_{sample})/ A_{control} \times 100 \quad \ldots (3.7)$$

where $A_{control}$ is the absorbance of the control (DPPH solution without extract) and A_{sample} is the absorbance of the sample mixture.

3.2.2.10 Rheological properties

Rheological properties of fresh, retort-processed, ripe jackfruit samples were evaluated using an MCR 72 rheometer (Anton Paar GmbH, Graz, Austria) with a concentric cylinder system (CC39). The bob had a length of 60.010 mm, a diameter of

38.722 mm, and a cup diameter was 42 mm. Measurements were conducted at a constant temperature of 30°C (±0.1°C). Shear stress was recorded at increasing shear rates from 0.1 to 400 s^{-1}, collecting data points that were analyzed for viscosity using Rheoplus software. All measurements were performed in triplicate (Maria *et al*., 2015.) The viscosity-shear rate relationship can be modeled using the Ostwald-de Waele power-law equation:

$$\eta = k\dot{\gamma}^{(n-1)} \quad \text{……. (3.8)}$$

where:

- η = viscosity (Pa.s)
- $\dot{\gamma}$ = shear rate (1/s)
- k = consistency coefficient
- n = flow behavior index (n < 1 indicates shear-thinning behavior)

3.2.2.11 Microbial analysis

The microbial quality analysis of thermally processed ripe jackfruit was estimated based on the procedure followed by Pritty and Sudheer (2020). The total aerobic mesophiles (TAM) and total yeast and mold populations in the processed samples were analysed by standard procedures. Initially, all glassware and media were sterilized in an autoclave at 121°C for 15 min. to eliminate any microbial contamination. Nutrient Agar was prepared for the TAM, while Potato Dextrose Agar (PDA) was formulated for yeast and mold count by mixing 200 grams of potato infusion, 20 g of dextrose, and 20 g of agar with distilled water to a total volume of one liter. The thermally processed jackfruit samples were then serially diluted in sterile saline or distilled water up to 10^{-8} dilutions. Following this, 1 mL from each dilution was inoculated into sterile Petri dishes containing the prepared media in a sterile environment. The plates for TAM were incubated at 35°C for 24 to 48 hours, whereas the PDA plates for yeast and mould were incubated at 25°C for three to five days. After incubation, colonies were counted, and the number of colony-forming units (CFU) per g of sample (Ns) was calculated using the following formula:

$$Ns = \frac{Ncfu \times DF}{Ws} \quad \ldots (3.9)$$

Where,

Ws: weight of the sample; DF: dilution factor; $N_{cfu:}$ number of colony-forming units

After incubation, colonies were enumerated, and the microbial reduction in log CFU/g was calculated using the following formula:

$$\text{Log reduction} = \log N_0 - \log N_t \quad \ldots. (3.10)$$

where:

- N_0 = Initial microbial count before processing (CFU/g)
- N_t = Microbial count after retort pouch processing (CFU/g)

The results were expressed as a total reduction in log CFU/g, indicating the effectiveness of retort pouch processing in microbial inactivation

3.2.2.12 Sensory evaluation

Sensory evaluation of the retort pouch processed ripe jackfruit samples was conducted to assess organoleptic characteristics such as colour, flavour, appearance, texture, and overall acceptability, as outlined by Ranganna (1986). A semi-trained panel consisting of 21 members, including faculty and research scholars from the Department of Agricultural Engineering at the College of Agriculture, Vellanikkara, carried out the evaluation. The panel used a nine-point Hedonic scale for the sensory assessment, with the scorecard model provided in Appendix B1. Fresh RJB and RJP were included as the control during sensory analysis for comparative study. The mean scores from the scorecards were analyzed to determine the most acceptable product.The sensory score cared used for the analysis was given in Appendix

3.2.3 Modelling and optimisation

The optimisation of process parameters was done using Design Expert Software version 12. CCD-based RSM and regression analysis were done to optimize the parameters to achieve desired goals in retort processing (Chhabra and Deswal, 2020). The effect of the process parameters on the various quality attributes was analysed. The responses obtained from the experimental runs of CCD were modelled by a second-order polynomial equation, as follows.

$$Y = b_0 + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} b_{ii} X_i^2 + \sum_{i=1}^{k} \sum_{j=i+1}^{k} b_{ij} X_i X_j \quad \ldots (3.11)$$

Where, *Y*: The predicted response variable, b_0: The intercept term, b_i: The coefficients for the linear terms, representing the effect of each independent variable on the response, b_{ii}: The coefficients for the quadratic terms, indicating how the response changes with the square of each independent variable, b_{ij}: The coefficients for the interaction terms, showing how the effect of one independent variable on the response depends on another variable

3.2.4 Statistical Analysis

The statistical data was analysed for ANOVA using Design Expert Software version 12. The p-values were used as a tool to check the significance of each of the coefficients, which, in turn, were necessary to understand the pattern of the mutual interactions between the test variables.

After conducting an ANOVA test to determine the statistical significance of each term in the polynomial model, the non-significant terms were deleted from the model and a new ANOVA test was conducted with a Design expert. It would allow for a more accurate determination of coefficients in the final equation. The data analysis of non-significant terms was performed using IBM SPSS Statistics© v.23.0. In the present study, optimisation was performed with significant terms to obtain the best treatment with superlative physicochemical properties. Afterwards, a one-way ANOVA of control to optimised values was performed. Ducan's test was applied to ascertain the range of values in which the differences were located.

3.2.5 Cost estimation

The total cost involved in the production of retort pouch processed ripe jackfruit was estimated using a standard procedure with suitable assumptions (Appendix G1 and G2).

3.2.6 Storage studies

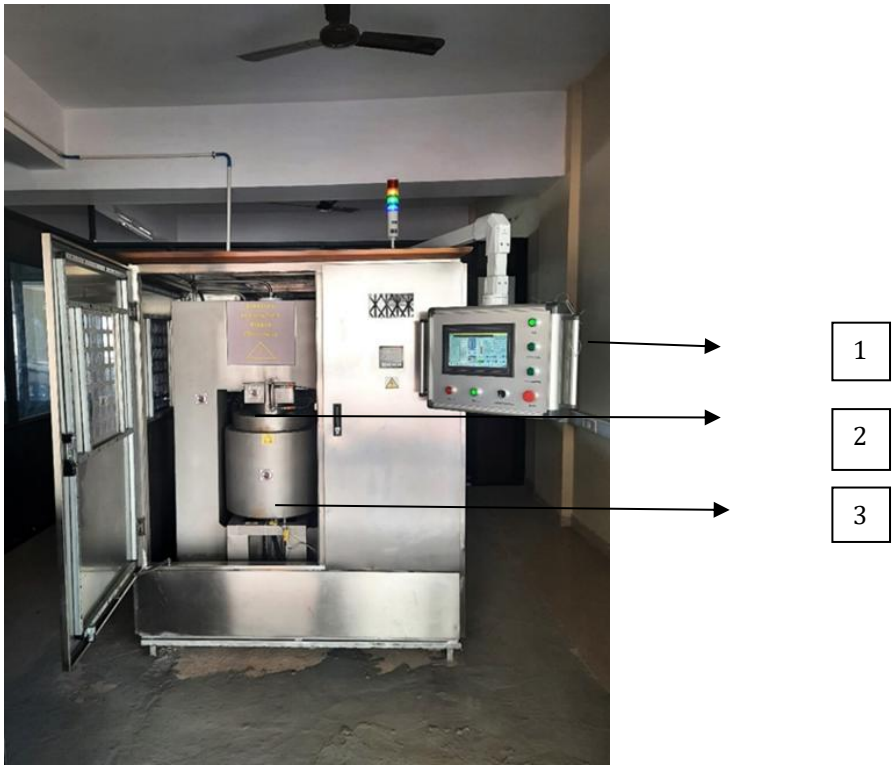
The shelf-life stability of the retort pasteurised ripe jackfruit samples was analysed at refrigerated storage conditions and retort sterilised samples were stored under ambient conditions. The best and most optimized treatment samples based on the sensory and quality evaluation were stored for shelf-life study (Chandan *et al.*, 2021). The changes in the samples' physicochemical attributes such as pH, TA, TSS, colour deviation, texture, AA content, TPC, total sugar and microbial analysis were analysed during the storage period at regular intervals. All the experiments were performed in triplicate and the mean values were taken for analysis.

EXPERIMENT II:

3.3 STANDARDISATION OF HPP PARAMETERS FOR RJB AND RJP

3.3.1 HPP system

High pressure was achieved with a batch-type HPP system (Make: KK Life science, India; Model: HPP-TE) available at College of Food Processing Technology & Bio-Energy, Anand Agricultural University, Gujarat.



1. PLC panel 2. Hydraulic piston 3. Pressure Vessel

Plate.3.4 Batch type HPP system

The pre-packaged fruit samples were treated in a chamber (Plate 3.3) surrounded by water or pressure-transmitting fluid. The main components of the system comprise a 3 L capacity pressure vessel, hydraulic piston, water storage tank, pressure valves, and a Programmable Logic Controller (PLC) unit. The equipment is fully automatic and operates within a temperature range of 30 to 80°C and maximum pressure of 600 MPa. The PLC system is the main control unit of the equipment where process inputs are entered and displayed during HPP. Perforated baskets aid in handling pre-packaged food in pressure vessel and allows filtering and reuse of compression fluid.

3.3.2 High pressure processing of RJB and RJP

Preliminary trials on HPP of ripe jackfruit were conducted prior to research trials. After fixing the treatments the vacuum-sealed jackfruit bulbs and pulp were subjected to high pressure treatment (300-600 MPa) for 10-15 min. at ambient temperature. The RJB samples were vacuum packed using vacuum packaging machine (Model:SC2, Make: Indvac ltd, Gujarat, India) and RJP samples were tightly packed or air-tight packaging was done in LPP plain transparent laminated stand pouches with overall migration of less than 10 mg/L. Followed by packing, samples were loaded into the perforated baskets inside the pressure vessel. After ensuring that the samples were closely packed process factors were keyed and the start command was given in the PLC display. Subsequently, the vessel was sealed, and pressure-transmitting fluid was pumped into the pressure vessel to displace the trapped air. Once filled, the pressure relief valve was closed, and the hydraulic piston moved downwards to pressurise the samples. Concurrently water continued to be pumped until reaching the desired process pressure.

The pressure relief valve was opened after the processing time, allowing the compression water to expand and return to atmospheric pressure. The hydraulic piston moves upwards and the pressure transmitting fluid re-enters the storage tank. During the experimental run, the compression led to an average temperature rise of 3 ± 0.5°C per 100 MPa increase in pressure, owing to adiabatic heating (Elamin *et al*., 2015). Upon completion of the HPP treatment, the samples were immediately refrigerated for further analysis. All samples were processed and analysed in triplicate for accuracy.

3.3.3 Experimental Design

The CCD of the Design Expert software was used for deciding the number of experiments and the combinations of independent variables. The experimental plan consisted of three levels of two independent variables, pressure (P) and holding time (Ht), which were encoded for detailed statistical analysis (Table 3.3). The levels of pressure for applying HPP to ripe jackfruit were set within the high pressure system's allowable limit, and based on previous studies. The regression analysis predicted by the Design Expert gave a model equation of the interaction of independent variables in the process.

Table 3.3 Experimental design for HPP ripe jackfruit

Factor	Independent variables	Units	Coded Low	Coded High
P	Pressure	MPa	-1 ↔ 300.00	+1 ↔ 600.00
Ht	Holding time	min	-1 ↔ 5.00	+1 ↔ 20.00

3.3.4 Quality analysis of HPP ripe jackfruit

3.3.4.1 Estimation of physicochemical characteristics

The physicochemical characteristics like pH, TSS, TA, AA content, total sugar, colour characteristics, TPC, TFC, DPPH radical scavenging activity, texture, rheological property, sensory evaluation and microbial analysis of HPP processed RJB and RJP etc were analysed for ripe jackfruit after HPP as detailed previously (section 3.12-3.14).

3.3.5 Statistical Analysis

The statistical analysis was conducted using Design Expert Software version v.7 for ANOVA to evaluate the significance of each coefficient as explained in section 3.2.4.

3.3.6 Process modelling and optimisation

Process parameter optimisation was carried out using Design expert software version v.7. A CCD approach based on RSM and regression analysis was employed to optimize the parameters for achieving desired outcomes in HPP as explained in section 3.2.3

3.3.7 Cost estimation

The total cost involved in the production of HP- processed ripe jackfruit was estimated using a standard procedure with suitable assumptions (Appendix G3 and G4).

3.3.8 Storage studies

The HPP ripe jackfruit samples were stored under refrigerated conditions, with quality analyses conducted at 10-day intervals. The samples selected for the shelf life study were those identified as the best and most optimized based on sensory and quality evaluations (Chandan *et al*., 2021). During the storage period, changes in physicochemical attributes, including pH, TA, TSS, colour deviation, texture, AA content, TPC, total sugar, and microbial load, were monitored as mentioned in section 3.2.21-3.2.2.12. All experiments were performed in triplicate, and the mean values were used for analysis.

EXPERIMENT III:

3.4 STANDARDISATION OF PL TECHNOLOGY FOR RJP

The PL treatment for RJP was carried out using a benchtop laboratory scale high-intensity PL system (Model: Xenon X-1100, Xenon, Wilmington, MA, USA). The PL system comprises a controller unit with a touchscreen operator display, a treatment chamber, and a blower. The treatments were performed batch-wise in an air-cooled treatment chamber where the lamp housing was positioned over the top of the sample tray. This PL machine offers several optional lamps (viz, UV-A, UV-B, and UV-C) mounted in air-cooled sealed housings. The triggered transformer present in the controller supplies the required energy for initiating the pulses. High-intensity noncollimated white light (240-1,100 nm) with a maximum voltage of 3 Kv could be produced by the linear xenon flash lamp (xenon flash lamp model LH-840, Ø 1.9 ×30.5 cm, UV-C, mercury-free). The lamp overheating is controlled by an air blower connected to the quartz window at the lamp housing. The distance of the sample from the lamp housing can be adjusted by shifting the sample tray inside the treatment chamber. The touchscreen-based graphical user interface (GUI) enables to input of the pulse parameters or program recipes such as voltage, pulse duration, energy, pulse number, and sequencing. The maximum and peak energies of each program recipe are

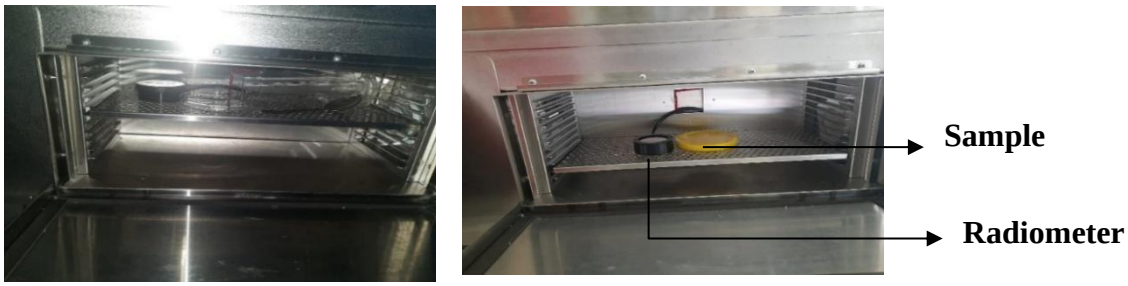
automatically calculated and displayed on the screen after treatment. The results of each input can be saved to the system for further studies (Vollmer *et al*., 2020).

3.4.1 PL processing

In the present study, the PL treatment of RJP was carried out according to the methodology described by Vollmer *et al*. (2020) with slight modifications. The factors considered for PL treatment of RJP consist of input voltage, pulse number, sample depth, distance from the sample to the light source and sample concentration (%). Preliminary trials were conducted to fix the treatment trials and 100% pulp and 1 mm sample thickness were standardised for the final treatment which gave the best colour, flavour and quality retention after treatment and storage. For each treatment, the ripe jackfruit pulp (100 g) was dispensed into Petri dishes (100 mm diameter) so that the entire dish surface was covered with the sample to a pre-set depth (1-5 mm). During the study, the sample was positioned at different perpendicular distances (4-10 cm) from the lamp source. PL treatment of RJP was carried out at varying voltage levels from 1 to 2.5 kV. The wave period was 950 ms, with a frequency of 1 Hz. The average fluence per pulse was determined using a radiometer (Model: PE-50, Ophir Optronics Solutions Ltd., Israel), which was positioned alongside the sample at varying distances from the light source (Plate 3.5b) and total fluency and fluency rate were calculated from the equation (3.10 and 3.11) by considering total number of pulses as treatment time in seconds. Aqueous ethanol (80% v/v) was used to disinfect the surfaces of the PL equipment and petri dishes before each treatment. Additionally, all utensils and labware were pulsed (3 kV/20 pulses) in the system for better surface sterilisation (Plate 3.5a) and hand gloves were sprayed with ethanol (80% v/v) prior to transferring sample from Petri dishes to PET bottles to avoid cross contamination. Immediately after processing, the samples were transferred to sterilised PP bottles and stored in refrigerated condition for further shelf-life study. The process optimisation was carried out by CCD with the aid of Design expert software version-V.7.

Total fluence ($J \cdot cm^{-2}$) = average fluence per pulse × number of pulses …(3.12)

Fluence rate ($W \cdot cm^{-2}$) = total fluence/treatment time … (3.13)



(a) **(b)**

Plate 3.5 Surface sterilisation of glassware and PL processing of RJP respectively

3.4.2 Experimental design

A face-centered central composite response surface analysis was used to determine the effect of voltage (kV), pulse number, and lamp to sample distance (cm) on the quality characteristics of PL-treated jackfruit pulp. The RSM with Box-Behnken design was carried out to test several variables using a limited number of trials, revealing interactions between the variables. The levels for each independent parameter were chosen considering sample and equipment limitations. Three (maximum, minimum and central) values of each factor were considered, leading to 17 experiments (Table 3.4). The experimental design was performed twice, resulting in one block of experiments. Experimental data were fitted to a polynomial response surface.

After conducting an ANOVA test to determine the statistical significance of each term in the polynomial model, the non-significant terms were deleted from the model and a new ANOVA test was conducted with a Design expert. It would allow for a more accurate determination of coefficients in the final equation. The data analysis of non-significant terms was performed using IBM SPSS Statistics© v.23.0. In the present study, optimisation was performed with significant terms to obtain the best treatment with superlative physicochemical properties. Afterwards, a one-way ANOVA of control to optimised values was performed to identify the range of values showing the differences.

Table 3.4 Experimental design for PL processed RJP

Treatment No.	Voltage (kV)	Pulse number	Lamp to sample distance (cm)
1	1.5	50	7
2	2.5	50	7
3	1.5	200	7
4	2.5	200	7
5	1.5	125	4
6	2.5	125	4
7	1.5	125	10
8	2.5	125	10
9	2	50	4
10	2	200	4
11	2	50	10
12	2	200	10
13	2	125	7
14	2	125	7
15	2	125	7
16	2	125	7
17	2	125	7

3.4.3 Quality analysis of PL processed RJP

The physicochemical characteristics like pH, TSS, TA, AA content, total sugar, colour characteristics, TPC, TFC, DPPH scavenging activity, texture, rheological property, sensory evaluation and microbial analysis were analysed for RJP after PL processing by standard procedures discussed under the section section:3.2.2.1-3.2.2.12. The statistical data was analysed for ANOVA using Design Expert Software version 12.

3.4.4 Process modelling and optimisation

The optimisation of process parameters was done using Design Expert Software version 12. Box Behnken design-based RSM and regression analysis was done to optimize the parameters to achieve desired goals for PL processing of ripe jackfruit pulp. The effect of the process parameters on the various quality attributes was analysed. The responses obtained from the experimental runs of BBD were modelled by a second-order polynomial equation, as follows.

$$Y = b_0+b_1A+b_2B+b_3C+b_4D+b_{11}A^2+b_{22}B^2+b_{33}C^2+b_{44}D^2+ b_{12}AB+b_{13}AC+b_{14}AD+b_{23}BC+b_{24}BD+b_{34}CD \quad ...(3.14)$$

where Y is the predicted response, A, B, C and D are the coded independent variables, b_0 is the intercept term, b_1, b_2, b_3, and b_4 are the linear coefficients, b_{11}, b_{22}, b_{33}, and b_{44} are the quadratic coefficients and b_{12}, b_{13}, b_{14}, b_{23}, b_{24}, and b_{34} are the interactive coefficients

3.4.5 Cost estimation

The total cost involved in the production of PL processed ripe jackfruit was estimated using a standard procedure with suitable assumptions (Appendix G5).

3.4.6 Storage studies

The shelf-life stability of PL ripe jackfruit samples was evaluated under refrigerated storage conditions, with assessments conducted at 10-day intervals. The samples selected for this study represented the most optimized treatments, determined through sensory and quality evaluations (Chandan *et al*., 2021). Physicochemical parameters such as pH, TA, TSS, colour deviation, texture, AA content, TPC, total sugar, microbial load and sensory analysis were monitored using standard analytical procedures (section: 3.2.2.1-3.2.2.12). All experiments were conducted in triplicate, and the mean values were used for data analysis.

Result and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

The objective of this chapter is to examine and assess how various processing methods, including thermal methods like retort processing, and nonthermal methods such as HPP and PL processing, impact the quality attributes of ripe jackfruit. The focus is on understanding how these diverse processing techniques influence the quality characteristics of the ripe jackfruit, providing insights into the effects of both thermal and nonthermal approaches on the final product during and after processing and throughout its storage period. The impact of both thermal and non-thermal processing methods on the quality characteristics of ripe jackfruit is elaborated in the subsequent section through three distinct experiments:

EXPERIMENT I: THERMAL PROCESS STANDARDISATION OF RJB AND RJP UTILIZING RETORT POUCH PROCESSING

4.1 Effects of retort pouch pasteurisation on the quality of RJB and RJP

Retort pouch processing was carried out to ensure the quality and safety of the ripe jackfruit samples. The effect of retort pouch pasteurisation and retort sterilisation at varying process conditions were studied and discussed below.

4.1.1 Physico-chemical properties of unprocessed ripe jackfruit

The collected ripe jackfruit intended for processing underwent a thorough analysis of its physico-chemical properties, and the results of this analysis have been systematically tabulated in Table 4.1. This comprehensive examination involved assessing various physical and chemical attributes of the fruit, providing a detailed understanding of its composition and characteristics before further processing.

Table 4.1 Physico-chemical and microbial properties of fresh ripe jackfruit prior to retort pouch pasteurisation

Sl.No	Parameters		RJB	RJP
1	pH		4.59 ± 0.17	04.50 ± 0.28
2	TSS (ºBrix)		20.00 ± 0.53	20.60 ± 0.94
3	TA (%)		0.63 ± 0.03	0.62 ± 0.02
4	Total sugar (%)		21.33 ± 0.76	22.56 ± 0.98
5	AA content (mg/100 g)		14.43 ± 0.52	10.32 ± 0.27
6	Colour	L*	66.83 ± 2.41	67.95 ± 0.39
		a*	7.86 ± 0.36	08.65 ± 0.23
		b*	49.88 ± 2.29	58.56 ± 0.29
7	DPPH radical scavenging activity (%)		87.34 ± 4.00	84.13 ± 3.01
8	TPC (mg GAE/g)		71.11 ± 2.56	68.53 ± 2.47
9	TFC (mg RE/g)		40.12 ± 1.44	20.33 ± 0.73

Where, RJB: Ripe jackfruit bulb; RJP: Ripe jackfruit pulp; values are expressed in mean ±SD

4.1.2 Effect of Retort pouch pasteurisation of Ripe jackfruit

4.1.2.1 Effect of retort pouch pasteurisation on pH, TSS and TA of RJB and RJP

The retort pouch pasteurisation of RJB and RJP was performed in a retort under varied process conditions aimed at extending their shelf life. It was observed that the pH levels of thermally processed RJB and RJP were raised compared to those of fresh or unprocessed samples of pH 4.59 ± 0.17 and 4.50 ± 0.28, respectively in RJB and RJP. As suggested by Igual *et al.* (2010), this increase in pH could be attributed to the depletion of organic acids during thermal processing, leading to a reduction in the acidic content of the samples.

The pH value varied from 4.49 ± 0.12 to 5.12 ± 0.18 and 4.50 ± 0.21 to 5.18 ± 0.14 respectively for pasteurised RJB and RJP (Table 4.2). The maximum pH value among the pasteurisation treatments was observed at 99˚C for15 min. which is 5.12 ± 0.18 and

5.18 ± 0.14, and the least pH was observed at 85˚C, one min. (4.49 ± 0.12 and 4.50 ± 0.21) respectively for RJB and RJP. From the data analysis, it was found that applied thermal treatments did not statistically affect pH value of the RJB and RJP ($p > 0.05$). The study conducted by Chakraborty *et al.* (2014) suggests that the absence of a significant impact could be attributed to the insufficient severity of both temperature and time conditions to induce the release of H^+ ions from the sample (ie, RJB and RJP) following thermal pasteurisation. The most remarkable result to emerge from the data is that an increase in acid damage can be caused by long heat contacts, rays, alkalis, enzymes, oxidizers, and copper and iron catalysts which amplify the pH value of ripe jackfruit samples (Astuti *et al.*, 2018). For pH value, the coefficient estimates and the corresponding p-values suggest that, among the test variables used in the study, temperature and time were non-significant model terms with p-values of greater than 0.05. This indicates that pH values were not much affected by temperature and time. The p-value of 0.17 and 0.21 respectively for pasteurisation of RJB and pulp implies the lack of fit is not significant relative to the pure error.

A consistent pattern was noted in the TSS values of retort-processed RJB and RJP. The initial TSS of the fresh RJB and RJP measured 20.00 ± 0.53 ˚Brix and 20.60 ± 0.94 ˚Brix, and after undergoing retort processing for pasteurisation, no significant changes ($p > 0.05$) were observed in TSS. Specifically, the TSS value for pasteurized RJB ranged from 19.00 ± 0.69 to 19.90 ± 0.87 ºBrix, while for pulp, it varied between 19.00 ± 0.72 and 22.00 ± 0.76 ˚Brix. Similar findings were documented in the thermally processed mixed formulations of fruit and vegetable pulps by Gonçalves *et al.* (2020). The study showed that the TSS value of RJB was comparable to the control sample. Additionally, a slight elevation was observed in pasteurised pulp, possibly due to the evaporation of water at higher temperatures, which increased the concentration of the pulp.

The initial TA of the control sample was noted as 0.63±0.03% in RJB. Subsequently, following treatment, a reduction in titratable acidity was observed, reaching 0.63±0.02% to 0.22 ± 0.01% after pasteurisation in RJP and 0.62 ± 0.02% to 0.27 ± 0.01% in RJB. From Fig.4.1 it is evident that a substantial reduction in TA was noted at 95℃ /25

min. in RJB and RJP. The statistical analysis indicated a significant ($p < 0.05$) reduction in TA of the RJB and RJP after thermal treatments, likely due to the loss of organic acids following the treatments. Singh *et al.* (2022) suggested that the reduction in acid content observed in pasteurised guava nectar could be attributed to the instantaneous high temperature causing the Maillard reaction. This reaction may have led to the consumption of amino acids and reducing sugars, ultimately resulting in a decrease in TA content in the retort pouch pasteurised products.

The statistical data suggests that the model is significant and the terms (Process temperature/Pasteurisation temperature, ºC) T, (Time, min) Pt, and Pt^2 are significant contributors to explaining the variation in the dependent variable. The model also appears to have a good fit to the data, as indicated by the high R^2 (0.91), Pred R^2 (0.84) and Adj R^2 values (0.85) for RJP. During statistical analysis, the $R^{2,}$ Pred R^2 and Adj R^2 values for RJB were 0.85, 0.69, and 0.75, respectively. The ANOVA for the response surface model is presented in Appendix A3 and A4. The final equation for TA in terms of coded factors likely represents the regression equation derived from the model. It provides a way to predict the dependent variable (TA) based on the values of the independent variables and is given below. The final regression equation for TA in terms of coded factors is given below.

$$TA_{RJB}\ (\%) = 0.35 - 0.078T - 0.097Pt - 0.021TPt + 0.035T^2 + 0.064Pt^2 \quad \ldots (4.1)$$

$$TA_{RJP}\ (\%) = 0.36 - 0.083\ T - 0.11\ Pt - 0.020TPt + 0.028T^2 + 0.061\ Pt^2 \quad \ldots (4.2)$$

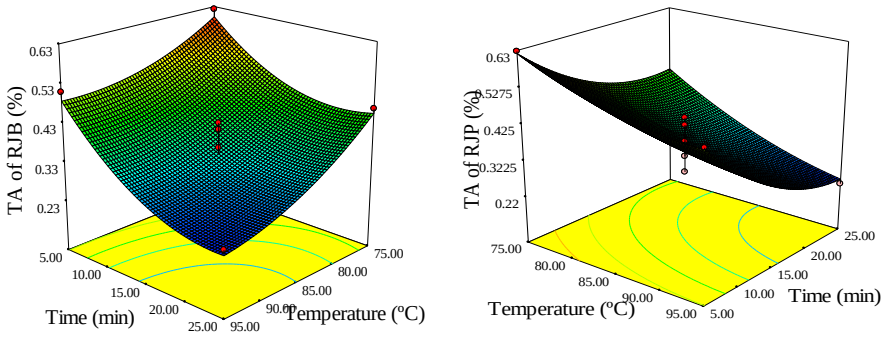
Where, TA_{RJB} and TA_{RJP}: Titrable acidity of RJB and ripe jackfruit pulp respectively

T is the pasteurisation temperature in ºC and Pt is the process time in min.

Table 4.2 Effect of retort pouch pasteurisation on pH, and TSS of ripe jackfruit samples

Pasteurisation temperature (˚C)	Process time (min.)	pH		TSS (˚Brix)	
		RJB	RJP	RJB	RJP
75	5	4.95±0.03	4.78±0.13	19.90±0.87	20.00±0.72
95	5	4.60±0.21	4.50±0.21	19.90±0.69	21.40±0.57
75	25	4.86±0.18	4.89±0.03	19.30±0.88	19.20±0.84
95	25	5.00±0.13	5.10±0.23	19.90±0.72	22.00±0.76
71	15	4.77±0.06	4.67±0.17	19.50±0.52	20.30±0.93
99	15	5.12±0.18	5.18±0.14	19.00±0.69	21.00±0.76
85	1	4.49±0.12	4.50±0.05	19.80±0.71	20.40±0.54
85	29	5.05±0.22	4.90±0.18	19.50±0.52	20.40±0.74
85	15	4.90±0.22	5.10±0.13	19.60±0.85	19.90±0.72
85	15	4.90±0.25	4.82±0.21	19.90±0.91	19.00±0.50
85	15	4.70±0.17	5.10±0.23	19.50±0.89	19.20±0.84
85	15	4.80±0.13	4.70±0.22	19.50±0.70	21.00±0.96
85	15	5.00±0.22	4.90±0.18	19.60±0.52	20.60±0.94

RJB: Ripe jackfruit bulb; RJP: Ripe jackfruit pulp; Data shown are the mean ± SD of three treatment repetition



(a) **(b)**

Fig.4.1 TA of retort pouch pasteurised RJB and RJP

4.1.2.2 Effect of Retort pouch pasteurisation on colour characteristics of ripe jackfruit

The effect of thermal treatment on the colour aspects of ripe jackfruit was studied, and the results were described in terms of CIELAB values. The L* value varied from 65.43 ± 1.59 to 67.63 ± 3.08 in pasteurised RJP and from 64.12 ± 2.70 to 66.63 ± 0.77 for RJB. The study revealed that L* value after pasteurisation non significantly ($p > 0.05$) declines in RJB and RJP. For the RJB, the lightness value slightly decreases after processing, indicating a marginal darkening likely due to natural browning reactions. In contrast, the pulp exhibits more pronounced changes. The lightness value of the RJP decreases slightly, suggesting it has become a bit darker, likely due to browning reactions. Compared with the control sample L* value of 67.95 ± 0.39 and 66.83 ± 2.41 in RJP and RJB the maximum variation was at a higher treatment condition of 99ºC, 15 min. (Fig.4.2 a & b). Aghajanzadeh *et al.* (2018) investigated the impact of thermal processing at 60–90°C for 15 min. on the colour characteristics of key lime juice. Their findings indicated a decline in the L* value with increasing temperatures during the heating process. Demirdoven and Baysal (2014) found that the L*, a*, and b* values of orange juice decreased by 5.5%, 98.1%, and 11.5%, respectively, when heated at 95°C for one min. due to Milliard reaction. The higher L* value or the lightness of the sample was retained at 85˚C one min., the respective L* values at this temperature were 66.63 ± 0.77 and 67.63 ± 3.08 in RJP and RJB.

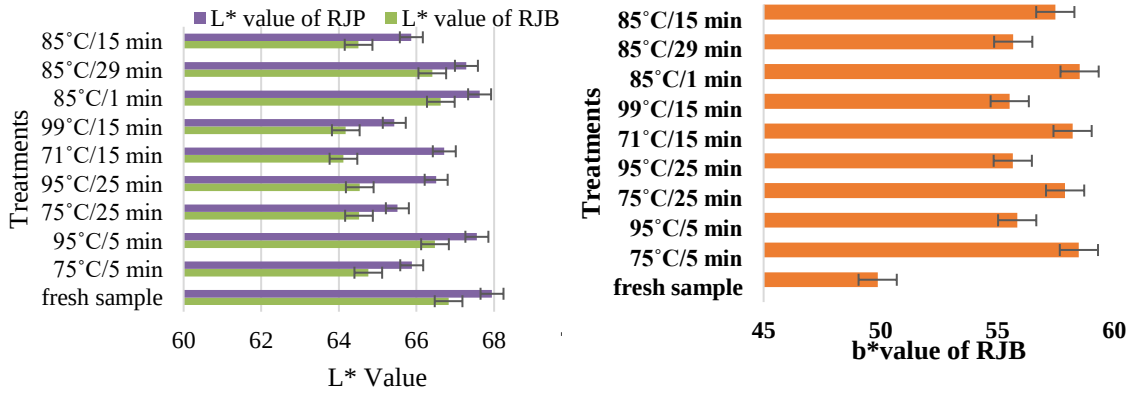
Similarly, the b* value, which represents the yellow to blue index of the sample ranged from 55.53 ± 0.50 to 58.49 ± 1.92 in pasteurised RJP (Fig.4.3a) and from 48.05 ± 1.55 to 49.65 ± 2.33 in RJB (Fig.4.3b). Maximum retention of yellow colour was retrained at a lower temperature and holding time in the pasteurisation process in both jackfruit samples. The a* (red-green) and b* (yellow-blue) values fluctuate slightly, with the b* value showing a minor reduction of 1.72%, suggesting a very slight decrease in yellowness. There was a significant ($p < 0.05$) reducing trend in b* with temperature and time was observed in pasteurised RJP. Compared with the control sample of 58.56 ± 0.29 in RJP there was a maximum reduction of 5.17 % and only 3.22% in pasteurised RJB. Temperature and time had a significant effect on the b* value of both pasteurised RJB and RJP. The study by Rattanathanalerk *et al*, 2005 explained that the decline in b* value at high temperatures may be due to the accelerated carotenoid isomerization, which led to the loss of yellowness. Badina *et al*. (2020) observed that the colour parameters of thermal processed raspberry pulp decreased with treatment time and temperature. Statistical study proved that retort pouch processing had a significant effect on b* value of RJP, and the observed R^2 value = 0.78, Adj R^2 value =0.73 and Pred R^2 value = 0.55. The ANOVA table for the response surface model is presented in Table A5 in Appendix and the regression equation is given below.

$$b^*_{RJP} = 57.06 - 1.08^* T - 0.26^* Pt - 0.067^* T * Pt - 0.20^* T\,2 + 0.37^* Pt^{2} \quad \ldots (4.3)$$

Where, T: Pasteurisation temperature (˚C), Pt: Process time in min., b^*_{RJB}: b* value of RJP.

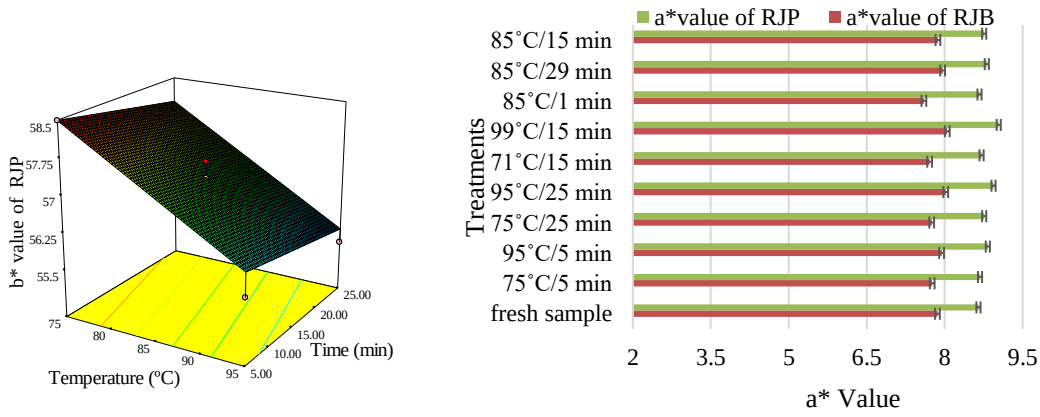
Furthermore, the a* value of RJB and RJP followed an increasing trend after pasteurisation. The control samples reported a* value of 8.65 ± 0.23 and 7.86 ± 0.36 respectively in RJB and RJP. After retort pouch pasteurisation the values varied from 7.14 ± 0.28 to 8.05 ± 0.31 and 8.56 ± 0.25 to 9.04 ± 0.33 respectively in RJB and RJP (Fig.4.2). This increase in a* value indicates the colour shift from yellow to brown in jackfruit samples after retort pouch pasteurisation and was a non significant ($p > 0.05$) variation that was noticeable at higher temperatures and a processing time of 99˚C, 15 min. The major

causes of colour change may be attributed to carotenoid degradation and nonenzymatic browning (Maillard) (Rattanathanalerk *et al.*, 2005).



(a) **(b)**

Fig. 4.2 L* and a* values of retort pouch pasteurised ripe jackfruit samples



(a) **(b)**

Fig. 4.3 b* values of retort pasteurised ripe jackfruit sample

4.1.2.3 Effect of Retort pouch pasteurisation on ΔE, YI and BI of ripe jackfruit

The ΔE value served as a critical index for evaluating colour change. Total colour deviation of pasteurised RJB varied from 0.40 ± 0.08 to 3.17 ± 0.43. As per the reference values, it indicates more colour deviation was at 99˚C, 15 min (Fig.4.4a). Meanwhile, the colour deviation for RJP after retort pouch pasteurisation was 0.46 ± 0.10 to 4.22 ± 0.34

(Fig.4.4b). It had generally been believed that a $\Delta E \geq 3.0$ could indicate a significant visual difference in various situations (Cao *et al.*, 2018). The minor fluctuations in chromatic attributes and the ΔE values imply that the bulb's appearance remains relatively unchanged to the naked eye, which is beneficial for consumer acceptance. The more noticeable changes in ΔE value for the pulp suggest more colour alterations after processing. According to Wu *et al.* (2021), the ΔE value of pasteurised pineapple fruit juice was recorded as 9.88, indicating a notable visual disparity between treated and untreated pineapple fruit juices. The elevation of a* and reduction in b* may be the major causes contributing to the total colour deviation in samples, which can be the effect of Maillard browning (Yi *et al.*, 2017). Similarly, Yuan *et al.* (2022) observed a significantly higher ΔE in pomegranate juice processed at 110℃ for 8.6 seconds compared to thermal retort pouch pasteurisation at 85℃ for 30 seconds. Statistical analysis revealed that process parameters have a significant effect on ΔE of RJB with R^2 value of 0.857(Appendix A6) and non-significant effect on RJP. The regression equation for the suggested quadratic model of ΔE of RJB in terms of the coded equation is given below, and the 3D surface plot showing the effect of independent variables is depicted in Fig.4.4

$$\Delta E_{RJB} = 2.57 - 1.509E\text{-}003\ T + 0.32Pt + 0.21TPt - 0.26T^2 - 0.83Pt^2 \quad \ldots (4.4)$$

Where, T: Pasteurisation temperature (ºC), Pt: Process time in min., ΔE_{RJB}: Total colour deviation of RJB

The YI values obtained for the processed RJB ranged from 103.69 ± 4.64 to 110.39± 5.19, while those for the RJP varied from 118.09 ± 4.93 to 127.54 ± 4.65 (Table 4.3). Notably, the YI values were higher for both the bulb and pulp when pasteurised at 75℃ for 5 min., indicating lower colour deterioration compared to other retort pouch pasteurisation conditions. Slight increases in the BI and YI indicate minor browning and yellowing, which could impact the perceived quality and appeal of the pulp. The data suggests that lower retort pouch pasteurisation temperatures result in reduced colour deterioration, as evidenced by the higher YI values observed at 71°C and 75°C for pulp (Fig 4.5b). This phenomenon aligns with the principles of thermal degradation, wherein higher

temperatures accelerate colour changes due to enzymatic and non-enzymatic reactions (Wu *et al.*, 2021).

The BI values for the processed RJB ranged from 93.92 ± 1.05 to 98.08 ± 3.66 (Table 4.3), while those for the pulp varied from 103.16 ± 2.41 to 109.74 ± 2.92 (Fig 4.5a). The lower BI values were observed at 95°C for 25 min. and 95°C for 5 min. may be due to the reduction in b* value suggest that enzymatic browning reactions were active under elevated thermal conditions. This finding aligns with previous research indicating that higher temperatures accelerate enzymatic browning, while shorter processing times minimize the exposure of phenolic compounds to thermal degradation (Badina *et al.*, 2020). The BI value of lettuce juice increased from 33.59 ± 3.01 in the control to 40.94 ± 7.67 during thermal retort pouch pasteurisation (Zhang *et al.*, 2024). Lower temperatures and shorter processing times were found to be effective in reducing enzymatic browning, offering valuable insights for the development of high-quality jackfruit products. According to Badina *et al.* (2020), the BI of thermally processed raspberry pulp was influenced by the increase in process temperature, a* and chroma (C*). The statistical study suggest that the BI values were non-significant for RJB and significant for RJP respectively, meaning that the independent variables in the models had no significant effect on the BI value of RJB. Statistical analysis demonstrated the significant effect ($p < 0.05$) of process temperature and time on BI of RJP and the regression equation for BI of RJP ($R^2 = 0.53$) in terms of coded factors is given in below.

$$BI_{RJP} = 106.75 - 172T - 0.089Pt \quad \ldots(4.5)$$

Where, T: Pasteurisation temperature (ºC), Pt: Process time in min., BI_{RJPB}: Browning index of RJP

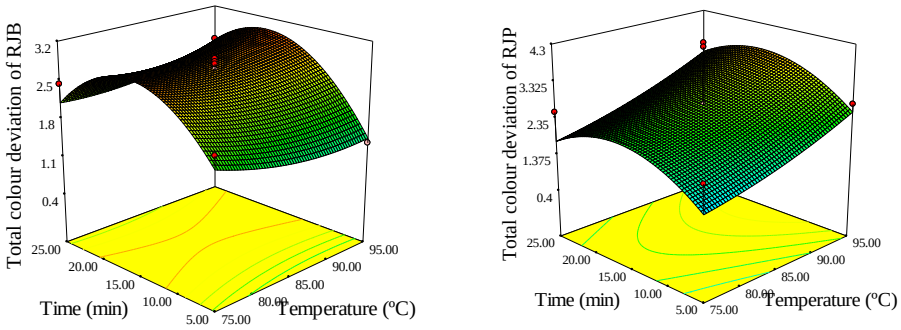


Fig. 4.4 ΔE values of retort pouch pasteurised ripe jackfruit sample

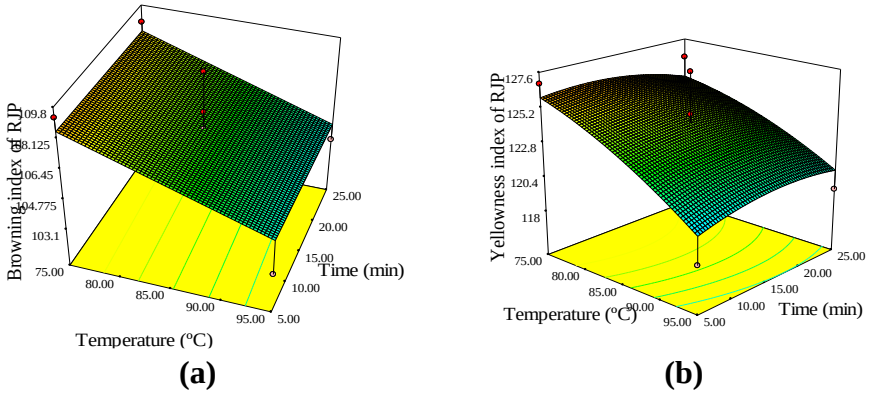


Fig. 4.5 BI and YI of retort pouch pasteurised ripe jackfruit sample respectively

4.1.2.4 Effect of Retort pouch pasteurisation on AA of ripe jackfruit

The initial mean concentration of AA in the RJB and RJP was 14.43 ± 0.52 mg/100 g and 10.32 ± 0.27 mg/100 g, respectively. The retort pouch pasteurisation process significantly influenced the AA content, resulting in a range of 11.03 ± 0.51 to 14.32 ± 0.62 mg/100 g for the RJB (Fig 4.6a) and 6.84 ± 0.18 to 10.28 ± 0.60 mg/100 g for the RJP (Fig 4.6b). The outcomes from thermal treatments revealed a negative impact on AA levels, with an observed increase in both temperature and processing time. The findings indicated that AA exhibited greater susceptibility to thermal instability compared to other assessed quality components. Processing RJP and RJB at 99°C for 15 minutes resulted in a

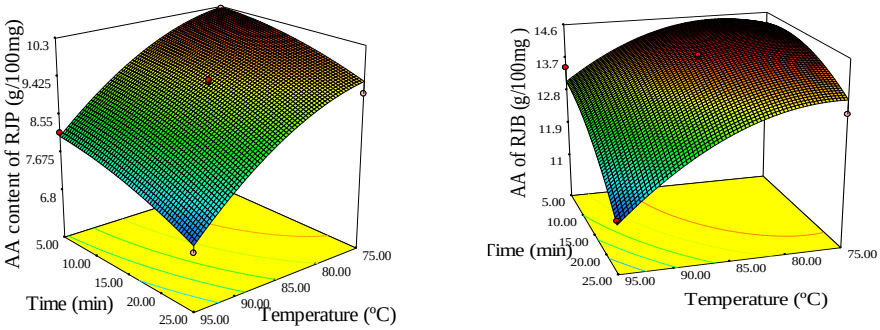
significant reduction in AA content, with RJP showing a 33.72% decrease and RJB a 23.56% decrease. Greater retention of 14.32 ± 0.62 mg/100 g and 10.28 ± 0.60 mg/100 g AA were reported in RJB and RJP ie., complete retention was noted at 71°C for 15 min. compared to the control value. Sinchaipanit *et al.* (2015) documented a decrease in AA content by 26% in guava juice subjected to retort pouch pasteurisation at 85˚C for 1 min. The instability of AA during thermal processing may be the reason for reduction of AA in pasteurised ripe jackfruit samples. Wu *et al.* (2021) reported that high temperatures intensified the loss of AA in the thermally processed pineapple juice.

Statistical analysis demonstrated the significant effect ($p < 0.05$) of process temperature and time on AA content of ripe jackfruit samples. The F values of 29.91 and 49.11 for RJB and RJP respectively indicated the model significance, and the Pred R^2 was in reasonable agreement with the Adj R^2 of the models. The R^2 values for RJP was 0.97 and for RJB it was 0.95 (Table A8 and A9). The regression equation for AA content of ripe jackfruit samples is given below

$$AA_{RJB} = 14.05 - 0.94^{*} T - 0.68^{*} Pt - 0.33^{*} T^{*} Pt - 0.68^{*} T^2 - 0.36^{*} Pt^2 \quad \text{... (4.6)}$$

$$AA_{RJP} = 9.33 - 1.16^{*} T - 0.44^{*} Pt - 0.052^{*} T^{*} Pt - 0.43^{*} T^2 - 0.16^{*} Pt^2 \quad \text{... (4.7)}$$

Where, AA_{RJB}: ascorbic acid of RJB, AA_{RJP} : ascorbic acid of RJP, T: Pasteurisation temperature (˚C) and Pt: Process time in min.



(a) **(b)**

Fig 4.6 AA content of retort pouch pasteurised ripe jackfruit samples

Table 4.3 Effect of Retort pouch pasteurisation on BI and YI of ripe jackfruit samples

Process temperature (˚C)	Process time (min.)	RJB	
		BI	YI
75	5	97.27±4.58	109.10±4.86
95	5	94.53±4.90	104.35±3.76
75	25	97.04±5.05	108.76±2.82
95	25	96.68±3.94	107.93±1.23
71	15	98.08±2.92	110.39±3.88
99	15	96.28±4.80	107.17±2.82
85	1	95.59±3.58	106.45±4.64
85	29	94.79±4.86	105.06±4.86
85	15	95.88±3.91	106.63±4.80
85	15	95.73±2.68	106.73±3.84
85	15	95.34±3.66	106.06±2.81
85	15	93.92±3.56	103.69±4.51
85	15	97.10±2.41	109.18±3.70

RJB: Ripe jackfruit bulb, BI: Browning index, YI: Yellowness index. Data shown are the mean ± SD of three treatment repetition

.4.1.2.5 Effect of Retort pouch pasteurisation on TPC and TFC of ripe jackfruit

The fresh RJB contained 71.11 ± 2.56 mg GAE/g total phenolic content and 40.12 ± 1.44 mg RE/g flavonoids, while the pulp had 68.53 ± 2.47 mg GAE/g total phenolic content and 20.33 ± 0.73 mg RE/g flavonoids. Retort pouch pasteurisation results in a significant ($p<0.05$) reduction in both TPC and TFC in jackfruit samples. Improved preservation of TPC and TFC was documented at lower temperatures and shorter processing times. The investigation yielded TPC values of 58.96 ± 2.12 mg GAE/g to 70.53 ± 2.54 for RJBs (Fig 4.7 a) and 52.33 ± 2.23 to 65.12 ± 2.34 mg GAE/g for pasteurised RJP samples (Fig 4.6 b). Concurrently, TFC values for pasteurised RJB and RJP ranged from

34.02 ± 1.22 to 40.02 ± 1.44 mg RE/g (Fig 4.7 a) and 15.68 ± 0.56 to 19.20 ± 0.69 mg RE/g (Fig 4.8b), respectively.

A comprehensive reduction of 17.08% and 23.63% in TPC was documented in RJB and RJP samples at 99°C for 15 min. Similarly, TFC in pasteurised samples showed an overall reduction of 15.80% and 20.48% for RJB and RJP, respectively, under the same process conditions. When compared with the reduction in AA content, the decrease in TPC and TFC were marginally lower. In contrast to these results, an elevation in phenolic compounds was documented in quince jam, potentially attributed to the modification and breakdown of cell walls, along with the thermal degradation of complexes with proteins (Baroni *et al.*, 2018). Conversely, a decline in total polyphenol content was noted in fruit drinks based on milk (Cilla *et al.*, 2012), likely resulting from the thermal degradation of compounds outside a protective matrix. In statistical analysis, it was reported that the F-values for ANOVA to determine the significance of the overall model were 90.63 and 110.62 for the TPC of RJB and RJP respectively (Table A10 and A11). At the same time, it was 115.50 and 35.10 for the TFC of RJB and RJP respectively (Table A12 and A13). The R^2 values for TPC of RJB and RJP were 0.98,0.98 respectively and 0.98 and 0.96 were for TFC of RJB and RJP respectively. The regression equation for TPC and TFC of pasteurized ripe jackfruit samples as follows;

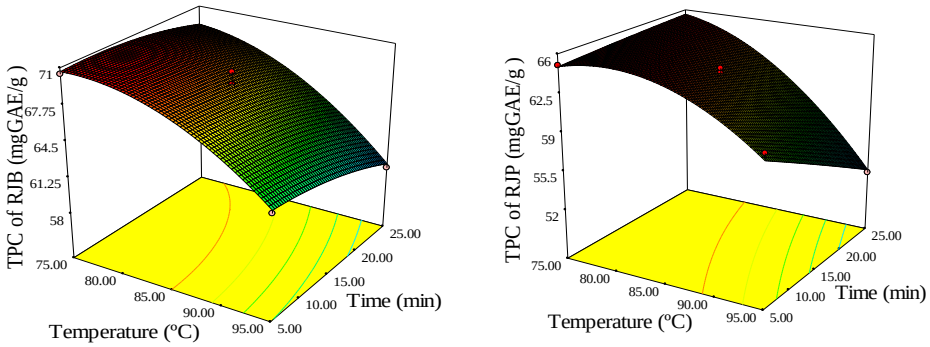
$$TPC_{RJB}\,(\text{mg GAE/g}) = 68.46 - 4.12T - 1.26Pt - 0.57TPt - 2.00T^2 - 0.60Pt^2 \quad \ldots (4.8)$$

$$TPC_{RJP}\,(\text{mg GAE/g}) = 63.40 - 4.27\,T - 1.57\,Pt - 1.90T\,Pt - 2.38\,T^2 - 0.061\,Pt^2 \quad \ldots (4.9)$$

$$TFC_{RJB}\,(\text{mg RE/g}) = 38.21 - 2.05\,T - 1.00\,Pt - 0.36T\,Pt - 0.60\,T^2 - 0.29\,Pt^2 \quad \ldots (4.10)$$

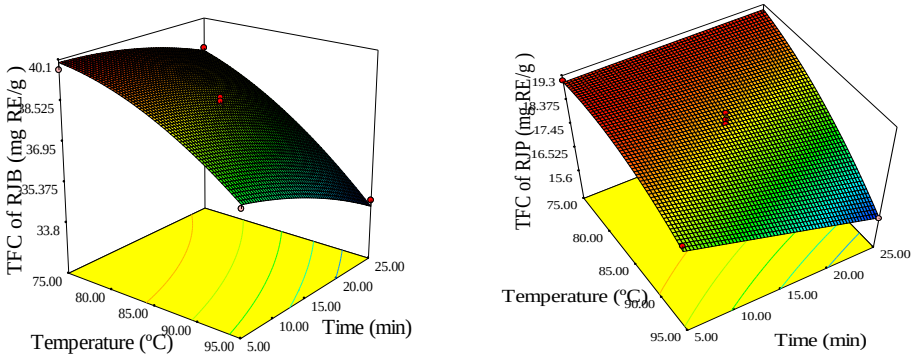
$$TFC_{RJP}\,(\text{mg RE/g}) = 18.43 - 1.14\,T - 0.54Pt - 0.56T\,Pt - 0.47T^2 - 4.00E\text{-}003\,Pt^2 \quad \ldots (4.11)$$

Where, TPC_{RJB}: Total phenolic content of RJB, TFC_{RJB}: Total flavonoid content of RJB, $TPC_{RJP:}$ Total phenolic content of RJP, $TFC_{RJP:}$ Total flavonoid content of RJP, T: Pasteurisation temperature (ºC) and Pt: Process time in min



(a) **(b)**

Fig 4.7 TPC of retort pasteurised ripe jackfruit samples



(a) **(b)**

Fig 4.8. TFC of retort pasteurised ripe jackfruit samples

4.1.2.6 Effect of Retort pouch pasteurisation on Antioxidant activity-DPPH radical scavenging activity of ripe jackfruit

The effect of thermal processing on antioxidant activity in fruits can vary based on factors such as temperature, duration of the processing, and the type of fruit. In the present research, the antioxidant activity was measured by the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay. It varied between 82.33± 2.80 to 86.55 ± 3.12% DPPH radical scavenging activity in RJB (Fig 4.9a) and 79.53 ± 2.10 to 84 ± 3.66% DPPH radical scavenging activity in RJP (Fig 4.9b). Higher retention of DPPH radical scavenging activity was observed at 71˚C and 75˚C respectively at 15 and 5 min. for pasteurized jackfruit RJB and RJP. Maximum loss was 5.73% and 5.46% accordingly in RJB and pulp. Temperature and process time had a significant ($p<0.05$) effect on antioxidant activity. It has been

reported that high temperatures and extended processing times in thermal treatments can reduce antioxidant activity by degrading heat-sensitive antioxidants, affecting their ability to neutralise free radicals. Additionally, the Maillard reaction, triggered at elevated temperatures between amino acids and reducing sugars, can produce compounds with antioxidant properties, which may also contribute to a reduction in overall antioxidant activity. According to Miller and Silva (2012), the decline in antioxidant capacity observed in black mulberry juice at 90°C/30 s was primarily attributed to the loss of total anthocyanins and vitamin C. Similarly, in apple, banana, orange, and strawberry smoothies, a comprehensive reduction in total antioxidant capacity, total phenols, anthocyanins, and color was noted at 70°C/10 min, with the complete inactivation of PPO reported. In the realm of statistical analysis, it was proposed that the F-values in the ANOVA, aimed at assessing the significance of the overall model, reached 11.49 and 17.93 (Table A14 and A15) for the DPPH radical scavenging activity of RJB and RJP, respectively. Equation 4.12 to 4.13 gives the regression equation in coded form. The R^2 value of the RJB and RJP were 0.89 and 0.92 respectively (Table A16 and A17).

$$DPPH_{RJB}\ (\%) = 83.34-1.32T-0.78\ Pt-0.27\ T\ Pt+0.55T^2+0.81\ Pt^2 \quad \ldots. (4.12)$$

$$DPPH_{RJP}\ (\%) = 83.21-1.44T-0.58\ Pt-0.33T\ Pt-0.75T^2-0.14\ Pt^2 \quad \ldots. (4.13)$$

Where, $DPPH_{RJB}$: DPPH radical scavenging activity of RJB, $DPPH_{RJP:}$ DPPH radical scavenging activity of RJP, T: Pasteurisation temperature (˚C) and Pt: Process time in min.

4.1.2.7 Effect of Retort pouch pasteurisation on total sugar of ripe jackfruit

The impact of thermal processing on the total sugar content of fruits can vary based on several factors, including the type of fruit, processing conditions, and the duration of heat exposure. Total sugar content in freshly prepared RJB and RJP was 21.33 ± 0.76% and 22.56 ± 0.98%. After retort pouch pasteurisation, it varied from 15.42 ± 0.53 to 20.22 ± 0.92% in RJB (Fig. 4.10a) and 15.31±0.40 to 22.45 ± 0.80% in RJP (Fig 4.10b). Temperature and process time had a significant effect ($p < 0.05$) on the total sugar content of RJB and RJP. Total sugar content decreased with an increase in temperature and process

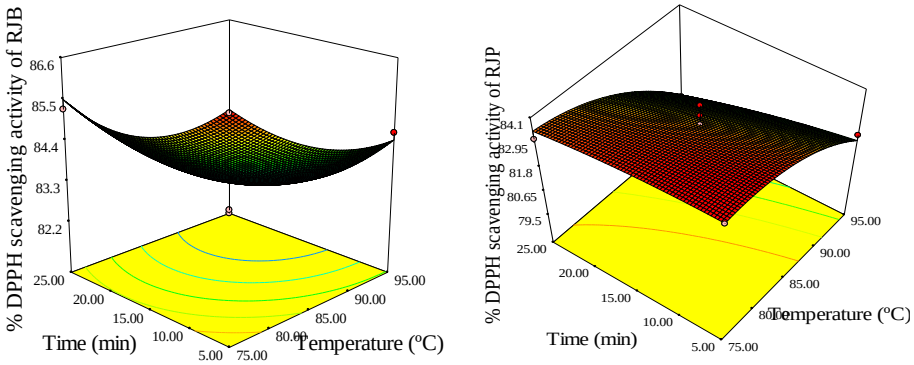
time and maximum reduction was found at 99˚C/15 min. A total of 27.70% and 32.13% reduction was reported as the maximum at this process condition. Extreme heat can lead to the degradation of certain sugar components, potentially resulting in a reduction in total sugar content. Maillard reaction products, formed at elevated temperatures between amino acids and reducing sugars, may contribute to the flavour profile and affect sugar content indirectly. Prolonged or intense heat exposure may lead to the leaching of sugars into the surrounding liquid or syrup, affecting the overall sugar content of the fruit. High temperatures can lead to the caramelization of sugars, contributing to changes in color and flavour. Yikmis *et al.* (2023) noted comparable findings in thermally pasteurized black grape juice, wherein a notable reduction in fructose and glucose levels was evident compared to the untreated control juice, with statistical significance ($p < 0.05$).

The F values of the models were determined as 76.72 and 64.28, respectively for RJB and RJP (Table A16 and A17), and this shows that the developed polynomial model is significant. The coefficient of determination, adjusted R^2 and R^2 values were above 96% which showed that the models were suitable for the experimental results. The significance of the quadratic polynomial model elucidated the impact of temperature, processing time, and the combined effect of temperature and temperature on the total sugar content of jackfruit samples, denoted by a notable coefficient ($p < 0.05$). The regression equation proposed for total sugar is given below

$$\text{Total sugar of RJB (\%)} = 19.02-1.74\ T-0.34Pt-0.37T\ Pt\ -0.64\ T^2-0.089*Pt^2 \quad \ldots (4.14)$$

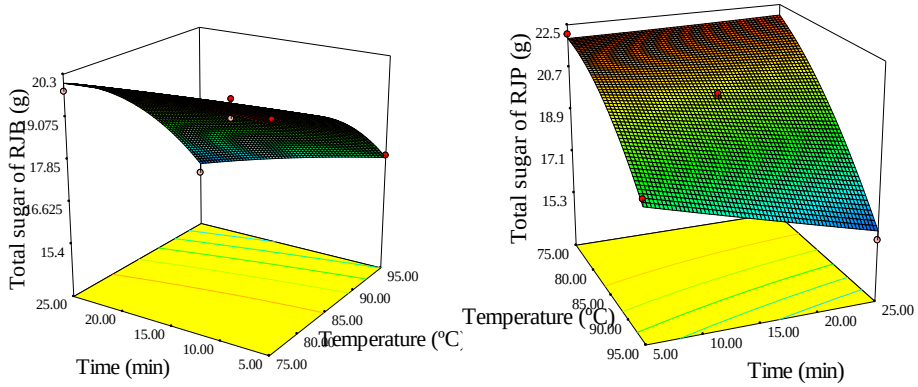
$$\text{Total sugar of RJP (\%)} = 20.24-2.46T\ -0.58\ Pt\ -0.63T\ Pt\ -0.74T^2+.021\ Pt^2 \quad \ldots (4.15)$$

Where, T: Pasteurisation temperature (˚C) and Pt: Process time in min.



(a) **(b)**

Fig.4.9 Effect of Retort pouch pasteurisation on DPPH radical scavenging activity



(a) **(b)**

Fig.4.10 Effect of Retort pouch pasteurisation on total sugar of ripe jackfruit

1.2.8 Effect of Retort pouch pasteurisation on textural property of RJB

The firmness of RJB after retort pouch pasteurisation was evaluated at different temperatures and times. The firmness values ranged from 45.85 ± 0.25 to 54.16 ± 0.54 N, with a control value of 55.46 ± 0.36 N. The highest firmness value was observed at 71°C for 15 min. (54.16 ± 0.54 N), while the lowest value was observed at 99.14°C for 15 min. (45.85 ± 0.25 N). The percentage loss in firmness compared to the control ranged from 2.2% to 17.3%. Generally, as the retort pouch pasteurisation temperature increased, the

firmness of the RJB decreased. However, the time of retort pouch pasteurisation also played a role in the textural properties. At a lower temperature of 71°C, the firmness increased as the time increased from 15 min. to 25 min. (Fig 4.11) However, at higher temperatures (95°C and 99°C), the firmness decreased with increasing time. This suggests that the textural properties of the RJB were affected by a complex interaction between the temperature and time of retort pouch pasteurisation. Overall, the results indicated that the retort pouch pasteurisation process significantly ($p<0.05$) affected the firmness of the RJBs, leading to a reduction in their textural quality. The highest temperature and longest duration led to the greatest loss in texture.

This aligns with the findings of Babu and Sudheer (2020) who observed that texture profile parameters decline as both the duration and temperature of thermal treatment increase for tender jackfruit. The reduction in firmness during thermal processing is mainly due to the degradation of cell wall structures.

The analysis of variance (ANOVA) for the response surface quadratic model reveals that the model is highly significant, with an F-value of 75.55 and a p-value of < 0.0001 (Table A18). This indicates that there is only a 0.01% chance that such a large model F-value could occur due to random noise, which suggests a very strong fit of the model to the data. The R^2 value of 0.981 indicated that the model explained 98.10% of the variation in the data and Eq 4.16 gives the regression equation.

$$\text{Firmness of RJB (N)} = 52.04 - 3.02T - 0.62Pt - 0.30T\,Pt - 1.22T^2 - 0.17Pt^2 \quad \ldots (4.16)$$

Where, T: Pasteurisation temperature (˚C) and Pt: Process time in min.

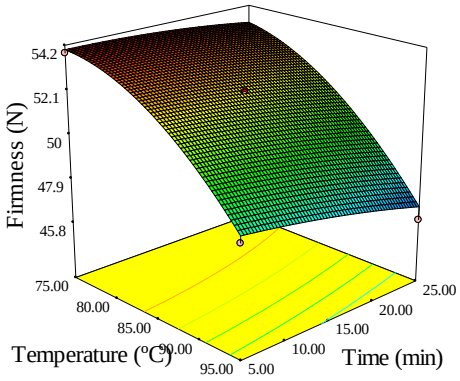


Fig.4.11 Textural property of retort pouch pasteurised RJB

4.1.2.9 Effect of Retort pouch pasteurisation on the rheological properties of RJP

The rheological behaviour of RJP was significantly influenced by variations in pasteurisation temperature and processing time during retort pouch pasteurisation. Dynamic viscosity, a critical parameter in determining the flow properties of fruit pulp, exhibited a general decreasing trend with increasing temperature and holding time, indicating the shear-thinning and non-Newtonian nature of the pulp. The control sample (unprocessed RJP) exhibited an initial viscosity of 60.50 Pa·s, which was reduced to a range of 34.25 ± 0.23 to 61.21 ± 0.02 Pa·s following retort pouch pasteurisation (Fig 4.12). This decline in viscosity highlights the effect of thermal degradation on the pulp's structural integrity.

As the pasteurisation temperature increased, a progressive decline in viscosity was observed across different treatment conditions. At 75°C for 5 min, the viscosity was recorded at 61.21 ± 0.02 Pa·s, whereas a substantial reduction to 36.42 ± 0.02 Pa·s occurred when the temperature was raised to 95°C for the same duration. A similar decreasing pattern was evident at extended processing times, with viscosity dropping from 38.75 ± 0.12 Pa·s at 75°C for 25 min to 35.62 ± 0.02 Pa·s at 95°C for 25 min. This decline can be attributed to the thermal degradation of pectin and polysaccharides, which are primarily responsible for the structural integrity and viscosity of fruit pulps. Previous studies have demonstrated that heat-induced depolymerisation of pectic substances leads to reduced intermolecular interactions, thereby lowering viscosity (Vidigal *et al.*, 2023).

Holding time during retort pouch pasteurisation also played a crucial role in viscosity modification. At a moderate temperature of 85°C, a significant variation in viscosity was observed depending on the duration of treatment. The viscosity of RJP at 85°C for 1 min was 60.24 ± 0.52 Pa·s, whereas an extended pasteurisation time of 29 min resulted in a viscosity of 35.58 ± 0.33 Pa·s, highlighting the substantial impact of prolonged heat exposure.

Remarkably, at 85°C for 15 min, viscosity values varied across different experimental replicates, ranging between 37.25 ± 0.02 Pa·s and 45.12 ± 0.12 Pa·s. This variation may be attributed to differences in pulp composition, moisture redistribution, and localized structural degradation during heat treatment. The breakdown of soluble and insoluble fiber fractions, along with the thermal modification of cell wall polymers, could contribute to this fluctuation. The observed trend aligns with previous reports where extended thermal exposure led to loss of water-binding capacity of hydrocolloids, further reducing viscosity (Vidigal *et al*., 2023).

The variation of viscosity with shear rate illustrated in Fig. 4.13 further confirms the non- newtonian behaviour of RJP. As shear rate increased from 0 to 400 s^{-1}, viscosity decreased consistently across all treatment conditions. The control sample and thermally processed samples exhibited a rapid decline in viscosity at lower shear rates, stabilising at higher shear rates. This trend aligns with shear-thinning behaviour, where intermolecular interactions weaken under shear stress, facilitating flow. Cunha *et al*. (2020) confirmed the shear-thinning behaviour of açai berry pulp across different temperatures, and the reduction in viscosity with increased shear rates. The absence of shear-thickening at any shear rate further supports the suitability of RJP for industrial processing.

Statistical analysis confirmed significant effects of temperature (T) and time (Pt) on viscosity, with p-values of 0.0011 and 0.0005, respectively and R^2 value was 0.92 (Table A19). The model had an F-value of 17.29 (p = 0.0008), confirming statistical significance. The interaction term (T Pt) was not significant (p = 0.0145) but contributed to the model. The lack of fit (p = 0.0066) suggests some unexplained variation, though the residual error

was small, indicating a good model fit. Eq. 4.17 gives the regression equation of dynamic viscosity.

$$\text{Dynamic viscosity (Pa.s)} = 38.91-6.35T-7.27Pt+5.42TPt+1.19T^2+3.97Pt^2 \quad \ldots (4.17)$$

Where, T: Pasteurisation temperature (˚C) and Pt: Process time in min

Overall, thermal treatment rendered the pulp more fluid-like, characteristic of non-Newtonian, shear-thinning materials. No shear-thickening behaviour was observed under any treatment condition, confirming enhanced processability and flow behaviour in industrial applications.

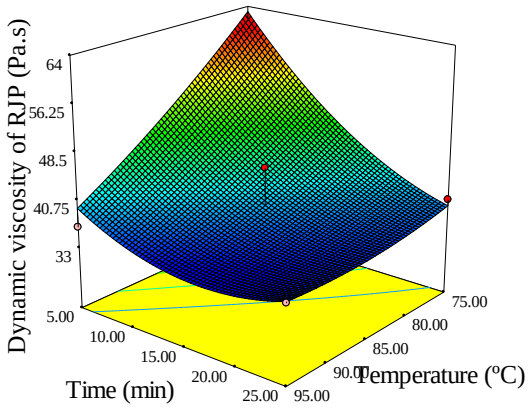


Fig.4.12 Dynamic viscosity of retort pouch pasteurised RJP

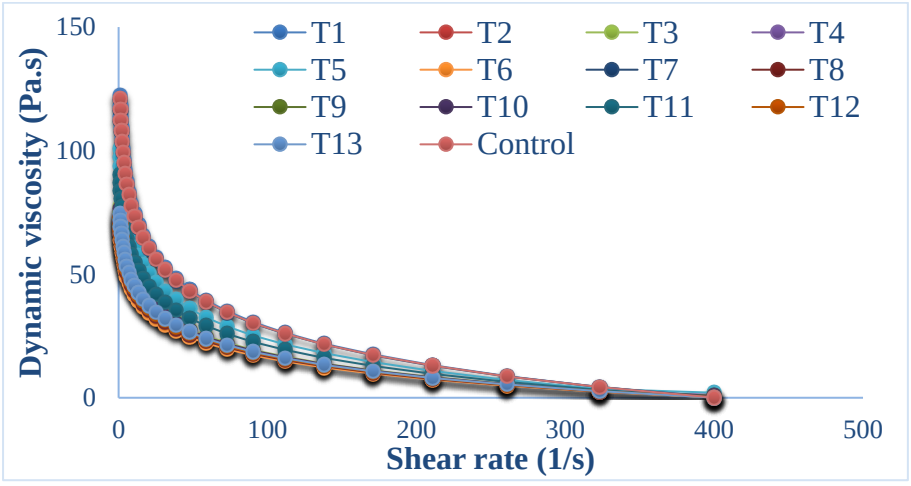


Fig.4.13 Viscosity vs Shear relation for retort pouch pasteurised RJP

4.1.2.10 Microbial analysis of retort pouch pasteurised ripe jackfruit

The initial populations of TAM in pasteurised RJB and RJP were 4.80±1.40 and 5.1±1.32 log CFU/g, respectively. The initial populations of yeast and mold were 4.6±1.55 log CFU/g in RJB and 5.3±1.24 log CFU/g in RJP. The reduction in TAM, yeast and mould in pasteurised ripe jackfruit samples after being subjected to retort pouch pasteurisation at different combinations of process parameters is presented in Fig 4.14 and 4.15. It is clear from Fig 4.13 and 4.14 that the total log reduction in TAM and yeast and mould ranged between 5.42±1.29 to 7.86±1.70 and 5.35±1.82 to 8.85±1.32 log CFU/g, respectively in RJB. These values in RJP varied between 5.50 ± 1.11 to 8.30±4.64 log cfu/g and 6.20±2.36 to 9.30±2.14 log CFU/g, respectively. The data revealed that microbial log reduction was more appreciably noticed over higher temperatures and process time. The highest bacterial log reduction of 7.86±1.70 log CFU/g and 8.30±4.64 log CFU/g in RJB and RJP respectively, was observed in samples treated at 99°C for 15 min. The reduction of yeast and mould was also higher under the same conditions in RJB and RJP. Therefore, the final population of the microbe is approximately zero, indicating an almost complete reduction of the microbes. The extended exposure to high temperatures resulted in the breakdown of microbial membranes and the deactivation of enzymes, thereby allowing for greater reduction in microbial levels at elevated temperatures (Hounhouigan *et al.*, 2020). This finding aligns with the discovery made by researchers who determined that subjecting the pineapple juice to mild heat treatment for 2 min. at 65°C and 8 min. at 63°C resulted in a reduction of yeast population by 6 log units, effectively preserving the nutritional and physicochemical qualities of the juice (Diaz and Aguayo, 2013). Santhirasegaram *et al.* (2013) observed complete inactivation (100%) of aerobic bacteria, coliform, yeast, and mold in thermally treated Chokanan mango juice, with initial microbial counts of 2.74 log CFU/mL, 0.99 log CFU/mL, and 2.42 log CFU/mL, respectively.

The Model F-values of 15.17 and 19.93 in RJB and RJP, respectively, indicate the significant relevance of the model. The response surface plots showing the effect of retort process parameters on microbial log reduction are presented in Fig.4.13 and Fig.4.14. From the figures, it can be observed that there is a decrease in microbial population with an

increase in temperature and time. A second-order regression model was developed relating the log reduction of bacterial and yeast & mold in RJB and RJP with the corresponding combinations of the independent variables in the coded form presented in Equations 4.18 to 4.21. The ANOVA table presented in Appendix A explains the effect of temperature and time on reduction in TAM, yeast and mold in RJB and RJP. The R^2 values for TAM was 0.99 and 0.94 respectively in RJB and RJP (Table A20 and A21). Similarly for yeast and mold the R^2 values noted as 0.91 and 0.93 in RJB and RJP respectively (Table A22 and A23).

Reduction in TAM of RJB (log CFU/g)

$$=6.88+0.87T+0.22Pt+0.11T\,Pt\,-0.14T^2-0.09\,Pt^{\,2} \quad \ldots (4.18)$$

Reduction in Yeast and mould in RJB (log CFU/g)

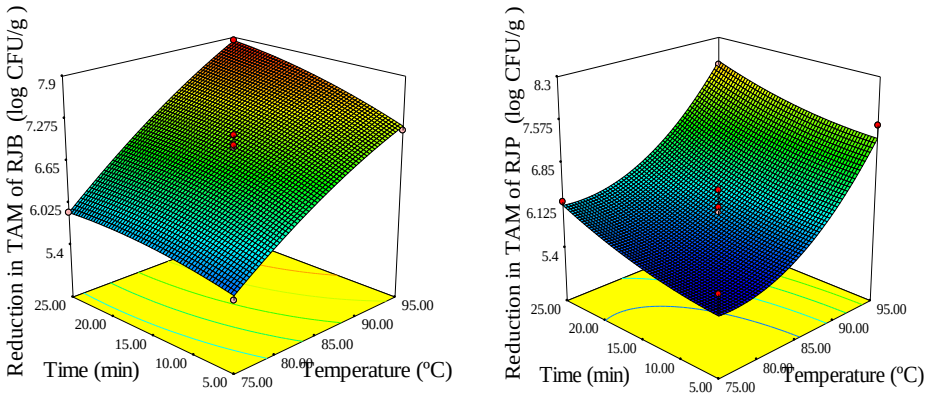
$$=6.33+1.11T\,+0.37\,Pt\,+0.025\,T\,Pt\,+0.42T^2+0.25\,Pt^2 \quad \ldots (4.19)$$

Reduction in TAM of RJP (log CFU/g)

$$=6.04+0.89T\,+0.32Pt\,-0.025TPt\,+0.52T^2+0.12\,Pt^2 \quad \ldots (4.20)$$

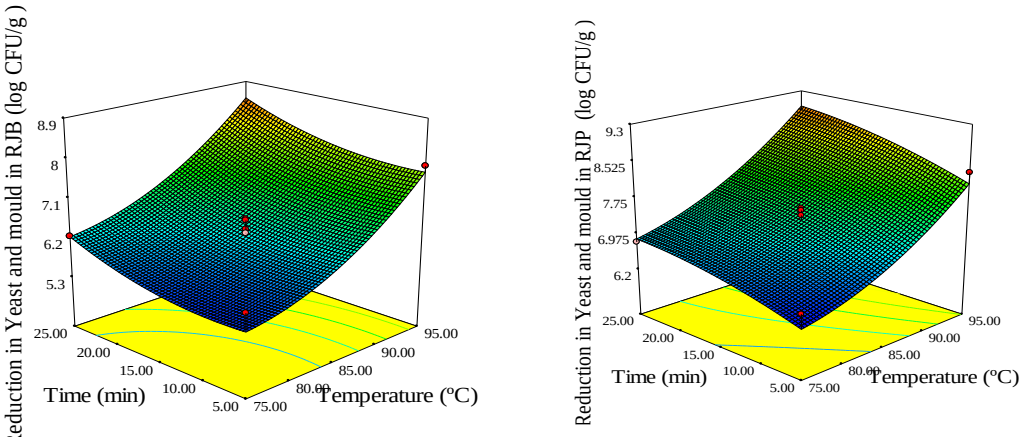
Reduction in Yeast and mould in RJP (log CFU/g)

$$=7.35\,+\,0.98\,T\,+\,0.39\,Pt\,+\,0.060\,TPt\,+\,0.30\,T^2-\,0.13Pt^2 \quad \ldots (4.21)$$



(a) **(b)**

Fig.4.14 Reduction in TAM of retort pasteurised ripe jackfruit samples



(a) **(b)**

Fig.4.15 Reduction in Yeast and mould in retort pasteurised ripe jackfruit sample

4.1.2.11 Sensory evaluation of retort processed ripe jackfruit

The mean sensory scores of the most important organoleptic characteristics that define the acceptance of the sample, such as taste, colour, aroma, texture, and overall acceptance provided by the judges, are presented in Appendix F. The radar chart showing the variation of mean scores is shown in Fig. 4.15 & 4.16. In which the treatments represented as R1:75˚C/5min., R2: 95˚C/5min., R3: 75˚C/25min., R4: 95˚C/25min., R5: 71˚C/15min R6: 99˚C/15min R7: 85˚C/1min R8: 85˚C/29min R9: 85˚C/15min.

It is revealed from the Fig 4.16 and 4.17 that ripe jackfruit samples after retort pouch pasteurisation processing showed the best results in terms of colour, taste, appearance, and overall acceptability and were close to that of the control. Treatments under elevated temperature and time scored comparatively less may be due to the reduction in colour and softness texture due to over-cooking. The major causes of colour change may be attributed to carotenoid degradation and nonenzymatic browning (Maillard) (Rattanathanalerk *et al*., 2005). During the sensory evaluation, it was found that the aroma of all the RJP samples did not stand out or differ notably from the control sample. However, the color of the RJP samples was found to be significant compared to the control. The overall acceptability of the R1 sample (i.e., 75°C for 5 min.) in RJB was high. In the case of RJP the temperature and process time variations had only minor effects on overall acceptability. This suggests that the R1 condition, characterized by 75°C for 5 min., was particularly favorable in terms of overall acceptability for RJB and RJP.

The statistical analysis of retort pouch pasteurised RJB and RJP showed no significant differences in sensory attributes across treatments (RJP: $F = 1.215$, $p = 0.427$; RJB: $F = 0.167$, $p = 0.954$). Correlation analysis indicated that Taste ($r = 0.97$), Texture ($r = 0.93$), and Colour ($r = 0.92$) were the key factors influencing Overall Acceptability. The optimized treatments were R1 (75°C, 5 min) and R7 (85°C, 0.86 min) for RJP and the treatment with balanced sensory scores for RJB. These results suggest that mild to moderate

retort conditions best preserve sensory quality, while extreme processing may reduce acceptability of the processed ripe jackfruit.

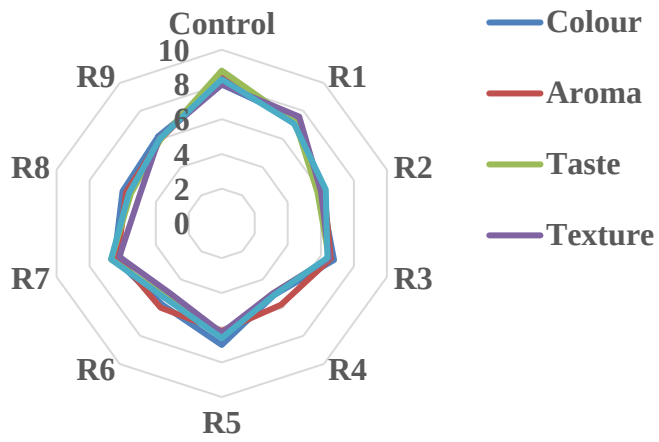


Fig 4.16 Sensory score card of retort pouch pasteurised RJB

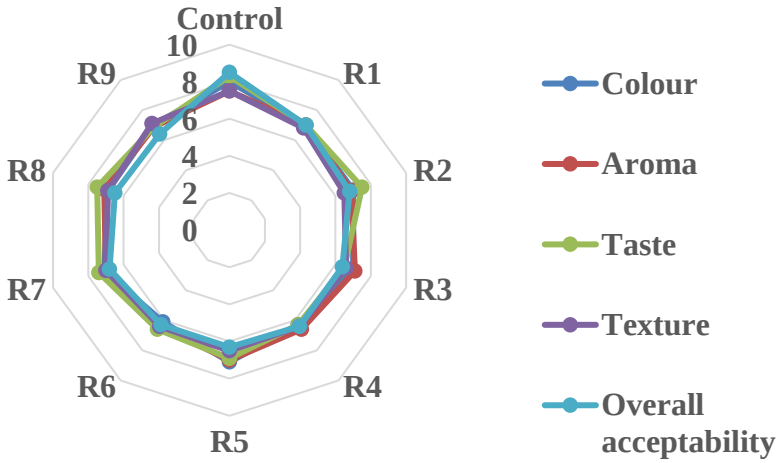


Fig. 4.17 Sensory score card of retort pouch pasteurised RJP

4.1.3 Optimisation of retort pouch processed ripe jackfruit

The optimisation of retort process parameters *viz.*, temperature (75 to 95°C) and time (5 to 25 min) was performed using central composite design (CCD). Treatment combinations with higher desirability values are taken as optimum process conditions. A higher desirability value of 0.987 was obtained for retort pouch pasteurisation of RJB at 79°C temperature 5 min processing time. In the case of RJP, a desirability value of 0.812 is obtained at 80°C temperature 12 min processing time. For RJB, the bioactive compounds were effectively retained, with total aerobic mesophiles (6.06 log CFU/g) and yeast/mold count (5.71 log CFU/g), while firmness was enhanced. Similarly, for RJP, maximum bioactive compound retention and minimal microbial load (5.64 log CFU/g) and yeast/mold count (6.81 log CFU/g) were observed under the optimised conditions.

4.1.4 Cost analysis

The cost estimation and Benefit-Cost Ratio (BCR) for pasteurised RJB and RJP reveal key insights into the profitability of processing these products. It was reported that the cost of producing retort pouch processed RJB amounts to approximately ₹211-/kg, while the current market value for such a product, when sold in syrup, is around ₹699.10 per kilogram. This results in a BCR of 3.3, indicating that for every ₹1 spent on production, a return of ₹3.3 is generated, reflecting a substantial profit margin. For jackfruit pulp, which has a market price of ₹240-/kg, the BCR was calculated to be 1.11, implying a smaller profit margin (Appendix G). This suggests that while both products are profitable, the jackfruit bulb, especially when sold in syrup, provides significantly higher returns compared to the pulp.

4.2 Effect of Retort pouch sterilisation of ripe jackfruit

4.2.1 Physico-chemical properties of unprocessed ripe jackfruit

The collected ripe jackfruit intended for sterilisation underwent a thorough analysis of its physico-chemical properties, and the results of this analysis have been systematically tabulated in Table 4.4. This comprehensive examination involved assessing various physical and chemical attributes of the fruit, providing a detailed understanding of its composition and characteristics before further processing**.**

Table 4.4 Physico-chemical and microbial properties of fresh ripe jackfruit prior to retort pouch sterilisation

Sl.No	Parameters		RJB	RJP
1	pH		5.01 ± 0.23	4.90 ± 0.18
2	TSS (ºBrix)		21.00 ± 0.24	18.50 ± 0.49
3	TA (mg/100 g)		0.58 ± 0.02	0.57 ± 0.02
4	Total sugar (%)		21.33 ± 0.56	22.56 ± 0.81
5	AA (mg/100 g)		13.81 ± 0.48	12.45 ± 0.57
6	Colour	L*	59.32 ± 2.72	66.83 ± 2.56
		a*	0.58 ± 0.03	0.44 ± 0.02
		b*	52.89 ± 2.31	53.56 ± 1.42
7	% DPPH scavenging activity		87.54 ± 2.32	83.29 ± 3.63
8	TPC (mg GAE/g)		71.11 ± 2.56	68.53 ± 2.47
9	TFC (mg RE/g)		40.12 ± 1.44	20.33 ± 0.73

4.2.2 Physico-chemical properties of retort pouch sterilised ripe jackfruit

4.2.2.1 Effect of retort pouch sterilisation on pH, TSS and TA of RJB

The impact of retort pouch sterilisation on the pH, TSS, and TA of RJB and pulp were examined and detailed in Appendix B. The data indicates that the pH ranged from 5±0.23 to 5.6 ± 0.28 in RJB (Fig 4.18a) and 5.06±0.24 to 5.28± 0.19 in RJP samples (Fig 4.18b). This contrasts with the control sample values of 4.9 ± 0.18

and 5.01 ± 0.23 for fresh pulp and bulb, respectively, suggesting a shift towards a more basic pH with increasing temperature and sterilisation time. The analysis reveals a significant rise in pH and a decrease in TA from 0.568% ± 0.03 to 0.152% ± 0.01 and 0.581 ± 0.02 to 0.226% ± 0.01, respectively, in sterilised RJP and RJB (Fig 4.20a &b). Notably, greater variations in pH and TA were observed under higher temperatures and a sterilisation time. This variation is likely due to the reduction in acid content resulting from the loss of organic acids in the jackfruit samples after heat treatment. Similar findings were reported by Velasco-Hernandez *et al*. (2020) for soursop pulp, Santhirasegaram *et al*. (2013) for mango juice.

There was a noticeable increase in TSS in sterilised ripe jackfruit samples, with a range of 18.2± 0.66 ºBrix to 19.5±0.23 ºBrix for RJP (Fig 4.19b) and 21.3±0.54 to 23.4 ± 0.24 °Brix for RJB (Fig 4.19a), compared to 18.5±0.49 ºBrix and 21±0.24 ºBrix in fresh pulp and bulb, respectively. This elevation in TSS, particularly in sterilised RJP, is likely attributed to the higher temperatures causing water evaporation and consequently increasing the pulp's concentration. These results are consistent with the findings of Zhu *et al*. (2022), who observed similar trends in thermally processed mixed formulations of fruit and vegetable pulps, specifically in cloudy apple juice.

The statistical analyses of TSS, pH, and TA for sterilised ripe jackfruit samples (RJB and RJP) reveal significant ($p>0.05$) insights. All three models are highly significant, explaining a substantial portion of the variability in each parameter. TSS was significantly influenced by temperature and an interaction effect was found in RJP, while pH and TA were significantly affected by temperature and time. The lack of fit is not significant relative to the pure error in all three models, indicating a good fit to the data. Overall, the analysis provides a comprehensive understanding of the influence of temperature and time on the quality attributes of sterilised ripe jackfruit bulbs, enabling informed optimization of the sterilisation process. The model regression equation in terms of coded form is given below

$$pH_{RJB} = 5.14+0.16T_S+0.085t_s-0.050T_S\,t_s+0.086\,T_S^2+0.11\,t_s^2 \quad \ldots (4.22)$$

$$pH_{RJP} = 5.24+0.044T_S+0.061t_s +0.015T_S\ ts -0.020\ T_S^2-0.040\ t_s^2 \quad \ldots (4.23)$$

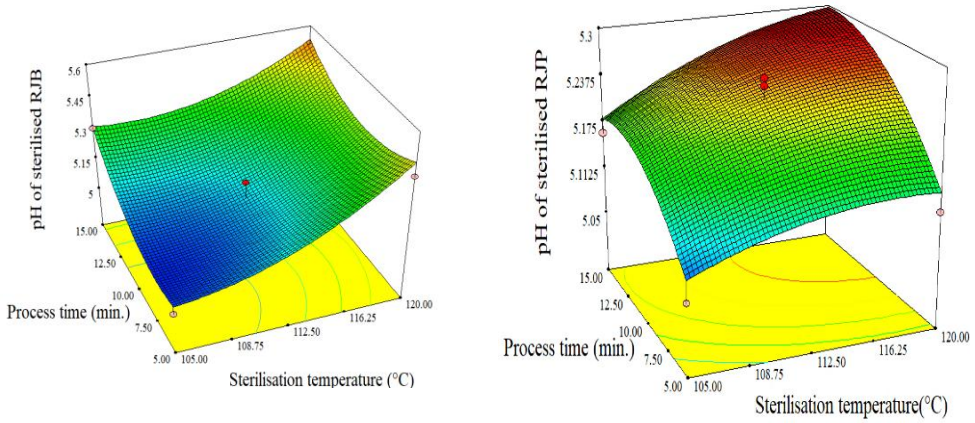
$$TSS_{RJB}\ (^{\circ}Brix) = 22.70+0.66T_S+0.20t_s +0.22T_S\ t_s -0.20T_S^2-0.48\ t_s^2 \quad \ldots (4.24)$$

$$TSS_{RJP}\ (^{\circ}Brix) =18.66+0.33T_S-0.043t_s +0.15\ T_S\ t_s +0.17\ T_S^2-0.030\ t_s^{\ 2} \quad \ldots (4.25)$$

$$TA_{RJB}\ (\%) = 0.47-0.14T_S-0.025\ t_s -0.018T_S\ ts -0.039\ T_S^2+9.763E-003t_s^2 \quad ...(4.26)$$

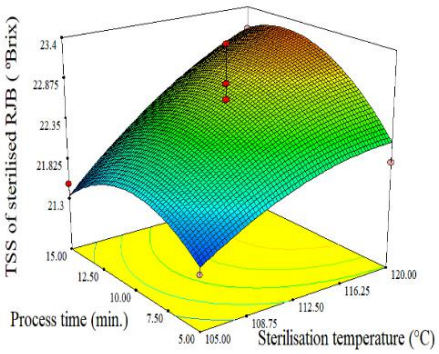
$$TA_{RJP}\ (\%) = 0.43-0.16T_S-0.050t_s +0.010T_S\ t_s -0.029T_S^2-0.049t_s^2 \quad \ldots (4.27)$$

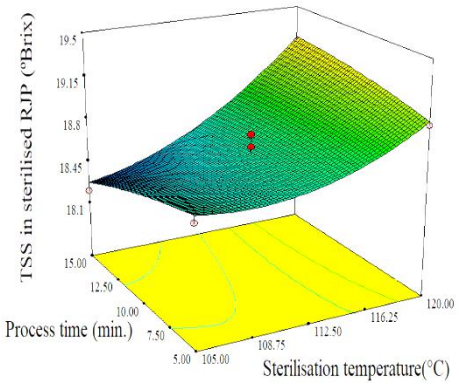
Where, pH_{RJB} and pH_{RJP}: pH of ripe jackfruit bulb and ripe jackfruit pulp, respectively. TSS_{RJB} and TSS_{RJP}: Total soluble solids in ripe jackfruit bulb and ripe jackfruit pulp, respectively. TA_{RJB} and TA_{RJP}: Titrable acidity of ripe jackfruit bulb and ripe jackfruit pulp, respectively. T_s is the sterilisation temperature in ºC and t_s is the process time in min.



(a) **(b)**

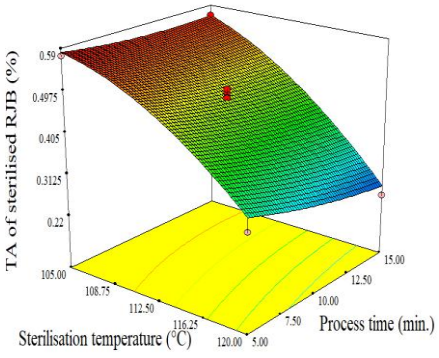
Fig.4.18 pH values of retort pouch sterilised ripe jackfruit samples

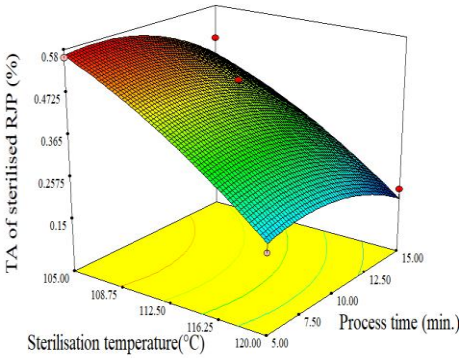




(a) **(b)**

Fig. 4.19 TSS in retort pouch sterilised ripe jackfruit samples





(a) **(b)**

Fig.4.20 TA of retort pouch sterilised ripe jackfruit samples

4.2.2.2 Effect of retort pouch sterilisation on colour characteristics of ripe jackfruit

In assessing consumer acceptance and indicating phytochemical changes post-sterilisation colour characteristics play a crucial role in product evaluation. Table 4.4 outlines the colour parameters of fresh ripe jackfruit samples. Following sterilisation the L* value of RJBs increased from 56.15 ± 2.21 to 61.18 ± 2.57 (Fig 4.21a). RJP exhibited a range of L* values from 62.19 ± 1.77 to 66.76 ± 2.85 (Fig 4.21b). At a temperature of 105˚C/5 min and 102˚C for 10 min, L* values exhibited

greater stability, with higher lightness values of 61.18 ± 2.57and 66.76 ± 2.85 were noted in RJB and pulp, respectively. A notable decline in lightness values in ripe jackfruit samples was evident with an increase in both temperature and sterilisation time. Comparable findings were observed by You *et al*. 2018 in sterilised mulberry juice. Conversely, certain studies indicated that sterilisation treatments markedly enhanced the brightness and colour saturation of the juice (Bao *et al*., 2023). Consequently, the determination of whether temperature or time exerts a more substantial influence on juice colour during thermal sterilisation necessitates further investigation.

The ANOVA for the response surface quadratic models for both sterilised RJB and RJP indicates that temperature (T_S) is the most significant factor affecting the L∗ values. For the bulb, temperature shows an F-value of 90.87 with a p-value of < 0.0001 and R^2 value was 0.95, while for the pulp, temperature shows an F-value of 160.30 with a p-value of < 0.0001 and R^2 value was 0.96 (Table B15 and B16). Time (t_s) is also significant for the RJB and RJP with p-values of 0.0091 and 0.011, respectively. Interaction ($T_S t_s$) and quadratic terms (T_S^2 and t_s^2) are not significant for the pulp. Overall, these results suggest that precise control of both temperature and time during the sterilisation process is essential for maintaining the desired quality of the RJB and RJP. The significant terms and the model's good fit indicate that the response surface quadratic model is effective in predicting the L∗ value based on the factors studied. The model regression equation in terms of coded form is given below

$$L^*_{RJB} = 56.65 - 1.57\,T_s - 0.59\,t_s + 0.70\,T_S\,t_s + 0.99\,T_S^2 + 0.21\,t_s^2 \quad \ldots (4.28)$$

$$L^*_{RJP} = 64.46 - 1.62\,T_S - 0.44\,t_s + 0.23\,T_S\,t_s - 0.099\,T_S^2 + 0.039\,t_s^2 \quad \ldots (4.29)$$

Where, L^*_{RJB} and L^*_{RJP}: L* value of ripe jackfruit bulb and ripe jackfruit pulp respectively. Ts is the sterilisation temperature in ^oC and t_s is the process time in min

The sterilisation process resulted in slightly higher a* values and lower b* values, indicating a loss of the fresh yellow colour in ripe jackfruit. Initially, the fresh samples exhibited a* values of 0.58 ± 0.03 and 0.44 ± 0.02 in the RJB and RJP, respectively, with b* values of 52.89 ± 2.31and 53.56 ± 1.42. The a* value varied between 0.61±0.03 to 1.26±0.03 in the RJB (Fig 4.22a) and 0.72 ±0.02to 3.15±0.10 in the RJP (Fig 4.22b) post-sterilisation. Conversely, the variation of b* values was recorded as 47.2±1.70 -53.41±1.92 in the RJB (Fig 4.23a) and 43.3±1.14-53.38±1.92 in the RJP (Fig 4.23b). Comparing the sterilised RJP to the fresh samples, there was a 23.69% loss in b* value, whereas the loss was lower at 10.75% in the bulb. These color changes are attributed to carotenoid degradation and nonenzymatic browning/Maillard reaction degradation of pigments, and the polymerization of phenolic compounds occurring during the sterilisation process (Rattanathanalerk *et al*., 2005).

The significant effect of temperature (T_S) on the a* and b* value implies that the sterilisation temperature is a critical factor in determining the colour of RJB and RJP. The ANOVA for the response surface quadratic models for both sterilised RJB (R^2 value = 0.973) and RJP indicates that temperature (T_S) is the most significant factor affecting the a* and b* values (Table B17 to B19). The R^2 for a* value of RJB is 0.973 and for RJP it is 0.924. The model regression equation in terms of coded form is given below

$$a^*_{RJB} = 0.74 + 0.22T_S + 0.088t_s + 0.057\, T_S\, t_s + 0.10T_S^2 + 0.011\, t_s^2 \quad \ldots (4.30)$$

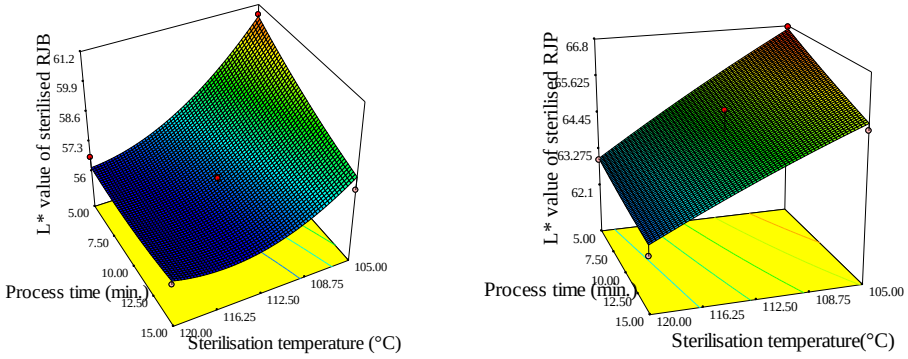
$$a^*_{RJP} = 2.59 + 0.85T_S + 0.41\, t_s - 0.018T_S\, t_s - 0.34T_S^2 - 0.38\, t_s^2 \quad \ldots (4.31)$$

$$b^*_{RJB} = 51.86 - 2.18T_S - 0.65t_s - 0.30\, T_S\, t_s - 0.92\, T_S^2 - 0.43\, t_s^2 \quad \ldots (4.32)$$

$$b^*_{RJP} = 48.46 - 2.53\, T_S - 0.84\, t_s - 1.40\, T_S\, t_s + 0.61\, T_S^2 - 0.48\, t_s^2 \quad \ldots (4.33)$$

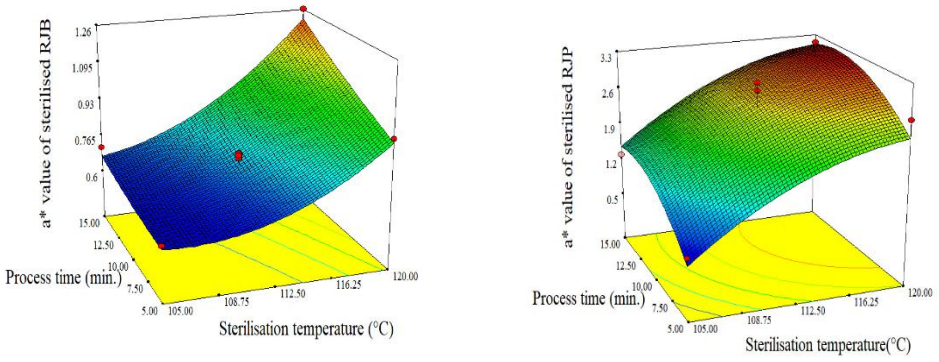
Where, a^*_{RJB} and a^*_{RJP}: a* value of ripe jackfruit bulb and ripe jackfruit pulp respectively. b^*_{RJB} and b^*_{RJP}: a* value of ripe jackfruit bulb and ripe jackfruit pulp respectively

T_s is the sterilisation temperature in ºC and t_s is the process time in min



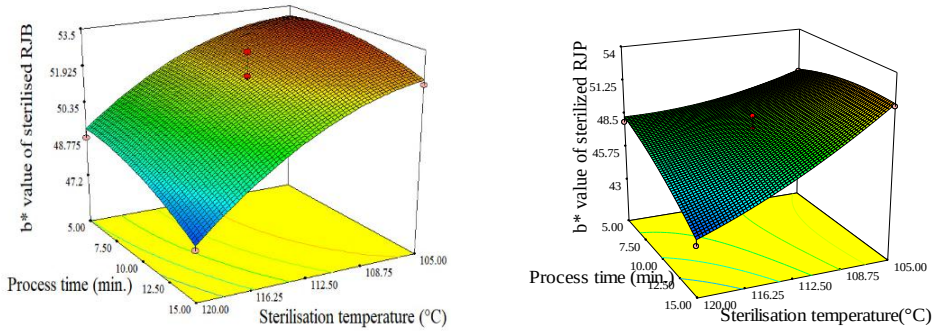
(a) **(b)**

Fig.4.21 L* value of retort pouch sterilised ripe jackfruit samples



(a) **(b)**

Fig.4.22 a* value of retort pouch sterilised ripe jackfruit sample



(a) **(b)**

Fig.4.23 b* value of retort pouch sterilised ripe jackfruit samples

4.2.2.3 Effect of Retort pouch sterilisation on ΔE, YI and BI of ripe jackfruit

The ΔE in ripe jackfruit samples was determined based on the observed L*, a*, and b* values using the standard equation outlined in the materials and methodology. It was found that the sterilised RJB exhibited a ΔE ranging from 1.48 ± 0.08 to 6.52 ± 0.33 (Fig 4.24a), while the pulp showed a ΔE of 6.58 ± 0.13 to 11.18 ± 0.35 (Fig 4.24b). It was observed that all samples experienced noticeable colour deviations following sterilisation with temperature and sterilisation time significantly influencing the ΔE values of both bulb and pulp. Particularly, a higher ΔE value of 6.52 ± 0.33 was noted in sterilised RJB at a higher temperature and sterilisation time of 120˚C for 15 min. Similarly, a ΔE value of 11.18 ± 0.35 was observed in sterilised RJP under at 120˚C for 15 min. The appreciable deviation in color of ripe jackfruit samples is likely attributed to thermal degradation in carotenoids, leading to a decline in b* and an increase in a*.

For the jackfruit bulb, the R^2 value is 0.8093, while for the pulp it is 0.9791, demonstrating that the models explain 80.93% and 97.91% of the variability in the responses, respectively. Temperature (T_S) is the most significant factor for bulb and p-values < 0.0001. Time (t_s) is also significant for RJB.

The data presented in the Fig 4.25 & 4.26 showcases the impact of varying sterilisation conditions on the colour parameters (BI and YI) of retort pouch-sterilised RJP and RJB. Across different temperatures and time intervals, noticeable variations in BI and YI were observed. In RJP, the YI ranged from 99.38 ± 0.24 to 114.48 ± 0.44 (Fig 4.26b), while BI fluctuated between 90.14 ± 1.11 and 97.91 ± 0.99 (Fig. 4.25b), indicating that higher temperatures and prolonged exposure contributed to enhanced browning. Similarly, in RJB, BI values spanned from 101.79 ± 0.21 to 111.50 ± 0.36 (Fig 4.25a), and YI varied between 119.96 ± 0.46 and 133.18 ± 0.74, (Fig 4.26a) suggesting a relatively stable yellowness but a slight increase in browning at higher intensities. This decrease in YI at elevated process conditions may be attributed to a decrease in the b* value due to non-enzymatic reactions and carotenoid

degradation. In RJP, the highest BI (97.91 ± 0.99) and YI (114.48 ± 0.44) were recorded at 102°C for 10 min, while the lowest BI (92.86 ± 0.24) and YI (86.74 ± 1.11) were observed at treatment with the lowest b* values. In RJB, the highest BI (113.71 ± 0.36) was found at 102°C for 10 min, whereas the lowest (95.51 ± 0.21) was recorded at 123°C for 10 min. The highest YI (135.88 ± 0.74) occurred at 102°C for 10 min, and the lowest (110.28 ± 0.46) was at 120°C for 15 min. These results indicate that higher temperatures and prolonged exposure contribute to the degradation of yellow colour, likely due to Maillard reactions and caramelization (Zhang *et al.*, 2024).

The ANOVA results indicated significant quadratic models for all response variables (YI and BI) in both RJB and RJP. Temperature was found to be the most influential factor affecting all responses, and time also showed a significant effect. The interaction between temperature and time was significant for YI and BI of RJP, and for BI in pulp, indicating complex relationships between these factors (Appendix B). While the models showed good fit for all responses, as indicated by high R^2 values (ie., YI_{RJB}= 0.8710, YI_{RJP}= 0.9102, BI_{RJB}= 0.8512 and BI_{RJP}= 0.9081). The regression equation for the ΔE, YI and BI and their contour diagram illustrating the effect of sterilisation on ripe jackfruit samples with varying process conditions are given below

$$\Delta E_{RJB} = 2.76+1.80T_S+0.59t_s+0.31T_S\,t_s+0.78T_S^2+0.075t_s^2 \quad \ldots (4.34)$$

$$\Delta E_{RJP} = 8.01+0.42T_S+0.45t_s+1.40\,T_S\,t_s-0.076T_S^2+0.31\,t_s^2 \quad \ldots (4.35)$$

$$YI_{RJB} = 130.34-2.04\,T_S-0.35\,t_s-2.27\,T_S\,t_s-4.26T_S^2-1.33\,t_s^2 \quad \ldots (4.36)$$

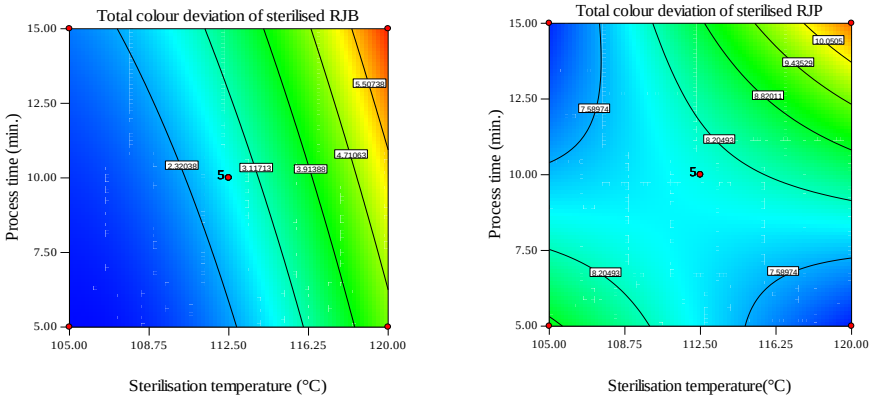
$$YI_{RJP} = 107.40-2.87T_S-1.18\,t_s-3.57\,T_S\,ts+1.45\,T_S^2-1.14t_s^2 \quad \ldots (4.37)$$

$$BI_{RJB} = 109.21-1.37T_S-0.21\,t_s-1.64\,T_S\,t_s-3.14\,T_S^2-1.02\,t_s^2 \quad \ldots (4.38)$$

$$BI_{RJP} = 94.32-1.34T_S-0.47\,t_s-2.05T_S\,t_s+0.77T_S^2-0.80\,t_s^2 \quad \ldots (4.39)$$

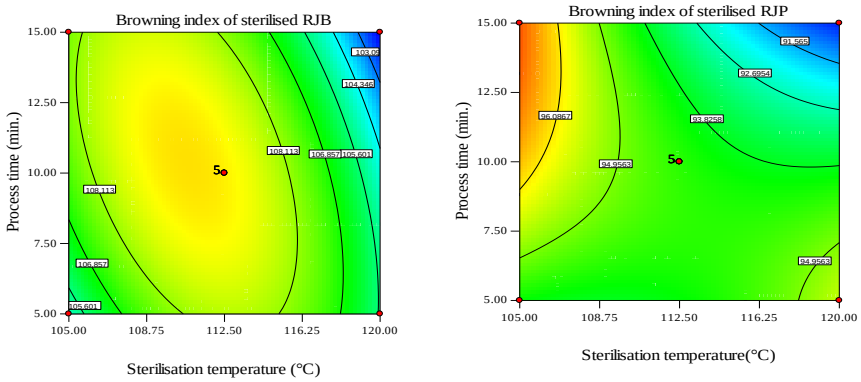
Where, E_{RJB} and E_{RJP}: Total colour deviation of ripe jackfruit bulb and ripe jackfruit pulp respectively. YI_{RJB} and YI_{RJP}: Yellowness index of ripe jackfruit bulb and ripe jackfruit pulp respectively. BI_{RJB} and BI_{RJP}: Browning index of ripe jackfruit bulb and ripe

jackfruit pulp respectively and T_s is the sterilisation temperature in ^oC and t_s is the process time in min



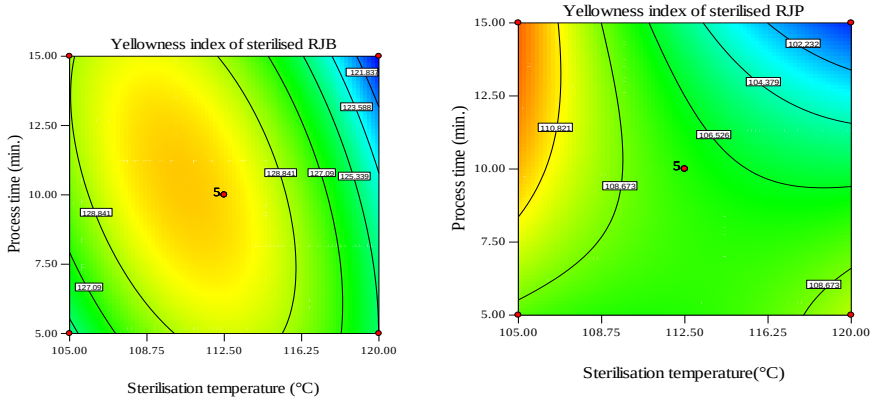
(a) **(b)**

Fig.4.24 ΔE value of retort pouch sterilised ripe jackfruit sample



(a) **(b)**

Fig.4.25 BI of retort pouch sterilised ripe jackfruit sample



(a) **(b)**

Fig.4.26 YI of retort pouch sterilised ripe jackfruit sample

4.2.2.4 Effect of Retort pouch sterilisation on AA of ripe jackfruit

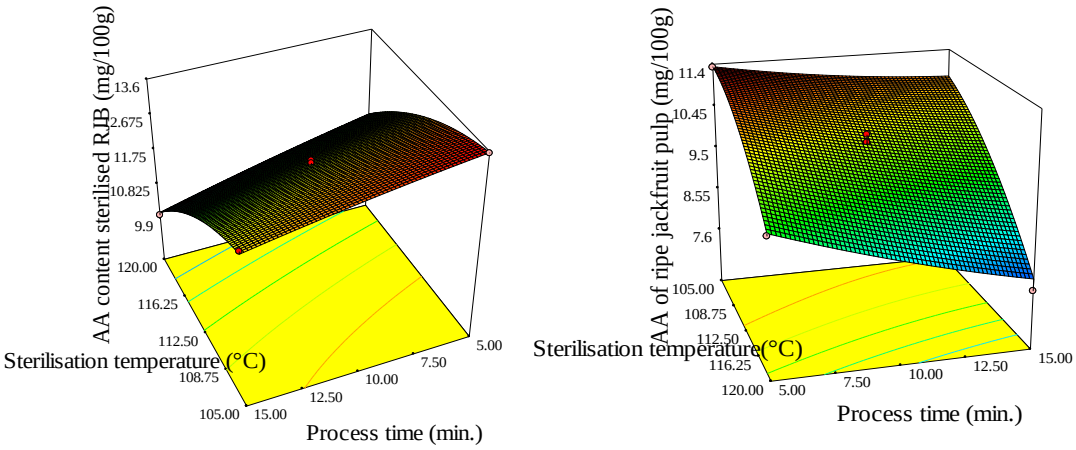
The AA in sterilised RJP ranged from 9.98±0.45 mg/100g to 13.56± 0.62 mg/100g (Fig 4.27b), while in bulb samples, it ranged from 7.83± 0.28 mg/100g to 11.33± 0.40 mg/100g (Fig 4.27a). Prior to sterilisation the fresh values were 13.81± 0.48 mg/100g for bulb samples and 12.45± 0.57 mg/100g for pulp samples. This data suggests that there was a decrease in the AA content of both RJB and RJP samples after sterilisation. The range of values observed in the sterilised samples indicates variability in AA content among different batches or sterilisation conditions. Comparing the AA content of the sterilised samples to the fresh values provides insight into the extent of degradation or loss of AA during sterilisation. In both bulb and pulp samples, the AA content decreased after sterilisation. This reduction in AA content could be due to the heat sensitivity of AA, leading to its degradation during the sterilisation process (Wu *et al.,* 2021).

The statistical analyses for the AA content in both sterilised ripe jackfruit bulb and pulp indicate highly significant models, with respective F-values of 247.89 and 65.03, and p-values < 0.0001, showing very low probabilities of the results being due to noise. For both the bulb and pulp, temperature (T_S) and time (t_s) are significant factors, with temperature being more impactful (F-values: bulb 973.94, pulp 250.37). The quadratic term for temperature (T_S^2) is also significant in both cases, suggesting an optimal temperature range for ascorbic acid retention. The interaction term ($T_S t_s$) is not significant in either model, and the quadratic term for time (t_s^2) is also not significant. Both models demonstrate excellent fits with high R^2 values (RJB= 0.9944, RJP= 0.9789), and their predicted R^2 values are in reasonable agreement with the adjusted R^2 values, confirming strong predictive capabilities (Table B12 and B13). The lack of fit is not significant for either model, indicating a good model fit overall. These findings highlight the critical importance of temperature control in optimizing ascorbic acid content during the sterilisation process for both jackfruit bulb and pulp. The model regression equation in terms of coded form is given below

AA_{RJB} (mg/100g) $= 12.35 - 1.23T_S - 0.53t_s - 0.12T_S t_s - 0.37T_S^2 - 0.049 t_s^2$ … (4.40)

AA_{RJP} (mg/100g) $= 10.14 - 1.21T_S - 0.52t_s - 0.24T_S t_s - 0.38T_S^2 + 0.094 t_s^2$ … (4.41)

Where, AA_{RJB} and AA_{RJP}: Ascorbic acid content of ripe jackfruit bulb and ripe jackfruit pulp respectively and T_s is the sterilisation temperature in ^oC and t_s is the process time in min



(a) **(b)**

Fig.4.27 AA content of retort pouch sterilised ripe jackfruit sample

4.2.2.5 Effect of Retort pouch sterilisation on TPC and TFC of ripe jackfruit

The TPC in sterilised RJP varied from 56.49±2.59 mg GAE/g to 64.85±2.83 mg GAE/g (Fig 4.28b), while in RJB samples, it ranged between 68.51±3.14 mg GAE/g and 58.51±2.11 mg GAE/g (Fig 4.28a). Before sterilisation the fresh phenolic content was measured at 68.53±1.81 mg GAE/g for RJP and 71.11±2.56 mg GAE/g for RJB samples. The observed degradation in TPC following sterilisation was significant, particularly at a temperature of 123°C for 10 min, where a reduction of 16.66% was noted in RJB samples and 17.56% in RJP samples. This substantial decrease in phenolic content could be attributed to the thermal degradation of phenolic compounds during the sterilisation process. These findings underscore the vulnerability of phenolic compounds to heat, suggesting the importance of carefully

considering sterilisation parameters to minimize the loss of these valuable bioactive compounds. The study by Oancea *et al*. (2017) investigated the degradation kinetics of antioxidant activity, flavonoids, and phenolic compounds in sour cherries during thermal processing. The results revealed that the degradation process follows first-order reaction kinetics. Additionally, the study found that increasing the temperature significantly accelerates the degradation of these bioactive compounds, highlighting the importance of temperature control during processing to preserve nutritional quality. Given the potential health benefits associated with phenolic compounds, such as their antioxidant properties, strategies to optimize sterilisation methods while preserving phenolic content may be warranted to ensure the nutritional quality of sterilised ripe jackfruit products.

The TFC in sterilised RJB was found to range from 31.50±1.09 mg RE/g to 38.8±1.03 mg RE/g (Fig 4.29a), indicating a considerable variability within this range. Similarly, in the pulp, the TFC ranged from 14.7±0.67 mg RE/g to 18.56±0.85 mg RE/g, (Fig 4.29b) demonstrating a slightly lower range compared to the bulb. Comparing these figures to the fresh values, we find that the TFC in the fresh bulb was notably higher at 40.12±1.45 mg RE/g, whereas in the fresh pulp, it was 20.33±0.73 mg RE/g. This suggests that the sterilisation process led to a reduction in the TFC in both bulb and pulp samples. Notably, a higher reduction in TFC was observed at a temperature of 120°C for 15 min. This indicates that higher temperatures during sterilisation may have a more pronounced effect on the degradation or alteration of flavonoid compounds. The similarity of these results to those reported in fruit drinks based on milk by Cilla *et al*. (2012) underscores the potential impact of sterilisation methods on the flavonoid content of food products. These findings highlight the importance of optimizing sterilisation parameters to minimize the loss of beneficial flavonoids while ensuring product safety and quality. The ANOVA table suggests that temperature exerted a highly significant ($p<0.0001$) influence on TPC in both jackfruit pulp ($R^2=0.9734$) and bulb ($R^2=0.9822$), with time also contributing significantly ($p<0.05$) (Table B9 and B8). While the models for both

pulp and bulb demonstrated strong overall fit, as indicated by high R^2 values, the lack of fit test for pulp was marginally significant (p=0.0503). The ANOVA for the response surface quadratic model revealed significant effects of sterilisation conditions on TFC in both jackfruit pulp and bulb (Table B11 and B10). For the jackfruit bulb, the model was highly significant (F = 63.90, $p < 0.0001$), with temperature ($p < 0.0001$), time ($p < 0.05$), and the quadratic effect of temperature ($p < 0.0001$) as significant factors influencing flavonoid content. The model exhibited a strong fit ($R^2 = 0.9786$) and adequate prediction (pred $R^2 = 0.9092$). In the jackfruit pulp, the model was also highly significant (F = 25.56, $p = 0.0002$), with temperature ($p < 0.0001$) and time ($p < 0.05$) as significant factors. Although the model fit was good ($R^2 = 0.9481$), with reasonable predictive ability (pred $R^2 = 0.8658$), the lack of fit was not significant ($p = 0.30$), indicating a satisfactory model. These findings suggest that the developed models effectively predict TFC in both jackfruit components under the studied conditions. The model regression equation in terms of coded form is given below

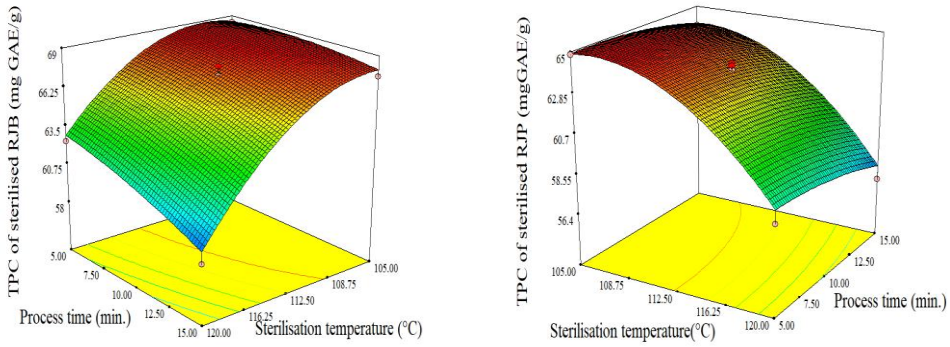
$$TPC_{RJB} \text{ (mg GAE/g)} = 67.35 - 3.62T_S - 1.02t_s - 0.74\,T_S\,t_s - 2.26T_S^2 - 0.39\,t_s^2 \quad \ldots (4.42)$$

$$TPC_{RJP} \text{ (mg GAE/g)} = 63.51 - 3.06\,T_S - 0.61t_s - 0.17T_S\,t_s - 1.79T_S^2 - 0.33t_s^2 \quad \cdots (4.43)$$

$$TFC_{RJB} \text{ ((mg RE/g)} = 37.21 - 2.61T_S - 0.83\,t_s - 0.63T_S\,t_s - 1.22T_S^2 + 0.050\,t_s^2 \quad \ldots (4.44)$$

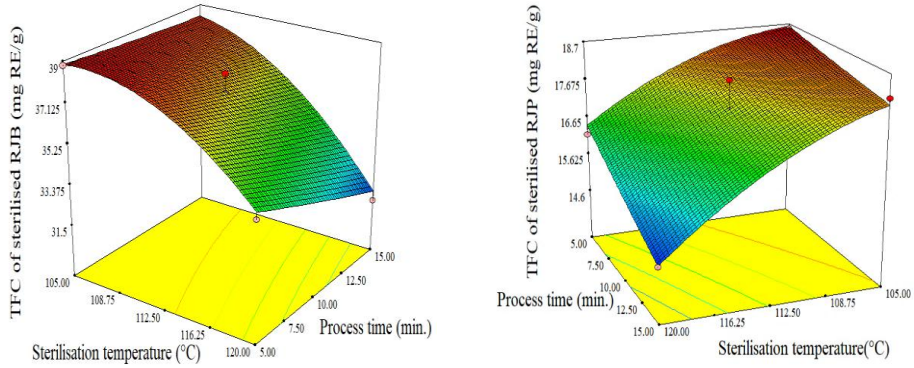
$$TFC_{RJP} \text{ (mg RE/g)} = 17.35 - 1.35T_S - 0.60t_s - 0.26T_S\,t_s - 0.43\,T_S^2 + 0.018\,t_s^2 \quad \ldots (4.45)$$

Where, TPC_{RJB} and TPC_{RJP}: Total phenolic content of ripe jackfruit bulb and ripe jackfruit pulp respectively. TFC_{RJB} and TFC_{RJP}: Total flavanoid content of ripe jackfruit bulb and ripe jackfruit pulp respectively and T_s is the sterilisation temperature in ^oC and t_s is the process time in min



(a) **(b)**

Fig. 4.28 TPC of retort pouch sterilised ripe jackfruit sample



(a) **(b)**

Fig. 4.29 TFC of retort pouch sterilised ripe jackfruit sample

4.2.2.6 Effect of Retort pouch sterilisation on DPPH radical scavenging of ripe jackfruit

The DPPH radical scavenging activity in sterilised RJB ranged from 86.52 ± 3.12% to 82.6 ± 3.79% (Fig 4.30a), while in the RJP, it varied from 82.83 ± 3.80% to 80.48 ± 2.90% (Fig 4.30b). Comparatively, the fresh DPPH radical scavenging activity values were higher, with the RJB measuring at 87.54 ± 2.32% and the RJP at 83.29 ± 3.63%. It's worth noting that a greater reduction in DPPH radical scavenging activity was observed when subjecting the samples to a temperature of 120°C for 15

min during sterilisation. This suggests that higher temperatures and longer sterilisation times could exert a more pronounced effect on the antioxidant activity of both jackfruit bulb and pulp as suggested by Miller and Silva (2012).

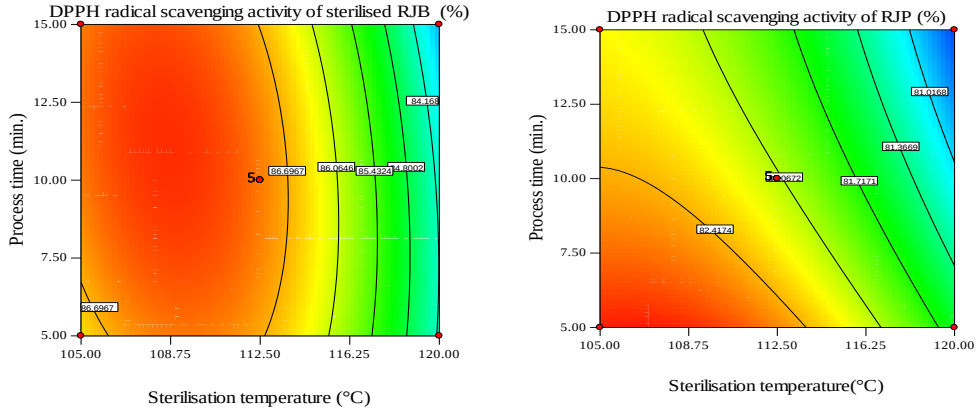
Overall, the decrease in DPPH radical scavenging activity after sterilisation highlights the potential loss of antioxidant compounds, which play a crucial role in protecting cells from oxidative damage. This underscores the importance of carefully considering sterilisation conditions to preserve the antioxidant properties of food products like ripe jackfruit.

The statistical analyses for the DPPH radical scavenging activity content in both sterilised ripe jackfruit bulb and pulp reveal significant models with F-values of 7.14 (RJB) and 35.33 (RJP), and p-values < 0.0001, indicating low probabilities of the results being due to noise. For both bulb and pulp, temperature (T_S) and time (t_s) are critical factors, with temperature having a more substantial impact, as seen in their respective F-values: bulb 19.00 and 16.35, pulp 115.68 and 32.51. The quadratic term for temperature (T_S^2) is significant in both models, indicating an optimal temperature range for maximizing DPPH content. The interaction term ($T_S\ t_s$) and the quadratic term for time (t_s^2) are not significant in either model. Both models demonstrate good fits with high R^2values (RJB= 0.8361, RJP= 0.9619), and their predicted R^2 values are in reasonable agreement with the adjusted R^2 values, confirming strong predictive capabilities (Table B26 and B27). The lack of fit is not significant for both models, indicating a good model fit overall. These findings underscore the critical role of temperature control in optimizing DPPH radical scavenging activity during the sterilisation process for both jackfruit bulb and pulp, highlighting the efficiency and effectiveness of the models in guiding optimal sterilisation parameters.The model regression equation in terms of coded form is given below

$$DPPH_{RJB}\ (\%) = 86.95 - 1.44\ T_S - 0.024\ t_s - 0.26\ T_S\ ts - 1.44T_S^2 - 0.25t_s^2 \quad \ldots (4.46)$$

$$DPPH_{RJP}\ (\%) = 82.09 - 0.68T_S - 0.36\ t_s - 0.11\ T_S\ ts - 0.34T_S^2 + 0.069t_s^2 \quad \ldots (4.47)$$

Where, $DPPH_{RJB}$ and $DPPH_{RJP}$: DPPH radical scavenging activity of ripe jackfruit bulb and ripe jackfruit pulp respectively and T_s is the sterilisation temperature in ºC and t_s is the process time in min



(a) **(b)**

Fig. 4.30 DPPH radical scavenging activity of retort pouch sterilised ripe jackfruit sample

4.2.2.7 Effect of retort pouch sterilisation on Total sugar content of ripe jackfruit

The analysis of total sugar content in sterilised RJB and RJP under various process conditions reveals that the total sugar content in RJB ranges from 15.8±0.56% to 21.33±0.55% (Fig 4.31a) and in RJP from 13.65±0.59% to 22.56±0.81% (Fig 4.31b). The control values for total sugar content are 21.33±0.56% for RJB and 22.56±0.81% for RJP. Post-processing, the sugar content decreased, with the minimum values being 15.8±0.56% for RJB and 13.65±0.59% for RJP at 120˚C/15 min. A notable trend is that higher temperatures generally reduce the sugar content in both RJB and RJP, likely due to thermal degradation or Maillard reactions (Gonclaves *et al*., 2020). Zhang *et al*. (2022) reported that post sterilisation did not affect much in the total sugar and reducing sugar in jujube juice fermented by *Lactobacillus plantarum*.

The ANOVA results indicate significant models for both RJB and RJP (Table B28 and B29), with F-values of 162.40 and 72.23, respectively, and p-values < 0.0001, confirming the impact of temperature (T_S) and time (t_s) on sugar content. For RJB, the interaction term ($T_S t_s$) and quadratic terms T_S^2 and t_s^2 are also significant. The R^2values of 0.9915 for RJB and 0.9810 for RJP suggest that the models explain a substantial portion of the variability. These findings underscore the importance of optimizing sterilisation conditions to preserve sugar content in sterilised jackfruit products. Final equation in terms of coded factors is given by

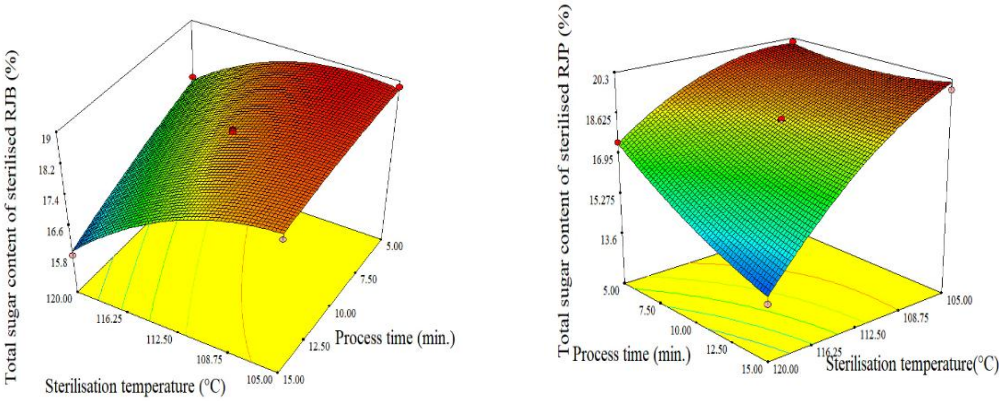
Total Sugar content in RJP (%)

$$= 18.39-2.22\ T_S-0.85t_s\ -0.89T_S\ t_s\ -0.82\ T_S^2+0.32\ t_s^2 \quad \ldots (4.48)$$

Total Sugar content in RJB (%)

$$= 18.32-0.97\ T_S\ -0.47t_s\ -0.30T_S\ t_s\ -0.57\ T_S^2 0.078\ t_s^2 \quad \ldots (4.49)$$

Where, T_s is the sterilisation temperature in ^oC and t_s is the process time in min



(a) **(b)**

Fig.4.31 Total sugar content of retort pouch sterilised ripe jackfruit sample

4.2.2.8 Microbial analysis of retort pouch sterilised ripe jackfruit

The microbial analysis of sterilised ripe jackfruit samples revealed that both RJB and RJP showed a significant reduction in microbial population post-sterilisation. According to the National Food Safety Standard for Beverages, the acceptable limit for TAM is less than 2 log CFU/g, and for yeast/mold, it is less than 1.3±0.03 log CFU/g (Wang *et al*., 2019). The control sample indicated initial microbial populations with TAM counts of 4.3±0.15 log CFU/g in RJB and 4.8±0.20 log CFU/g in RJP (Table 4.5), and yeast/mold counts of 4.5 ±0.11 log CFU/g in RJB and 4.8±0.20 log CFU/g in RJP, which were above the standard safety limits, demonstrating a high risk of microbial contamination. Upon sterilisation at various temperatures and durations, total aerobic bacteria were not detected in most RJB and RJP samples, except for a few cases at 105°C and 120°C, where minimal counts were observed. Yeast and mold counts were similarly reduced to non-detectable levels in most samples, with few exceptions at 105°C and 120°C. Notably, at 112.5°C for 10 min, microbial populations in both RJB and RJP were consistently undetectable, indicating that this condition is highly effective for sterilisation. These results highlight the efficacy of the sterilisation process in significantly reducing microbial loads in ripe jackfruit bulb and pulp, ensuring enhanced safety and shelf life of the product. This sterilisation treatment is critical for ensuring the safety and extending the shelf life of the product by effectively killing microorganisms through protein denaturation, metabolic enzyme inactivation, and DNA damage (Zhang *et al*., 2024). Bhat *et al*., 2016 observed similar results in bottle guard juice in which microbial population (bacteria, yeast and mould) was below detection limit.

4.2.2.9 Effect of retort pouch sterilisation on firmness of ripe jackfruit

The analysis of the firmness of ripe jackfruit after retort pouch sterilisation revealed significant variations depending on the temperature and time of treatment. The firmness of the treated samples ranged from 40.15 ± 1.80 N to 53.65 ± 1.93 N. Compared to the control sample, which had a firmness of 54.55 ± 1.44 N, all treated

samples exhibited a reduction in firmness. The treatment with the highest firmness value was at a temperature of 101.89°C for 10 min, yielding a firmness of 53.65 ± 1.93 N, representing a minimal reduction of 1.65% from the control. Conversely, the treatment at 123°C for 10 min resulted in the lowest firmness value of 40.15 ± 1.80 N, indicating a significant reduction of 26.40%. The firmness of the jackfruit decreased with increasing temperature and time. For instance, at 105°C, the firmness was 51.4 ± 1.35 N at 5 min and slightly increased to 52.68 ± 1.40 N at 15 min (Fig 4.32). At 120°C, the firmness decreased from 45.65 ± 1.64 N at 5 min to 42.85 ± 1.13 N at 15 min. This trend highlights the temperature-dependent nature of firmness reduction, with higher temperatures causing more significant softening. The reduction in firmness during retort pouch sterilisation is primarily attributed to the breakdown of cell wall structures and the gelatinization of starches within the fruit. Additionally, heating can lead to the splitting of glycosidic bonds in pectins through β-elimination, resulting in increased pectin solubilization and subsequent texture loss (Ranganathan *et al*., 2015). These factors collectively contribute to the softening of the tissue during thermal processing.

Table 4.5 Microbial analysis of retort pouch sterilised ripe jackfruit samples

Sterilisation temperature (˚C)	Process time (min)	TAM (RJB) (log CFU/g)	TAM (RJP) (log CFU/g)	Yeast/mold (RJB) (log CFU/g)	Yeast/mold (RJP) (log CFU/g)
Control sample		4.3±0.15	4.8±0.20	4.5 ±0.11	4.8±0.20
105	5	10±0.36	9±0.31	8±0.30	7.05±0.25
120	5	9±0.32	10±0.38	7.35±0.31	9.65±0.35
105	15	10±0.31	11±0.41	8.17±0.28	10.47±0.34
120	15	ND	ND	ND	ND
102	10	8±0.33	7±0.25	6.2±0.21	6.03±0.28
123	10	ND	ND	ND	ND
112.5	3	8±0.29	8±0.32	6.21±0.18	6.8±0.27
112.5	17	ND	ND	ND	ND
112.5	10	ND	ND	ND	ND
112.5	10	ND	ND	ND	ND
112.5	10	ND	ND	ND	ND
112.5	10	ND	ND	ND	ND
112.5	10	ND	ND	ND	ND

ND: Not detected

The ANOVA table provided further insights into the effects of temperature and time on the firmness of the jackfruit. Temperature (T_S) was the most significant factor affecting firmness, with an F-value of 230.45 and a p-value of less than 0.0001 and R^2 value of 0.97. Time (t_s) also had a significant impact, with an F-value of 5.58 and a p-value of 0.0502. The interaction between temperature and time ($T_S t_s$) was significant as well, with an F-value of 6.38 and a p-value of 0.0394, indicating that the combined effect of these two factors plays a crucial role in determining the firmness of the jackfruit. In conclusion, the retort pouch sterilisation process significantly affects the firmness of ripe jackfruit, with higher temperatures and longer times leading to greater reductions in firmness. The model regression equation in terms of coded form is given below

Firmness (N) $=50.06-4.33T_s-0.67t_s-1\ t_s+.02\ T_s\ \ t_s\ 1.67\ T_s^2-0.069t_s^2$ …(4.50)

Where, T_s is the sterilisation temperature in ºC and t_s is the process time in min

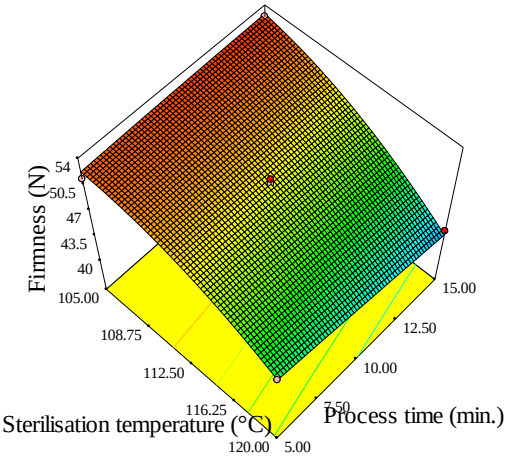


Fig.4.32 Firmness of retort sterilised ripe jackfruit sample

4.2.2.10 Effect of retort pouch sterilisation on rheological property of pulp

The rheological analysis of thermally sterilised ripe jackfruit pulp under varying treatment conditions revealed distinct behaviours in dynamic viscosity. The data indicated that the dynamic viscosity of the pulp was influenced by both the

temperature and the holding time during sterilisation. Specifically, as the temperature and holding time increased, a noticeable reduction in dynamic viscosity was observed, particularly at higher shear rates, suggesting a shear-thinning behavior of the pulp. At lower shear rates, the jackfruit pulp exhibited higher dynamic viscosity values. For instance, at 105°C with a holding time of 5 min the dynamic viscosity was measured at 50.74 ± 0.25 Pa·s. As the shear rate increased the dynamic viscosity decreased significantly to 30.14 ± 0.32 Pa·s, demonstrating the pulp's non-Newtonian, shear-thinning behavior (Fig 4.34) as discussed earlier in pasteurised samples. This trend is consistent with the behavior of many fruit pulps, where molecular interactions are reduced under shear forces, leading to lower resistance to flow. A similar pattern is seen at 120°C and a holding time of 5 min.in RJP. This indicates that increasing shear rate accelerates the breakdown of the pulp's structure, reducing dynamic viscosity (Abdullah *et al*., 2018).

Temperature and holding time played critical roles in influencing the dynamic viscosity of the jackfruit pulp. At 105°C and a holding time of 5 min, the dynamic viscosity was 50.74 ± 0.25 Pa·s but this decreased to 41.76 ± 0.52 Pa·s at 105°C, 15 min. However, at 120 °C and the same holding time (5 min.), dynamic viscosity dropped further to 30.14 ± 0.32 Pa·s. This sharp decline highlights the impact of heat on the molecular structure of the pulp, likely leading to the breakdown of pectin, cellulose, and other structural components (Sato and Cunha 2007).

At higher temperatures, such as 123 °C with a holding time of 10 min, the dynamic viscosity decreased from 51.21 ± 0.23 Pa·s to 27.49 ± 0.41 Pa·s. Fig 4.33 shows that increasing both temperature and holding time can accelerate the reduction in dynamic viscosity, which is important for processes requiring precise control over flow properties. The decrease in dynamic viscosity with increasing temperature can be explained by the enhanced molecular mobility of the pulp constituents, leading to reduced flow resistance. The data supports the shear-thinning behavior of the jackfruit pulp, where the dynamic viscosity decreases as the shear rate increases. This behavior

is typical of non-Newtonian fluids, where increased shear causes alignment of macromolecules such as starches and fibers, resulting in lower dynamic viscosity (Krokida *et al*.,2001).

The ANOVA for the response surface quadratic model of dynamic viscosity data revealed that the model was significant. Among the model terms, temperature and time were highly significant, with p-values of less than 0.0001 and 0.0025, respectively with R^2 value of 0.81 (Table B14). The interaction term and the quadratic terms were not significant, with p-values greater than 0.05, suggesting that they did not contribute significantly to the model. The lack of fit was not significant (p = 0.3166), indicating that the model adequately fits the data. Given the significant terms and the lack of significant lack of fit, the model is reliable in explaining the variation in dynamic viscosity based on temperature and time.

Dynamic viscosity

$$= 37.68 - 8.81 * T_S - 4.59 * t_s + 1.08 * T_S * t_s + 0.079 * T_S^2 + 0.77 * t_s^2 \quad \ldots (4.51)$$

Where, T_s is the sterilisation temperature in ^oC and t_s is the process time in min

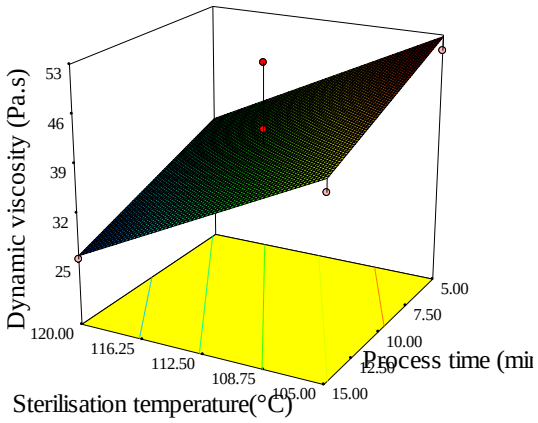
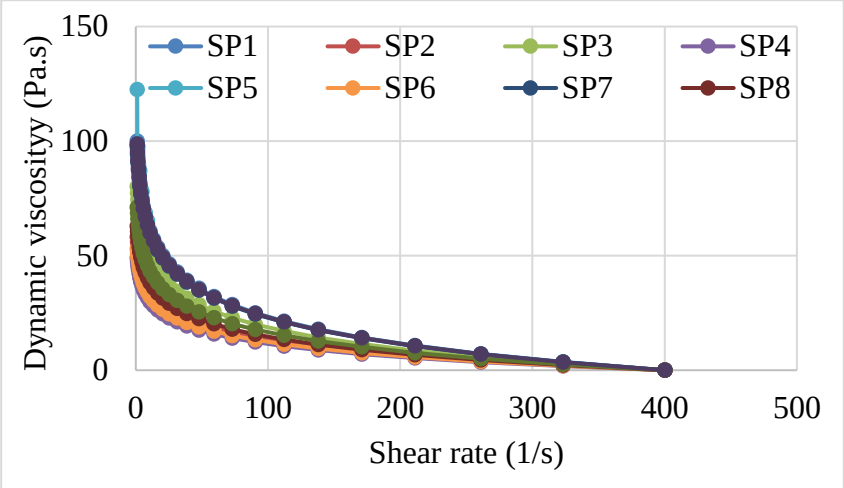


Fig.4.33 Dynamic viscosity of retort sterilised RJP



SP1:105°C/5min., SP2:120°C/5min., SP3:105°C/15min., SP4:120°C/15min., SP5:102°C/10min., SP6:123°C/10min., SP7:112.5°C/3min., SP8:112.5°C/17min.,

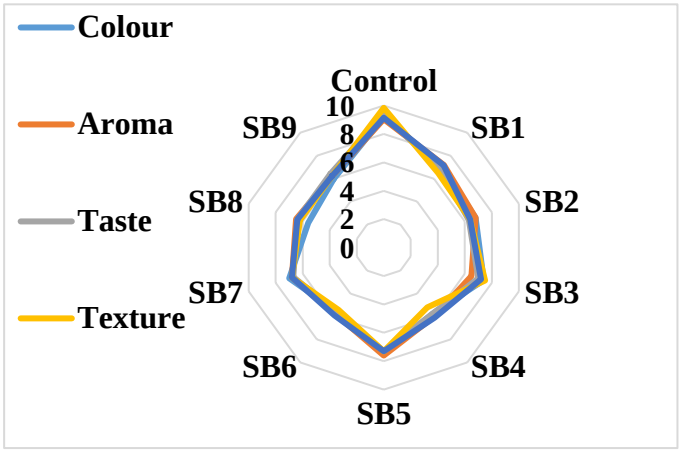
Fig.4.34 Dynamic viscosity vs shear rate of retort pouch sterilised RJP

4.2.2.11 Sensory evaluation of retort pouch sterilised ripe jackfruit

The sensory evaluation of sterilised RJB and RJP was conducted to assess the impact of different sterilisation treatments on key sensory attributes: color, aroma, taste, texture, and overall acceptability. The sensory scores were provided by a panel of trained evaluators, and the results are summarized in the sensory scorecards for both RJB and RJP. The control sample of RJB exhibited the highest sensory scores across all attributes, with particularly high ratings for color (9.21 ± 1.02), aroma (9.04 ± 1.12), taste (9.41 ± 1.03), texture (9.84 ± 1.20), and overall acceptability (9.14 ± 1.04). Among the treated samples, SB1 (105°C, 5 min) and SB3 (105°C, 15 min) showed relatively better scores compared to other treatments. Specifically, SB1 had scores of 7 ± 0.85 for aroma, 7.2 ± 0.47 for taste, 6.8±0.88 for texture, and 7.15 ± 0.74 for overall acceptability, indicating that a moderate sterilisation condition can retain favorable sensory qualities (Fig 4.35). In contrast, SB4 (120°C, 15 min) exhibited the lowest scores for aroma (5.8 ± 1.22), taste (5.8 ± 1.41), texture (5.21 ± 1.04), and overall acceptability (6.1 ± 1.11), suggesting that higher temperatures and prolonged times

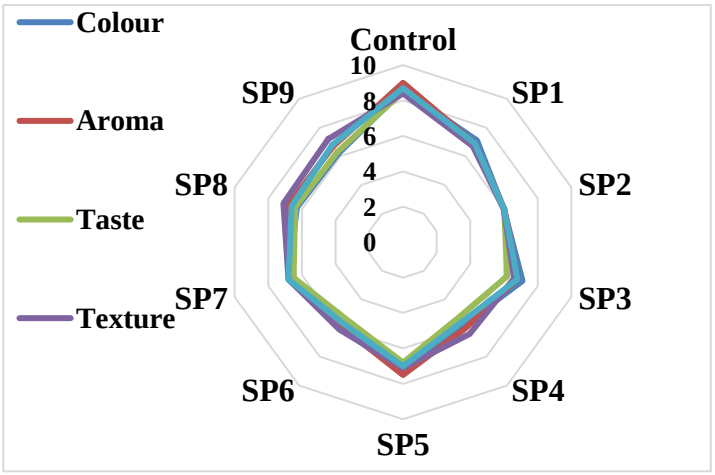
may negatively impact the sensory attributes of jackfruit bulbs. For RJP, the control sample again received the highest scores across all sensory attributes, with notable ratings in aroma (9 ± 1.14), taste (8.5 ± 1.41), texture (8.4 ± 2.01), and overall acceptability (8.7 ± 2.11). Among the treated samples, SP5 (102°C, 10 min) had a relatively high overall acceptability score of 7.01 ± 1.20, indicating a balanced treatment condition that preserves sensory qualities. On the other hand, SP4 (120°C, 15 min) had the lowest scores in aroma (5.8 ± 1.23), taste (5.3 ± 1.25), texture (5.3 ± 1.04), and overall acceptability (5.6 ± 1.44), further emphasizing that high temperatures and extended sterilisation times detrimentally affect the sensory attributes of jackfruit pulp (Fig 4.36). The data suggest that lower to moderate sterilisation temperatures and shorter times generally preserve the sensory qualities of jackfruit bulbs and pulp better than higher temperatures and longer durations. For RJB, the optimal treatment appears to be SP1 (105°C, 5 min) as it balances sensory attributes while maintaining a high level of overall acceptability. Similarly, for RJP, treatment SP5 (102°C, 10 min) emerges as the most favorable, providing a good balance of sensory attributes.

These findings align with previous research indicating that thermal sterilisation parameters significantly influence the sensory and nutritional quality of fruits and vegetables (Ma *et al*, 2020). Specifically, controlled heat treatments can enhance or preserve desirable sensory characteristics while minimizing the degradation of essential nutrients and sensory qualities. By optimizing sterilisation conditions, it is possible to produce sterilised jackfruit products that meet consumer expectations for sensory quality, thereby enhancing their marketability and acceptance. The statistical analysis of sterilised RJB and RJP provides key insights for treatment standardization. ANOVA results indicate that temperature and time significantly impact all sensory attributes (color, aroma, taste, texture, and overall acceptability) ($p < 0.0001$).



SB1:105°C/5min., SB2:120°C/5min., SB3:105°C/15min., SB4:120°C/15min., SB5:102°C/10min., SB6:123°C/10min., SB7:112.5°C/3min., SB8:112.5°C/17min., SB9:112.5°C/10min.

Fig.4.35 Sensory analysis of retort pouch sterilised RJB



SP1:105°C/5min., SP2:120°C/5min., SP3:105°C/15min., SP4:120°C/15min., SP5:102°C/10min., SP6:123°C/10min., SP7:112.5°C/3min., SP8:112.5°C/17min., SP9:112.5°C/10min.

Fig.4.36 Sensory analysis of retort pouch sterilised RJP

4.2.3 Process optimization

The process optimization for sterilised ripe jackfruit bulbs involved determining the optimal combination of sterilisation parameters to achieve desired quality attributes. The analysis indicated that the selected solution presented an ideal set of conditions, including a temperature of 106°C, a sterilisation time of 7 min, and

a pH of 5.02. It was reported that the TSS and TA were set at 21.76 and 0.567, respectively, to ensure the product's sweetness and acidity were within acceptable ranges. The colour parameters (L*, a*, b*) were optimized to maintain the natural appearance of the jackfruit bulb, while undesirable attributes such as ΔE (1.68) and BI (96.48) were minimized. The report also indicated that beneficial attributes like YI (107.21), AA at 13.40 mg/100g, TPC at 68.85 mg GAE/g, TFC at 38.76, mg RE/g DPPH at 86.86%, total sugar at 18.82%, and firmness at 52.42 N were maximized. The overall desirability of this solution was reported to be 0.825, indicating a high degree of suitability and balance among the various quality parameters. The optimal conditions for sterilised RJP were determined to be 106°C for 5 min., yielding a desirability value of 0.956 and for RJB it was 106ºC for 7 min. Under these conditions, the AA, TPC, and TFC reached their peak levels, while microbial load was minimised. It was concluded that this comprehensive optimization ensured that the sterilised ripe jackfruit samples had superior quality, balancing nutritional value, sensory properties, and shelf life.

4.2.4 Cost analysis

The cost analysis and BCR for processed RJB and RJP demonstrate significant profitability potential. The production cost for retort pouch sterilised RJB is approximately ₹211/kg, while the market price of RJB in syrup is around ₹700/kg. This results in a BCR of 3.3, indicating that for every ₹1 spent on production, a return of ₹3.3 is generated, highlighting a substantial profit margin. In contrast, the RJP production cost is Rs 235/kg has a market price of ₹226/kg, also yielding a BCR of 1.13. However, this suggests a smaller profit margin compared to the bulb (Appendix G). Overall, both products are profitable, but the RJB, particularly when sold in syrup, offers significantly higher returns than the pulp.

4.3 Effect of storage on retort pouch pasteurised and sterilised ripe jackfruit samples

Ripe jackfruit samples processed under retort pouch pasteurisation processing were standardised as 80ºC for 5 min, in RJB and 80ºC for 12 min for RJP. Similarly, the retort pouch sterilisation process for ripe jackfruit samples was optimised as 106ºC for 7 min for RJB and 106ºC for 5 min for RJP. In this study, the quality analysis of optimised samples of retort pouch pasteurised and sterilised RJB and RJP was analyzed over a period of 180 days under refrigerated (4 ± 2ºC, Relative humidity:95%) and ambient storage (30± 2ºC, Relative humidity:70%) conditions, respectively. The result and discussion of the shelf-life analysis of the optimised samples are described under this session.

4.3.1 Effect of storage on pH, TA and TSS on retort pouch pasteurised and sterilised ripe jackfruit samples

In this study, the pH values, TA, and TSS of retort pouch pasteurised and sterilised RJB and pulp were analysed over 180 days under refrigerated and ambient storage conditions respectively. The results showed that all three parameters remained stable throughout the storage period, with no significant changes observed.

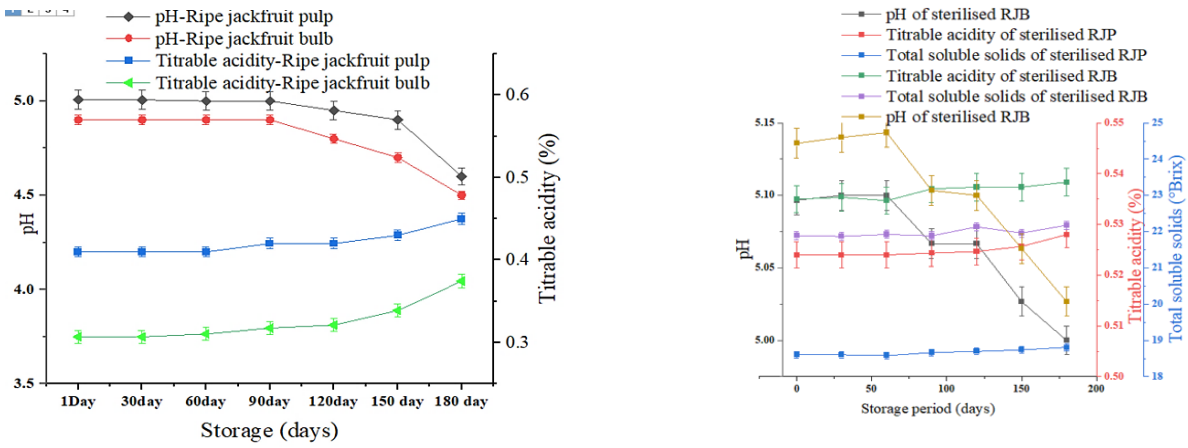
The pH values of sterilised and retort pouch pasteurised RJB and pulp were analysed for 180 days under ambient storage and refrigerated conditions, respectively. For retort pouch pasteurised samples, the pH of freshly prepared RJP remained stable at pH 5 ± 0.22 during refrigerated storage for up to 10 days, before declining to 3.20 ± 0.16, indicating spoilage. In contrast, fresh jackfruit bulbs were stable for up to 15 days, with pH values ranging from 4.82 ± 0.23 to 3.74 ± 0.18 during storage. Retort-processed RJB and RJP showed pH ranges of 4.5±0.21- 4.9 ± 0.17 and 4.6 ± 0.23 - 5.01 ± 0.13, respectively. retort pouch pasteurised jackfruit pulp and bulb exhibited minimal pH variation throughout most of the storage period, with noticeable changes occurring towards the end. The p-value suggests that storage time has a non-significant impact on the pH of retort pouch pasteurised jackfruit pulp, possibly due to microbial activity or chemical changes over time.

In contrast, the pH values of sterilised RJP and RJB remained stable throughout the storage period, with no significant changes observed. The initial pH values of the RJP and RJB were 5.0 ± 0.57 and 4.9 ± 0.18, respectively. After 180 days of storage, the pH values of the RJP ranged from 5.09 ± 0.18 to 5.00 ± 0.23, while the RJB showed pH values ranging from 5.14 ± 0.23 to 5.03 ± 0.18 (Fig 4.37b). Across all treatments, a gradual decrease in pH was observed over 180 days of storage, likely due to mesophilic bacteria metabolizing nutrients such as sugars, producing organic acids, and subsequently lowering the pH (Kaddumukasa *et al*., 2017).

Regarding retort pouch pasteurised samples, the TA of the fresh pulp was initially 0.621 ± 0.11%, increasing to 0.75 ± 0.32 % after 10 days. Similarly, the TA of RJB rose from 0.63 ± 0.03% to 0.68 ± 0.29% after 15 days, leading to bulged packets that were considered spoiled. Concerning retort pouch pasteurised samples, the TA values varied from 0.42 ± 0.03 to 0.59 ± 0.02% in RJB and 0.41 ± 0.02 to 0.62 ± 0.03% in RJP. (Fig. 4 .37a). The TA of the ripe jackfruit samples remained stable during storage, with a slight increase noted after 150 days. There was no significant variation in TA immediately after processing and up to the 90^{th} day. The final increase in acidity can be attributed to a rise in the concentration of weakly ionized acids and their salts during storage. This indicates that storage significantly impacts the TA of retort pouch pasteurised jackfruit pulp, likely due to the formation of organic acids or other biochemical changes during storage (Yi *et al*., 2017). Initially, the sterilised fresh pulp and bulb exhibited similar TA values, with 0.57 ± 0.02% and 0.58 ± 0.02%, respectively. During storage, the TA of the pulp underwent a slight fluctuation, ranging from 0.53 ± 0.01% on day 60 to 0.54 ± 0.11% on day 180. Similarly, the TA of the bulb showed a minor variation, starting at 0.52 ± 0.03% on day 0 and reaching 0.52 ± 0.02% by day 180. Notably, the variation in TA values across the sterilised samples was found to be non-significant, suggesting that the TA remained relatively stable throughout the storage period, with only minor changes occurring.

The TSS content of fresh RJP initially measured 20.60 ± 0.94°Brix, increasing to 21°Brix after 10 days of storage. In retort pouch pasteurised RJB and retort pouch pasteurised RJP, TSS values ranged from 20 to 20.21 ± 0.53°Brix and 19 ± 0.68 to 20.01 ± 0.69°Brix, respectively, over a four-month storage period (Fig 4.38), with a slight,

non-significant increase observed in all samples. Similarly, for the sterilisation process, the initial TSS values for fresh pulp and bulb were 18.5 ± 0.64°Brix and 21 ± 0.96°Bix, respectively, and during storage, the TSS of the pulp ranged from 18.56 ± 0.49°Brix to 18.83 ± 0.65°Brix, while the TSS of the bulb ranged from 21.90 ± 0.62°Brix to 22.16 ± 0.64°Brix. All treatments exhibited a slight increase in TSS throughout the storage period. This modest rise in TSS is likely due to the hydrolysis of polysaccharides into sugars. Similar observations were reported by Muhammad *et al*. (2011) in apple pulp. As presented in Fig., the data indicate that TSS increased in all samples under storage conditions, suggesting that prolonged storage results in higher soluble solids in fruits due to the ongoing conversion of organic acids into starch and sugar through gluconeogenesis (Johari *et al*., 2023). Overall, the storage duration did not significantly affect the TSS content of the retort pouch pasteurised and sterilised jackfruit pulp, suggesting that the sugar content remains stable during storage.



(a) **(b)**

Fig. 4.37 Effect of storage on pH and TA on retort pouch pasteurised and pH, TA and TSS of retort pouch sterilised ripe jackfruit samples respectively

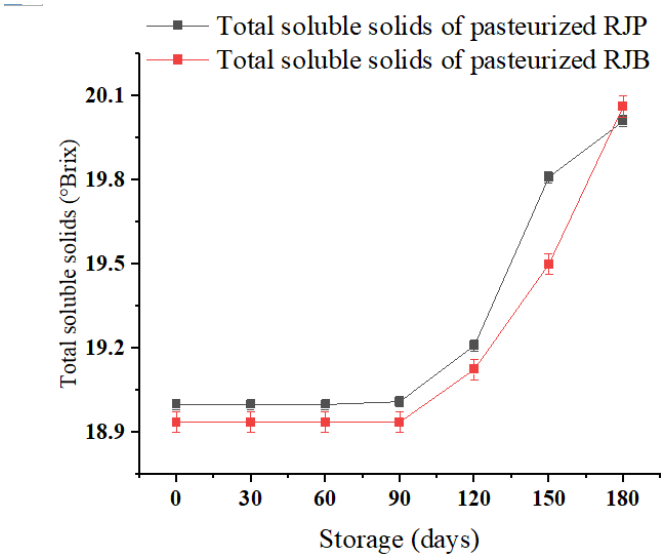


Fig. 4.38 Effect of storage on TSS of retort pouch pasteurised ripe jackfruit samples

4.3.2 Effect of storage on ΔE value on retort pouch pasteurised and sterilised ripe jackfruit samples

The ΔE value was a critical index to evaluate the colour change. The ΔE of fresh RJP increased to 5.8 ± 1.29 and 5.3 ± 1.82 in fresh RJB following 15 days of storage. The changes in ΔE of retort pouch pasterurised ripe jackfruit samples during 180 days of refrigerated storage were presented in Fig 4.39. The research study on the storage of retort pouch pasteurised RJB and RJP indicated notable changes in colour deviation over time. For RJB, it was reported that the initial colour deviation values remained relatively stable, with values of 2.30±1.70 on the 0^{th} and 30^{th} days and a slight increase to 2.40 ± 1.29 on the 60^{th} day. However, a significant deviation began from the 90^{th} day (3.05 ± 1.11), further increasing to 3.50 ± 0.86 on the 120^{th} day, 4.20 ± 1.71 on the 150^{th} day, and reaching the highest deviation of 5 ± 1.56 on the 180^{th} day. Similarly, for RJP, the colour deviation reportedly started at 1.61 ± 1.02 on the $0t^{h}$ day, showing minor changes up to the 90^{th} day with values of 1.62 ± 1.23, 1.63 ± 1.31, and 1.73 ± 0.85, respectively. A marked deviation was observed from the 120^{th} day (2.52 ± 1.65), which significantly increased to 3.82 ± 1.13 on the 150^{th} day, and peaked at 4.27 ± 1.71 on the

180th day. The homogeneous subsets analysis confirmed that the changes in colour deviation for both RJB and RJP were statistically significant ($p<0.05$) only after prolonged storage, with significant differences emerging after the 90th day. This analysis underscored a clear trend of increasing colour deviation with extended storage time, highlighting the impact of storage duration on the quality of retort pouch pasteurised jackfruit bulbs and pulp.

The findings showed that treated jackfruit samples exhibited a darker colour compared to untreated samples, a trend also observed in studies on kiwi fruit juice (Xu *et al*., 2023). Additionally, Yi *et al*. (2017) noted an increase in ΔE values in apple juice following treatment with thermal pasteurisation.

The analysis of total colour deviation in sterilised RJB and RJP during 180 days of ambient storage revealed a range of colour deviations from 6.00 ± 0.27 to 6.31 ± 0.07 for the pulp and from 2.17 ± 1.29 to 2.25 ± 0.10 for the bulb, as measured from the 0th day to the 180th day, respectively. The ANOVA results indicated no significant ($p<0.05$) differences between the groups for both the pulp and bulb samples, with F-values of 0.251 and 0.015 and corresponding p-values of 0.951 and 1.000, respectively. The Duncan multiple range test further confirmed the lack of significant differences in colour deviation across different storage periods. These findings suggest that the sterilised RJP and RJB maintained consistent colour stability throughout the 180-day ambient storage period. Chang *et al*. (2017) found no significant changes in ΔE values for thermally treated white grape juices during a 20-day storage period, whereas the ΔE values for retort pouch pasteurised pineapple juice increased noticeably after 21 days.

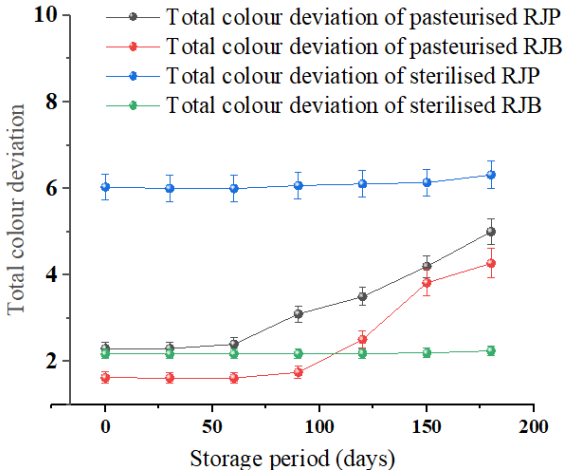


Fig.4.39 Effect of storage on ΔE on retort processed ripe jackfruit samples

4.3.3 Effect of storage on AA of retort pouch pasteurised and sterilised ripe jackfruit amples

The AA content of RJB and RJP decreased significantly over a 180-day storage period, regardless of whether they were retort pouch pasteurised or sterilised. The AA content of the fresh pulp was 10.32 ± 0.27 mg/100 g, which decreased to 6.28 ± 0.19 after 10 days of refrigerated storage, whereas for RJB, it decreased from 14.43 ± 0.52 to 8.45 ± 0.30 mg/100 g after 15 days. The effect of the storage period at refrigerated conditions for 180 days on the AA content of ripe jackfruit samples was found to be significant. In retort pouch pasteurised RJB, the AA content decreased from 14.09±0.64 mg/100 g to 12.91 ± 0.46 mg/100 g, while in sterilised RJB, it decreased from 13.11 ± 0.57 mg/100 g to 10.62 ± 0.49 mg/100 g. Similarly, in retort pouch pasteurised RJP, the AA content decreased from 9.90 ± 0.43 g/100 g to 6.32 ± 0.27 mg/100 g (Fig. 4.40), while in sterilised RJP, it decreased from 11.03 ± 0.38 mg/100 g to 8.75 ± 0.23 mg/100 g.

Regarding retort pouch pasteurised RJP, the analysis revealed that the AA content showed notable stability in the initial storage days, with values of 9.90 ± 0.43 mg/100g on the 0^{th} day and 9.85 ± 0.45 mg/100 g on the 60^{th} day. However, a significant decrease was observed from the 90^{th} day, continuing to decline to 8.25 ± 0.21 mg/100 g on the 120^{th} day, 7.58 ± 0.34 mg/100 g on the 150^{th} day, and reaching the lowest value of 6.32 ± 0.28 mg/100 g on the 180^{th} day. In the case of RJB, the initial AA content was

also relatively high, starting at 14.09 ± 0.61mg/100 g on the 0th day and 14.05 ± 0.52 mg/100 g on the 60th day. The AA content then showed a marked decline, dropping to 13.67±0.62 mg/100 g on the 90th day and 13.65 ± 0.49 mg/100 g on the 120th day. This downward trend continued, with values of 13.26 ± 0.60 mg/100 g on the 150th day and 12.91 ± 0.44 mg/100 g on the 180th day, indicating a significant reduction over the storage period.

The analysis revealed that the AA content of sterilised RJB showed notable stability in the initial storage days, with values of 13.11 ± 0.57 mg/100 g on the 0th day and 13.12 ± 0.60 mg/100 g on the 60th day (Fig 4.41). However, a significant decrease was observed from the 90th day (12.84 ± 0.33 mg/100 g), continuing to decline to 12.65 ± 0.45 mg/100 g on the 120th day, 12.06 ± 0.42 mg/100 g on the 150th day, and reaching the lowest value of 10.62 ± 0.38 mg/100 g on the 180th day. In the case of RJP, the initial AA content was also relatively high, starting at 11.03 ± 0.29 mg/100 g on the 0th day and 10.87 ± 0.45 mg/100 g on the 60th day. The AA content then showed a marked decline, dropping to 10.87±0.49 mg/100g on the 90th day and 10.87 ± 0.50 mg/100 g on the 120th day. This downward trend continued, with values of 9.72 ± 0.25 mg/100 g on the 150th day and 8.75 ± 0.38 mg/100 g on the 180th day, indicating a significant reduction over the storage period.

In both retort pouch pasteurised and sterilised samples, the AA content remained relatively stable during the initial storage days, but began to decline significantly after the 90th day. The rate of decline was more pronounced in retort pouch pasteurised samples, with a 29.38% reduction in RJP and a 10.50% reduction in RJB over the 180-day storage period. In sterilised samples, the reduction was 19.38% in RJP and 10.50% in RJB. The study demonstrates that storage time has a significant impact on the nutritional quality of RJB and pulp, with significant degradation occurring after the initial three months of storage. This reduction in AA content may be due to oxidation in the presence of oxygen by enzymatic catalyst (Jawaheer *et al*., 2003).

4.3.4 Effect of storage on TPC of retort pouch pasteurised and sterilised ripe jackfruit samples

The research investigated the impact of storage time on TPC in retort pouch pasteurised and sterilised RJB and RJP. The research study on the storage of retort pouch pasteurised RJB and RJP analysed the changes in TPC over time, yielding significant insights into the degradation patterns. The control sample (fresh bulb) with a TPC of 71.11 ± 2.56 mg GAE/g decreased to 66.41 ± 2.39 mg GAE/g in 15 days, showing a variation of 6.60%. The fresh pulp with a TPC of 68.53 ± 2.47 mg GAE/g decreased to 55.14 ±1.98 mg GAE/g in 10 days, showing a variation of 15.16%. For RJB, the TPC values during the 180 days of storage ranged from 70.55 ± 3.07 mg GAE/g to 64.24 ± 2.31mg GAE/g , compared to the control sample, representing a reduction of approximately 9.66%. For RJP, the TPC values ranged from 65.11 ± 1.72 mg GAE/g to 57.82 ± 2.52 mg GAE/g over the storage period, compared to the control sample, indicating a reduction of approximately 15.64%.

Statistical analysis through ANOVA for RJB indicated a significant effect of storage time on TPC. The initial TPC values for RJB were relatively stable, starting at 70.53 ± 1.86 mg GAE/g on the 0^{th} day and 70.55 ± 3.23 mg GAE/g on the 30^{th} day. However, a noticeable decline began by the 120th day (69.27 ± 2.49 mg GAE/g), and this trend continued, dropping to 66.52 ± 3.04 mg GAE/g on the 150^{th} day and further to 64.24 ± 2.80 mg GAE/g on the 180^{th} day.

In the case of RJP, ANOVA results showed an even more pronounced impact of storage time on TPC. The initial TPC values were 65.11 ± 1.72 mg GAE/g on the 0^{th} day and 65.10 ± 1.71mg GAE/g on the 30^{th} day, maintaining relative stability until the 60^{th} day (65.02 ± 1.72 mg GAE/g). However, from the 90^{th} day onwards, there was a marked decrease, with TPC values dropping to 64.83 ± 1.24 mg GAE/g, followed by 63.73 ± 2.92 mg GAE/g on the 120^{th} day. The most significant reductions were observed on the 150^{th} and 180^{th} days, with TPC values of 58.45 ± 1.54 mg GAE/g and 57.82 ± 2.64 mg GAE/g , respectively.

Sterilisation also had a notable effect on TPC. The TPC of sterilised jackfruit pulp decreased from 68.53 ± 3.14 mg GAE/g to 42 ±1.51 mg GAE/g over the first three

days of storage, representing an 38.6% loss (Fig 4.40). The TPC of the pulp ranged from 56.93 ± 2.05 mg GAE/g on the 180th day to 64.03± 2.30 mg GAE/g on the 0^{th} day, indicating an 11.1% loss. The bulb, which started with a TPC of 70.11 ± 3.21 mg GAE/g, decreased to 54 ± 1.42 mg GAE/g in the first three days, representing a 23.1% loss, and ranged from 61.79 ± 1.63 mg GAE/g on the 180^{th} day to 68.06 ± 3.11mg GAE/g on the 0^{th} day, indicating a 9.2% loss. These findings suggest that ambient storage significantly reduces TPC in both sterilised pulp and bulb, highlighting the impact of prolonged storage on the phenolic content.

The observed reduction in TPC during storage for both RJB and RJP can be attributed to the oxidation of phenolic compounds, which is likely accelerated by the presence of oxygen and enzymatic activity during prolonged storage (Xu *et al*., 2016). Similarly, the total phenolic content in pasteurised mango pulp also reduced with storage due to the oxidation degradation of phenolic compounds and the polymerization of phenolic compounds with proteins (Kaushik *et al*., 2016)

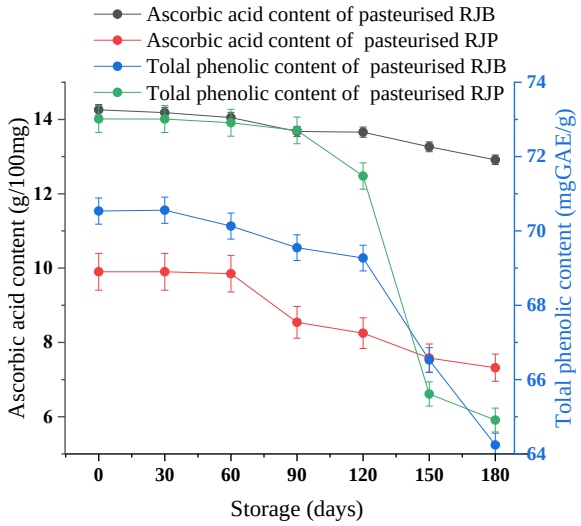


Fig.4.40 Effect of storage on AA and TPC on retort pouch pasteurised ripe jackfruit samples

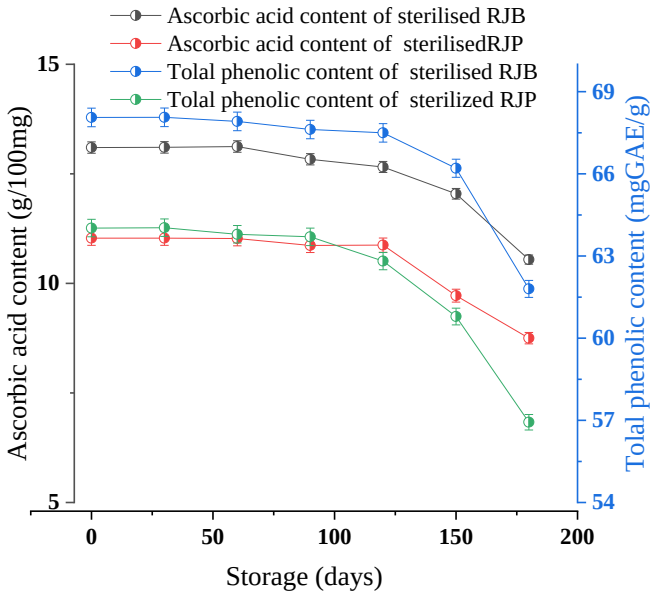


Fig. 4.41 Effect of storage on AA and TPC on retort pouch sterilised ripe jackfruit samples

4.3.5 Effect of storage on total sugar content of retort pouch pasteurised and sterilised ripe jackfruit samples

The total sugar content in pasteurised RJB ranged from 19.87 ± 0.86 to 20.84 ± 0.72%, while for RJP, it ranged from 21.29 ± 0.76 to 23.44 ± 0.62%. The total sugar content in RJB initially showed stability with values of 19.87 ± 0.86% on the 0th day, 19.88 ± 0.86% on the 30th and 60th days, and a slight increase to 20.05 ± 0.72% on the 90th day. This trend continued with values reaching 20.45 ± 0.54% on the 120th day, 20.72 ± 0.74% on the 150th day, and 20.84 ± 0.75% on the 180th day. For RJP, the total sugar content started at 21.29 ± 0.76% on the 0th day, remained similar at 21.29 ± 0.76% on the 30th day, and slightly increased to 21.42 ± 0.56% on the 60th day. The upward trend persisted with values rising to 21.52 ± 0.98% on the 90th day, 21.62 ± 0.99% on the 120th day, 22.61 ± 1.01% on the 150th day, and peaking at 23.44 ± 10.2% on the 180th day. The control sample (fresh pulp) with total sugar content of 22.56 ± 1.03% increased to 23.11 ± 0.83% in 10 days, and 21.33 ± 0.76% in control (fresh bulb) increased to 21.95 ± 0.95% in 15 days. The statistical analysis of total sugar content in pasteurised RJB and RJP during storage revealed notable variations.

The analysis of total sugar content in sterilised RJB and RJP during 180 days of ambient storage revealed a range from 20.07 ±0.69% to 20.14 ± 0.53% and from 18.75 ± 0.85% to 18.82 ± 0.49%, respectively (Fig. 4.42). The ANOVA results indicated no significant difference in total sugar content among the storage days for both samples, with p-values of 1.000 in both analyses. Specifically, the total sugar content in the pulp showed a slight variation, with the mean values recorded as 20.07 ± 0.71% on the 0^{th} and 60^{th} days, 20.08 ± 0.53% on the 30^{th} day, 20.10 ± 0.72% on the 90^{th} day, 20.11±0.53% on the 120^{th} day, 20.12 ± 0.53% on the 150^{th} day, and 20.14 ± 0.87% on the 180^{th} day. For the bulb, the mean values were 18.75 ± 0.51% on the 0^{th} day, 18.77 ± 0.86% on the 60^{th} day, 18.77 ± 0.49% on the 30^{th} day, 18.79 ± 0.86% on the 90^{th} day, 18.80 ± 0.67% on the 150^{th} day, 18.81 ± 0.86% on the 120^{th} day, and 18.82 ± 0.88% on the 180^{th} day. The Levene's test for homogeneity of variances for the bulb indicated a significant result with a p-value of 0.023, suggesting some variability in sugar content consistency. However, the homogeneous subsets analysis using Duncan's multiple range test confirmed that the storage days did not significantly differ in total sugar content at the 0.05 significance level, with the subsets showing p-values of 0.955 and 0.959 for the pulp and bulb, respectively. These findings suggest that the total sugar content in both sterilised RJP and bulb remains stable over a 180-day period under ambient storage conditions.

Over a five-month storage period, the total sugar content in the soft bulb type jackfruit pulp from the Western Ghats increased to 20.93%. This increase could be attributed to the conversion of some acids into sugars. Similar findings have been reported in other fruits: Kavya (2014) observed an increase in the total sugar content of custard apple, Hiremath *et al*. (2012) documented this phenomenon in sapota.

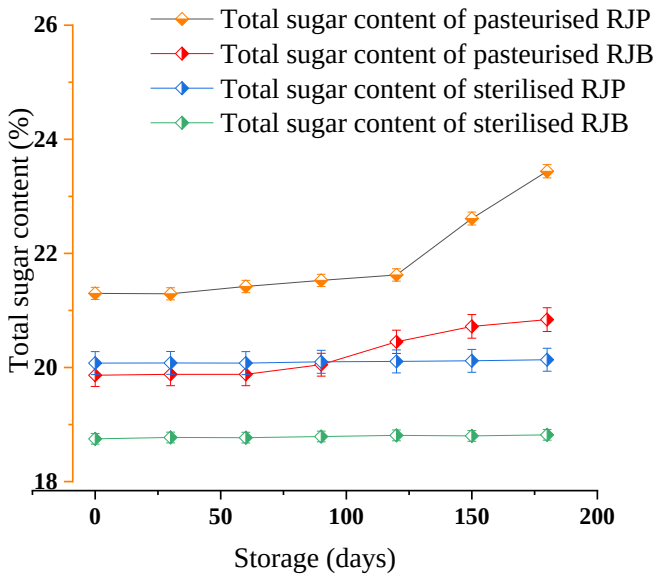


Fig.4.42 Effect of storage on total sugar content of retort pouch pasteurised and sterilised ripe jackfruit samples

4.3.6 Effect of storage on microbial activity of retort pouch pasteurised and sterilised ripe jackfruit samples

The microbial analysis of retort pouch pasteurised RJP and RJB during refrigerated storage revealed distinct patterns in the TAM and yeast and mold populations. In the control sample of jackfruit pulp, the TAM increased from 5.1 ± 1.30 log CFU/g on day 0 to 8.60 ± 1.83 log CFU/g by day 10, resulting in spoilage by day 15. In contrast, the retort pouch pasteurised RJP showed no detectable microbial growth (<1 log CFU/g) up to 60 days of storage (Table 4.6). However, TAM began to rise to 1.55 ± 1.07 log CFU/g at 90 days, reaching 3.14 ± 1.08 log CFU/g by 180 days. Similarly, yeast and mold populations were not detectable in the retort pouch pasteurised pulp up to 60 days, but increased to 1.43 ± 1.06 log CFU/g at 90 days and 3.05 ± 5.19 log CFU/g at 180 days. In the control sample of jackfruit bulb, the TAM increased from 4.8±1.21 log CFU/g on day 0 to 5.62±1.14 log CFU/g by day 15. In contrast, the retort pouch pasteurised RJB exhibited no detectable microbial growth (<1 log CFU/g) up to 90 days of storage. TAM began to increase to 1.31±1.04 log CFU/g at 120 days and reached 2.48 ± 1.08 log CFU/g by 180 days. Yeast and mold populations

in the retort pouch pasteurised bulb were also undetectable up to 90 days but increased to 1.17 ± 1.05 log CFU/g at 120 days and reached 2.17 ± 1.07log CFU/g at 180 days.

The microbial analysis of retort sterilised RJP and RJB during ambient storage was conducted to determine the TAM and yeast and mold counts (log CFU/g) over various storage periods. The control samples exhibited significant microbial growth, with the pulp showing an initial TAM of 4.6 ± 1.02 log CFU/g and yeast and mold count of 4.5 ± 1.11 log CFU/g. By day 3, these values increased to 20.60 ± 1.94 log CFU/g and 21.23 ± 1.56 log CFU/g, respectively, and for RJB it was 4 ± 1.14 and 4.1 ± 1.15 log CFU/g, which increased to 16.24 ± 0.74and 18.41 ± 1.48 log CFU/g, the sample was spoiled after 3 days (Table 4.7). In contrast, the sterilised RJP displayed TAM and yeast and mold counts of less than one log CFU/g from 0 to 150 days, with slight increases to 1.33 ± 1.06 and 1.16 ± 1.053 log CFU/g at 180 days.

Similarly, the control jackfruit bulb exhibited initial TAM and yeast and mold counts of 4.4 ± 1.20 log CFU/g and 4.2 ± 1.15 log CFU/g, which rose to 12.52 ± 1.57 log CFU/g and 15.48 ± 1.78 log CFU/g by day 3. The sterilised bulb samples maintained TAM and yeast and mold counts of less than 1 log CFU/g from 0 to 150 days, with minor increases to 1.02 ± 1.02 and 1.23 ±1.04 log CFU/g at 180 days.

The results are consistent with findings from other studies. For instance, Wu *et al*. (2021) reported an increase in TAM in TP-treated pineapple juices, reaching 1.85 log CFU/mL after 28 days of storage, with undetectable yeast and mold and coliform counts for the first 21 days. Similarly, Monteiro *et al*. (2005) observed that passion fruit pulp retort pouch pasteurised at 70°C maintained yeast and mold and aerobic psychrophilic counts below 10 CFU/mL for up to 180 days of storage, followed by two log cycles of growth from 198 to 207 days. Additionally, Monteiro *et al*. (2005) evaluated the microbiological quality of passion fruit pulps retort pouch pasteurised at 70°C, 75°C, and 80°C, finding that all pulps were suitable for consumption for up to 180 days under refrigeration.

According to the Food Safety and Standards Authority of India (FSSAI), the acceptable limit for TAM in ready-to-eat foods is generally up to 5 log CFU/g, and for yeast and mold, it is up to 3 log CFU/g. Based on these standards, the retort pouch

pasteurised jackfruit pulp and bulb were safe for consumption up to 150 days of storage. Beyond this period, the increase in microbial counts, especially in yeast and mold populations, suggests that the products may not be safe for consumption due to potential spoilage and safety concerns. The results indicate that retort sterilisation effectively reduced microbial loads in both jackfruit pulp and bulb, ensuring microbial stability and safety for up to 180 days under ambient storage conditions. The slight increase observed at 180 days suggests minimal microbial activity, but the overall log reduction confirms the efficacy of the sterilisation process in preserving the quality and safety of the jackfruit products.

Table 4.6 Effect of storage on microbial activity of retort pouch pasteurised ripe jackfruit samples

Sample	storage period (days)	Total aerobic mesophiles (log CFU/g)	Yeast and mold (log CFU/g)
Control sample (Fresh pulp)	0	5.1 ± 1.30^{a}	5.3 ± 2.15^{a}
	10	8.60 ± 1.83^{a}	7.43 ± 3.14^{a}
	15	spoiled	Spoiled
Retort pouch pasteurised RJP	0	<1	<1
	30	<1	<1
	60	<1	<1
	90	1.55 ± 1.07^{a}	1.43 ± 1.06^{a}
	120	1.81 ± 1.02^{a}	1.72 ± 0.95^{a}
	150	1.88 ± 1.35^{b}	2.16 ± 1.4^{a}
	180	3.14 ± 1.08^{b}	3.05 ± 5.19^{a}
Control sample (Fresh bulb)	0	4.8 ± 1.21^{a}	4.6 ± 1.02^{a}
	10	5.24 ± 2.05^{a}	5.30 ± 2.07^{a}
	15	5.62 ± 1.14^{a}	6.43 ± 1.35^{a}
Retort pouch pasteurised RJB	0	<1	<1
	30	<1	<1
	60	<1	<1
	90	<1	<1
	120	1.31 ± 1.04^{a}	1.17 ± 1.05^{a}
	150	2.01 ± 1.85^{a}	2.39 ± 1.25^{a}
	180	2.48 ± 1.08^{c}	2.17 ± 1.07^{c}

Table 4.7 Effect of storage on microbial activity of retort pouch sterilised ripe jackfruit

Samples	storage period	TAM (log CFU/g)	Yeast and mold (log CFU/g)
Control sample (Fresh pulp)	0	4.6 ± 0.02[a]	4.5 ± 0.11[a]
	3	20.60 ±1.94[a]	21.23 ± 1.56[a]
Sterilised RJP	0	<1	<1
	30	<1	<1
	60	<1	<1
	90	<1	<1
	120	<1	<1
	150	1.33 ± 1.06[a]	1.16 ± 1.05[a]
	180	1.14 ± 1.25[a]	1.05 ± 1.87[a]
Control sample (Fresh bulb)	0	4.4 ± 1.20[a]	4.2 ± 1.15[a]
	3	12.52 ± 1.57[a]	15.48 ± 1.78[a]
Sterilised RJB	0	5.62±1.11[a]	6.43 ± 2.35[a]
	30	<1	<1
	60	<1	<1
	90	<1	<1
	120	<1	<1
	150	<1	<1
	180	1.02 ± 1.02[a]	1.23 ± 1.04[a]

4.3.7 Effect of storage on firmness of retort pouch pasteurised and sterilised RJB

The firmness of the jackfruit bulbs was significantly affected by the storage period and the processing method. The control sample (fresh RJB) showed the highest firmness (55.46 ± 2.54 N) at the beginning of the storage period, but it decreased steadily with increasing storage time. At the end of the 180 days storage period, the firmness of the control sample dropped to 48.25 ± 2.38 N, representing a 12.97%

reduction in firmness. The retort pouch pasteurised RJB showed an initial firmness of 54.55 ± 2.49 N, which is slightly lower than the control sample. The firmness decreased to 48.18 N after 180 days, exhibiting a reduction of 11.66% in firmness. The sterilised RJB showed the lowest initial firmness of 51.24 ± 2.42 N. It maintained a relatively stable firmness throughout the storage period, dropping to 49.65 ± 2.27 N after 180 days, demonstrating a mere 3.1% reduction in firmness (Fig 4.43). Overall, the results indicate that the storage period had a significant effect on the firmness of all three samples, leading to a decrease in firmness over time. The pasteurisation process slightly lowered the initial firmness compared to the fresh sample, but resulted in a slightly less significant decrease in firmness over time compared to the fresh sample. Notably, the sterilised jackfruit bulb exhibited the slowest rate of firmness reduction, indicating its superior preservation of firmness throughout the storage period.

The statistical analysis of the retort pouch pasteurised and sterilised jackfruit bulb data revealed distinct patterns. For retort pouch pasteurised bulbs, the ANOVA test indicated a significant difference in firmness across different storage times, suggesting that storage time had a significant impact on firmness. In contrast, the ANOVA test for sterilised bulbs showed no significant difference in firmness across storage times, indicating that the sterilisation process maintained consistent firmness levels regardless of storage time. Additionally, the Levene's test for homogeneity of variances showed that the variances of firmness were not significantly different for both retort pouch pasteurised and sterilised bulbs. Overall, the analysis highlights the importance of considering the effects of storage time and processing methods on the quality of jackfruit bulbs.

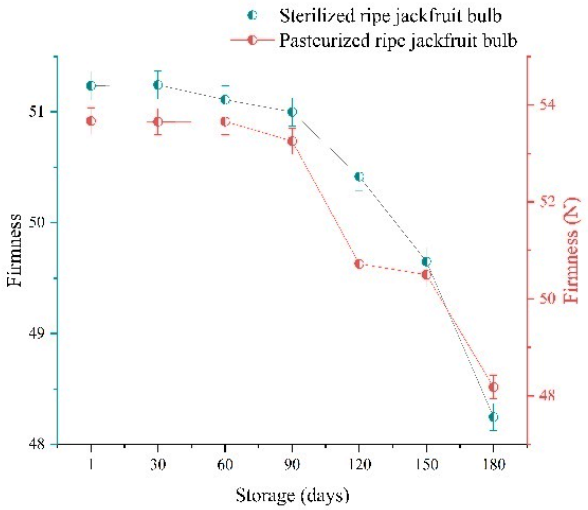


Fig 4.43 Effect of storage on firmness of retort pouch pasteurised and sterilised RJB

4.3.8 Effect of storage on sensory characteristics of retort pouch pasteurised and sterilised ripe jackfruit samples

The study on the sensory evaluation of retort pouch pasteurised RJB and RJP during storage yielded promising initial results, showcasing high acceptability and quality. On day 1, RJB demonstrated excellent overall acceptability with a score of 7.8 ± 0.22, and notable scores in colour (7.4 ± 0.33), aroma (7.2 ± 0.25), and consistency/texture (7.7±0.20). Similarly, RJP started with an overall acceptability score of 7 ± 0.08, with colour, aroma, and consistency/texture scoring 7 ± 0.25, 7 ± 0.18, and 7.1 ± 0.30, respectively. These high initial scores highlight the effectiveness of the retort pouch processing method in preserving the sensory qualities of jackfruit products. However, a declining trend in sensory scores was observed over the six-month storage period. For RJB, the decrease in colour score from 7.4 ± 0.35 to 6 ± 0.27 can be attributed to pigment degradation and potential non-enzymatic browning (Fig 4.44). The aroma score dropped from 7.2 ± 0.25 to 5.7 ± 0.15, likely due to the volatilization and oxidation of aromatic compounds. The consistency/texture score diminished from 7.7± 0.33 to 6.3 ± 0.21, possibly because of moisture migration and textural changes in the product matrix. Overall acceptability for RJB decreased from 7.8 ± 0.35 to 5.8 ± 0.20, reflecting the cumulative effect of these sensory changes. In the case of RJP, the colour score decreased from 7± 0.15 to 5.8 ± 0.18, which might be due to similar reasons

of pigment degradation. The aroma score reduction from 7 ± 0.25 to 5.92 ± 0.21 can be attributed to the loss of volatile flavor compounds over time. The consistency/texture score fell from 7.1 ± 0.18 to 5.72 ± 0.24, likely due to the breakdown of cell structure and changes in the pulp's physical properties. Consequently, the overall acceptability of RJP decreased from 7 ± 0.32 to 5.6 ± 0.20 (Fig 4.45), demonstrating the impact of these changes on the product's sensory profile. Overall, while the initial sensory qualities of retort pouch processed RJB and RJP were high, the natural decline over storage highlights areas for further research and optimization to enhance shelf life and maintain sensory attributes.

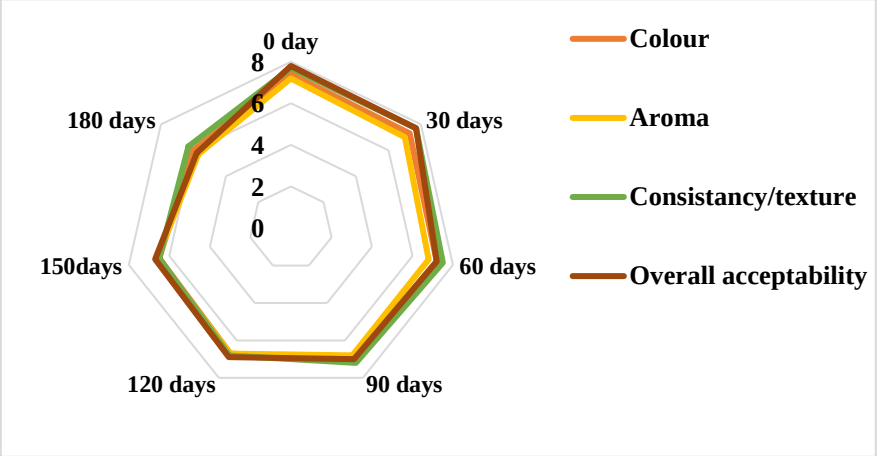


Fig 4.44 Effect of storage on sensory characteristics of retort pouch pasteurised RJB

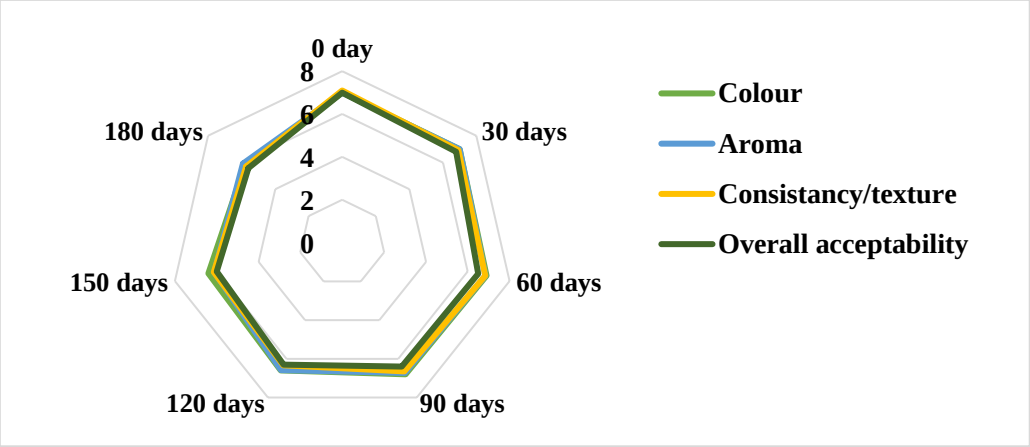


Fig 4.45 Effect of storage on sensory characteristics of retort pouch pasteurised RJP

The study on the sensory evaluation of retort pouch sterilised RJB and RJP during storage showed encouraging initial results, highlighting the effectiveness of the retort sterilisation process in maintaining high sensory quality. On day 1, RJB exhibited high overall acceptability with a score of 7.15 ± 0.19, supported by scores of 7 ± 0.15 for colour, 7.2 ± 0.21 for aroma, and 6.8 ± 0.31 for consistency/texture (Fig 4.46). Similarly, RJP demonstrated strong initial performance with an overall acceptability score of 6.8 ± 0.12, and scores of 6.8±0.24 for colour, 6.5 ± 0.23 for aroma, and 6.5 ± 0.29 for consistency/texture (Fig 4.47).

However, the data revealed a gradual decline in sensory attributes over the storage period. For RJB, the colour score decreased from 7 ± 0.34 to 6.12 ± 0.28 over 180 days, likely due to pigment degradation and non-enzymatic browning. The aroma score fell from 7.2 ± 0.34 to 5.8 ± 0.27, possibly caused by the volatilization and oxidation of aromatic compounds. The consistency/texture score declined from 6.8 ± 0.17 to 5.79 ± 0.26, which may be attributed to moisture loss and textural changes in the product matrix. Consequently, the overall acceptability of RJB decreased from 7.15 ± 0.04 to 5.8 ± 0.26, reflecting these cumulative changes.

In the case of RJP, the colour score dropped from 6.8 ± 0.24 to 5.91 ±0.21, which could be due to similar pigment degradation. The aroma score decreased from 6.5 ± 0.30 to 5.32 ± 0.19, possibly due to the loss of volatile flavor compounds over time. The consistency/texture score reduced from 6.5 ± 0.17 to 5.7 ± 0.06, likely because of the breakdown of cell structure and changes in the pulp's physical properties. As a result, the overall acceptability of RJP declined from 6.8 ± 0.18 to 5.71 ± 0.20 over 180 days, illustrating the impact of these changes on the product's sensory profile. These findings are consistent with previous studies on the storage stability of jackfruit powder, which reported a significant decrease in the intensities of fruity odour, taste, and an increase in lumpiness over time, particularly at higher temperatures and humidity levels. The gradual decline in sensory attributes observed in the current study illustrates the challenges of maintaining quality in retort pouch sterilised jackfruit products during storage (Lakshmana *et al*, 2013)

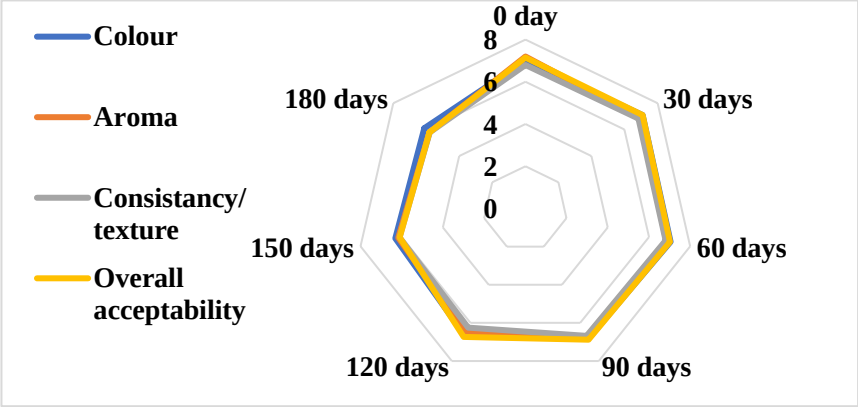


Fig.4.46 Effect of storage on sensory characteristics of retort pouch sterilised RJB

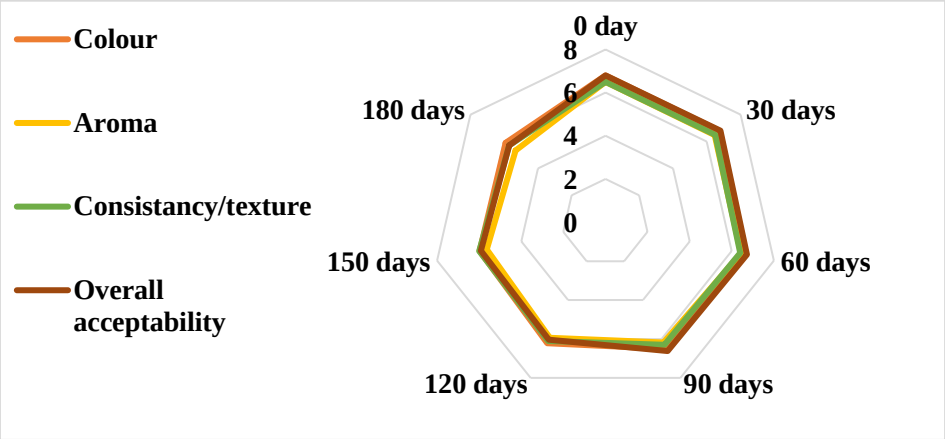


Fig.4.47 Effect of storage on sensory characteristics of retort sterilised RJP

The storage study demonstrated that the retort pouch-processed RJB and RJP maintained their quality and safety for up to 180 days. Throughout the storage period, there were no significant changes in sensory attributes, microbial safety, or physicochemical properties, confirming the effectiveness of retort processing in preserving these products. These findings highlight the potential of retort pouch packaging as a viable method for extending the shelf life of RJB and RJP, ensuring their stability for long-term storage and commercial distribution.

EXPERIMENT II:

4.4 STANDARDISATION OF HPP PARAMETERS FOR RJB AND RJP

This chapter focuses on the physico-chemical properties and economic aspects of high-pressure processed RJBs and RJP. The investigation explores the effects of applying various pressures at different holding times on these properties explained below. Table 4.8 below is the physico-chemical properties of ripe jackfruit samples prior to processing

Table. 4.8 Proximate composition of fresh ripe jackfruit prior to HPP

Sl. No.	Parameter		RJB	RJP
1	pH		5.10 ± 0.23	5.00 ± 0.18
2	TSS (ºBrix)		22.60 ± 0.59	23.00 ± 1.05
3	TA%		0.50 ± 0.013	0.51 ± 0.018
4	TPC (mg GAE/g)		61.63 ±2.82	64.78 ± 3.06
5	TFC (mg RE/g)		34.89 ±1.69	17.06 ± 0.61
6	Ascorbic acid (mg/100 g)		13.68 ± 0.64	7.84 ± 0.38
7	Colour	L^*	33.06 ± 1.61	48.56 ± 1.75
		a^*	8.01 ± 0.367	8.13 ± 0.37
		b^*	51.83 ± 1.79	56.65 ±1.49
8	Total Sugar (%)		25.49 ± 1.11	22.62 ± 0.59

Where RJB: Ripe jackfruit bulb, RJP:Ripe jackfruit pulp; Data shown are the mean±SD of three treatment repetition

4.4.1 Effect of HPP on quality characteristics of ripe jackfruit

4.4.1.1 Effect of HPP on pH, TA, and TSS of ripe jackfruit

Assessing pH and TA is crucial, as these factors can influence the microbial growth and stability of food products. Consequently, the pH and TA of ripe jackfruit samples (RJB and RJP) were examined before and after processing. The initial pH of the fresh RJB and RJP was 5.10 ± 0.23 and 5.00 ± 0.18, respectively. Following high-pressure treatment, these values varied from 4.80 ± 0.22 to 5.20 ± 0.03 in RJP and 4.6 ± 0.12 to 4.9 ± 0.13 in RJB. For fresh RJP and RJBs, the initial TA was 0.51 ± 0.03% and 0.50 ±

0.21%, respectively, with post-processing values ranging from 0.49 ± 0.02% to 0.69 ± 0.02% for the RJP and 0.50 ± 0.02% to 0.65 ± 0.02% for the RJB. A significant decline in pH and a rise in TA were noted in both RJB and RJP as the pressure and holding time increased. However, these trends were determined to be statistically insignificant ($p > 0.05$). This aligns with the findings from numerous studies, which consistently reported minimal to minor variations in pH and TA following the pressure treatment of juices and purees. A study by Bialkowski and Kaczmarek (2019) on passion fruit purée found that HPP (600 MPa/5 min) had little effect on pH and TA compared to control samples. This underscores the non-damaging effect of high pressure on the covalent bonds present in ripe jackfruit samples (Pacheco and Kauffman, 2020).

The elevated pressure has previously been confirmed to boost the ionic dissociation constant of water and weak acids in food, as noted by Zhang *et al*., 2021. This outcome leads to a higher concentration of freely available H+ ions within the food matrix. From the Table 4.9, it is evident that the maximum pH reduction was reported at elevated processing conditions of 600 MPa, 20 min and the TA increased by a maximum of 0.19 units at 600 MPa for a 20 minut treatment for high pressure processed RJB. Similarly, RJP processed under lower pressure and holding time exhibited the minimum variation in pH and titrable acidity values in processed RJP.

The TSS content in the fresh RJB was determined to be 22.6 ± 0.59 ˚Brix, while for the RJP, it measured 23 ± 1.05 ˚Brix. Following HPP, there was a variation in TSS, ranging from 21.04 ± 1.04 to 22.6 ± 0.80 ˚Brix for the RJB and 22.75 ± 0.82 to 23.10 ± 0.83 ˚Brix for the RJP. TSS, indicative of the approximate soluble sugar content in a solution, exhibited a marginal decrease in RJBs after HPP; nevertheless, this decrease was not statistically significant ($p > 0.05$). The slight decrease in the TSS value observed after HPP may be attributed to the loss of sugars seeping out from the RJBs under elevated pressures. A notable reduction in TSS amounting to 21.04 ± 1.04 ˚Brix and 22.75 ± 0.82 ˚Brix was observed under the treatment conditions of 600 MPa for 20 min, respectively for RJB and RJP. In contrast, a stable TSS value of 22.6 ± 0.81˚Brix was maintained in RJB when subjected to 300 MPa for 5 min. The TSS content of RJP subjected to HPP remained nearly constant (23.10 ± 0.83 ˚Brix) at lower pressure. This stability can be attributed to the absence of anticipated bond breaking initiated by the

applied pressure, indicating the resilience of the soluble components in the RJP to structural changes under these processing conditions (Jayachandran *et al*., 2015).

Table 4.9 Effect of HPP on pH, TA, and TSS of ripe jackfruit

Treatment		RJB			RJP		
Pressure (MPa)	**Holding time (min)**	**pH**	**TSS (˚B)**	**TA (%)**	**pH**	**TSS ˚(B)**	**TA (%)**
300	5	4.9±0.18	22.6±0.81	0.53±0.02	5.2±0.03	23.1±0.83	0.50±0.02
600	5	4.8±0.13	22.4±0.59	0.57±0.02	4.9±0.23	23.2±0.61	0.59±0.02
300	20	4.8±0.22	22.5±0.12	0.56±0.03	4.9±0.12	22.9±0.83	0.55±0.03
600	20	4.6±0.03	21.0±1.04	0.69±0.02	4.8±0.13	22.75±0.82	0.65±0.02
238	12.5	4.9±0.22	22.6±0.80	0.54±0.02	5.0±0.06	23.00±0.61	0.55±0.01
662	12.5	4.8±0.17	22.1±0.60	0.59±0.02	4.9±0.18	23.1±1.01	0.60±0.02
450	2	4.9±0.13	22.5±0.25	0.57±0.02	5.1±0.14	23.1±1.06	0.55±0.02
450	23	4.7±0.05	21.9±0.80	0.6±0.007	4.8±0.21	22.95±1.05	0.56±0.01
450	12.5	4.8±0.17	22.3±0.60	0.57±0.02	4.9±0.23	23.0±0.83	0.55±0.02
450	12.5	4.6±0.12	22.5±0.92	0.55±0.03	4.8±0.22	22.8±0.60	0.6±0.03
450	12.5	4.8±0.21	21.1±1.02	0.57±0.02	4.8±0.17	23.7±1.03	0.49±0.02
450	12.5	4.9±0.22	22.3±1.01	0.43±0.03	5.1±0.14	23.15±0.81	0.53±0.02
450	12.5	4.6±0.21	22.0±0.80	0.56±.004	5.2±0.23	22.9±1.05	0.52±0.01

Where TSS-Total soluble solids, TA-Titrable acidity; Data shown are the mean±SD of three treatment repetition

4.4.1.2 Effect of HPP on colour characteristics of ripe jackfruit

The untreated ripe jackfruit samples demonstrated colour characteristics with L*=35.06 ± 1.60, a*=8.01 ± 0.29, b*=51.83 ± 1.37 for the RJB, and L*=48.56 ± 0.56, a*=8.13 ± 0.29, b*=56.65 ± 1.49 for the RJP. Following processing, the general trend in the colour of ripe jackfruit indicated an elevation in lightness (L* value) from 34.09 ± 1.51 to 42.64 ± 1.86 and 49.54 ± 2.27 to 51.48 ± 1.85 respectively for RJB and RJP (Fig 4.48 a&b). The study's results reveal that the lightness of ripe jackfruit samples experienced a notable change at the minimal applied pressure, and this modification was statistically significant ($p < 0.05$). This effect on lightness was observed consistently across various compression pressures. The results emphasize the sensitivity of the lightness parameter to the applied pressure, irrespective of the specific compression pressure employed. In this study, it was observed that ripe jackfruit samples treated with the lowest pressure (300 MPa) exhibited the darkest colour, while those treated with the highest pressure (600 MPa) displayed the lightest shade.

The pressure and holding time also had significant effect on L* value of HPP processed RJB and RJP. The effect of pressure on L* was found to be significantly higher compared to holding time. The polynomial model was found to fit well in describing the effect of variables on the L* value showing the adequacy of the model (R^2_{RJB} = 0.98%, R^2_{RJP}= 0.83% given in Table C3 & C4). The regression model obtained can be written as follows for L* value.

$$L_{RJB}^{*} = 35.81 + 2.14\,P + 0.64\,Ht + 0.26\,P\,Ht + 1.01\,A^2 + 0.68\,Ht^2 \quad \ldots (4.52)$$

$$L_{RJP}^{*} = 50.42 + 0.50\,P + 0.37\,Ht - 0.38\,P\,Ht + 0.20\,P^2 + 0.28\,Ht^2 \quad \ldots (4.53)$$

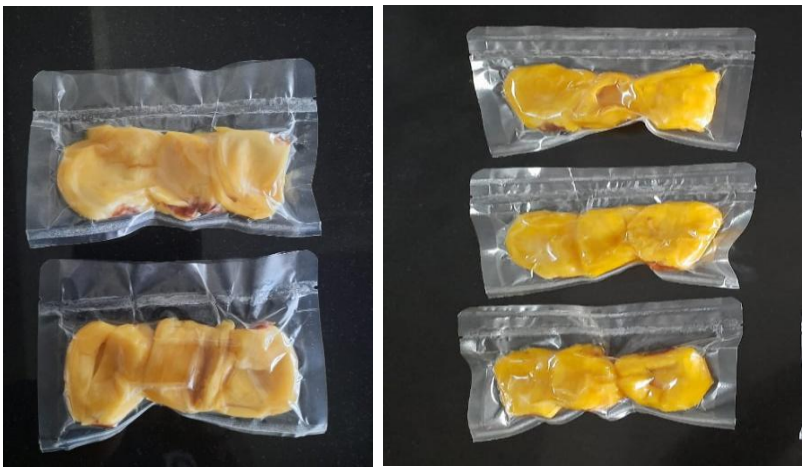
Where, L_{RJB} *: L* of RJB; L_{RJP} *: L* of RJP; P: Pressure in MPa and Ht: Holding time in min

A minor rise in L* (lightness) values was detected in the treated ripe jackfruit samples, suggesting the potential expulsion of air from RJB tissue during pressurization. This phenomenon contributed to the lightening and increased opacity of the samples (Saranya *et al*., 2024). The results, consistent with Kaushik *et al*. (2014), reflected an increase in lightness in pressurized mango pulp processed at 100 to 600 MPa for holding times of 1 to 20 min. The lightness value L* for the HP-treated jackfruit

shreds increased with pressure and holding time, aligning with Ng *et al*. (2020) hypothesis that the decline in L* was possibly due to micelles breaking up into small fragments under pressure. Oey *et al*. (2008) suggested that alterations in L* values in pressurized fruit products could be linked to the creation of a jelly-like translucent structure. This structure, in turn, influences the transparency or opacity of the product.

In comparison to the L* value, other chromatic parameters like a* and b* values exhibited a decrease following HPP processing. The a* value for jackfruit samples subjected to HPP treatment varied from 7.93 ± 0.02 to 8.08 ± 0.02 in RJB (Table 4.10) and 8.06 ± 0.21 to 9.32 ± 0.25 in RJP and were non significant ($p>0.05$) also lower than that of the untreated control sample (Table 4.10). A similar declining pattern in a* values was also noted by Varela-Santos *et al*. (2012) in pomegranate juice processed under high pressure. The negative a* value indicated an incomplete enzyme inactivation post-processing, contributing to the loss of red colour.

The yellow colour in ripe jackfruit is primarily attributed to the presence of carotenoid pigments including compounds like beta-carotene and lutein. The stability of the yellow colour, as indicated by the b* value, remained stable at higher pressures and holding times. The b* value for the fresh untreated RJB sample was 51.83 ± 0.37, while for the treated samples, it varied from 51.26 ± 0.93 to 51.77 ± 0.58. While the b* value for the untreated RJP sample was 56.65 ± 1.49, the treated samples exhibited a range from 55.12 ±1.46 to 56.62 ± 2.04. Referring to Figure 2, the treatments conducted at 600 MPa for 20 min showcased the maximum yellowness for both treated RJP and RJB. These results are consistent with earlier investigations by Oey *et al*. (2008) and Andrés *et al*. (2016), indicating that the carotenoid pigments accountable for the yellow hue in jackfruit remain stable under high-pressure conditions and are preserved. According to Stinco *et al*. (2019), in the treatment of cloudy carrot juice, the application of the highest pressure not only led to reduced degradation of carotenoids but also facilitated a more effective extraction of carotenoids compared to other treatments assessed. These results resonate with the present study, underscoring the resilience and preservation of carotenoid pigments in ripe jackfruit when subjected to high-pressure conditions. Plates 4.9 and 4.10 given below is the change in appearance of the jackfruit samples



(a) (b)

Plate 4.9 RJB samples (a) before HPP and (b) after HPP

(a) (b)

Plate 4.10 RJP samples (a)before HPP and (b)after HPP

4.4.1.3 Effect of HPP on ΔE, BI and YI of ripe jackfruit

The HPP-treated ripe RJB exhibited ΔE values ranging from 1.12 ± 0.01 to 9.58 ± 0.20 (Fig 4.49c), while the range for the RJP was 1.54 ± 0.05 to 2.94 ± 0.11 CIELAB units. This implies that the colour disparities in the treated RJB were observed within a broader range compared to the RJP, as indicated by the ΔE values in the CIELAB colour space. These variations suggest that HPP treatments induce colour changes in ripe jackfruit, which are discernible by untrained observers. Among the treatments, the RJP displayed the least colour deviation, registering at 1.54 ± 0.05, following exposure to HPP at 300 MPa for 5 min, compared to the fresh sample. Similarly, for the RJB, the colour deviation was 1.12 ± 0.01 at 300 MPa for 5 min.

Jayachandran *et al*. (2015) delineated ΔE values across various ranges to signify the degree of colour disparity in processed samples concerning the fresh untreated sample. According to their study, the ΔE values of treated RJP fell within the range of 1.5–3.0, indicating a distinct difference, while high treatment combinations (600 MPa, 20 min) for the HPP treated RJB showed a great difference. Stinco *et al*. (2019) also documented the most substantial colour difference observed at 600 MPa in HPP treated cloudy carrot juice.

$$\Delta E_{RJB} = 2.78 + 2.97\,P + 0.87\,Ht + 0.28\,P\,Ht + 1.51\,P^2 + 0.67\,Ht^2 \quad \ldots (4.54)$$

$$\Delta E_{RJP} = 2.17 + 0.36\,P + 0.29\,Ht - 0.27\,P\,Ht + 0.13\,P^2 + 0.19\,Ht^2 \quad \ldots (4.55)$$

Where, ΔE_{RJB} and ΔE_{RJP} represents the total colour deviation of RJB and RJP respectively, P: Pressure in MPa and Ht: Holding time in min. The R^2 values for ΔE_{RJB} and ΔE_{RJP} is 0.98 and 0.75 respectively (Table C4 & C5).

The BI for fresh RJB was reported as 308.16±1.69, contrasting with 150.34 ± 1.88 for fresh RJP. Post-processing, the BI ranged from 160.49 ± 1.62 to 268.05 ± 2.47 for RJB (Fig 4.49a) and 137.01 ± 1.67 to 143.56 ± 2.17 for RJP. Despite varying pressure and treatment times during HPP, there were no significant ($p > 0.05$) changes in BI values for RJP compared to the control sample. This aligns with findings from Zou *et al*. (2016), they reported that HPP treatment did not induce significant changes in the BI value of mulberry juice. During HPP, there were notable changes in the BI values observed in RJBs, with statistical significance ($p < 0.05$). The pronounced alterations in L*, a*, and b* values in the RJBs, compared to the RJP, likely contribute to the observed significant variations in BI values. BI exhibited a decline across all alternative pressure treatments, correlating with an escalation in both pressure magnitude and the duration of holding time. Maximum reduction in BI was noted at 600 MPa, 20 min. in HPP processed RJB. This observation underscores a consistent inverse relationship between BI values and the intensified pressure conditions, suggesting a notable impact on the biological response with increased pressure levels and prolonged exposure duration. The observed decrease in BI values across various pressure treatments is likely a result of pressure-induced partial enzyme inactivation. The literature has documented that pressure can diminish the rate of enzymatic reactions by causing alterations in the native structure of enzymes. This can occur through either

protein denaturation or by inducing changes in the spatial arrangement of the active site. Therefore, the consistent decline in BI values as pressure levels and holding times increase may be attributed to the pressure-induced modifications in enzyme activity (Ludikhuyze *et al*., 2003). An R^2 value of 0.99 indicates strong fitness for the polynomial model used to describe the impact of variables on BI. The influence of pressure and holding time on BI can be visually represented through the 3D surface plots depicted in Figure 4.49a. The expression for the regression model concerning the BI value of RJB processed under high pressure is as follows.

$$BI_{RJB} = 231.85 - 36.24\ P - 11.57\ Ht + 3.37\ P\ Ht - 12.89\ P^2 - 8.57\ Ht^2 \quad \ldots (4.56)$$

Where, RJB: RJB; RJP: RJP; P: Pressure in MPa and Ht: Holding time in min.

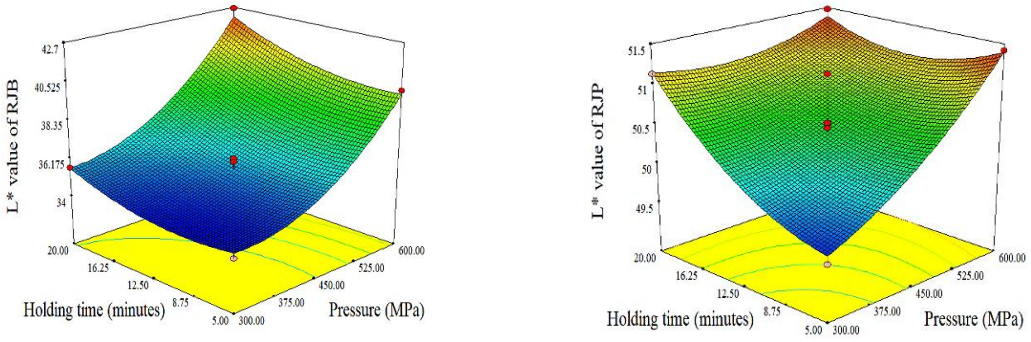
The YI for RJB after pressurization ranged from 173.44 ±1.56 to 215.58 ± 2.61 (Fig 4.48b), differing from the untreated samples at 223.96 ± 2.67. Similarly, in HP-processed RJP, it ranged from 156.15 ± 2.12 to 161.38 ± 2.81, contrasting with the fresh control having 166.66 ± 2.40 YI. Pressure and holding time had a significant effect ($p < 0.05$) on the YI of the RJB. However, a non-significant effect ($p>0.05$) on YI was observed in RJP. In the case of the YI value of HPP processed RJB, the pressure and holding time were determined as significant model terms. Equation (4.55) describes the relationship between the independent variables and BI of HPP processed RJB.

$$YI_{RJB} = 205.54 - 14.67\ P - 4.38\ Ht - 0.54\ PHt - 6.79P^2 - 3.35\ Ht^2 \quad \ldots (4.57)$$

Where, P: Pressure in MPa and Ht: Holding time in min. The R^2 value for YI_{RJB} noted as 0.98 and for BI_{RJB} it is 0.97 (Table C20 & C19).

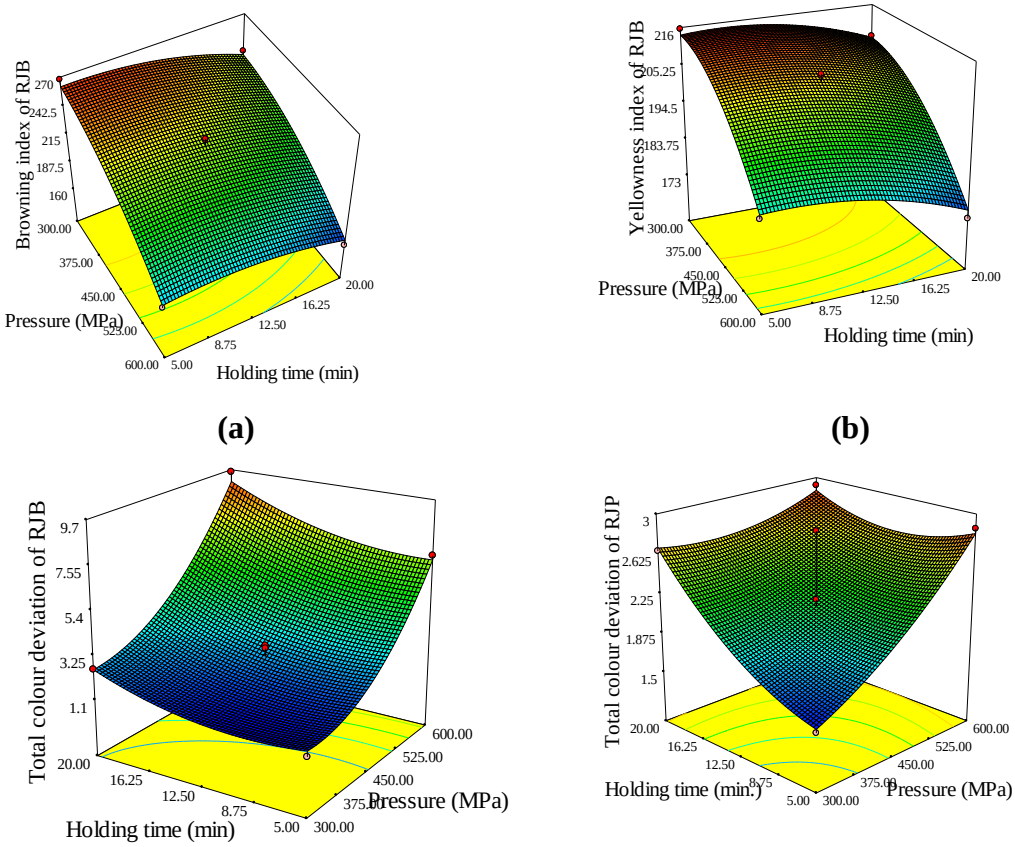
In HPP ripe jackfruit samples, YI was noticed to be decreasing with an increase in pressure. A maximum decrease of about 6.31% in YI at 300 MPa for 20 min treatment was obtained for RJP and maximum carotenoid retention was observed at lower treatment conditions of 300 MPa, 5 min. The elevation in L* may have contributed to the reduction in YI, while the samples' opacity increased post-pressurization due to air release, leading to a decline in YI at elevated pressures (Kaushik *et al*., 2014). The research emphasized that carotenoids, known for their resilience to pressure, did not contribute to the negative effects observed in YI under increased pressure conditions.

This corresponds with the findings of González-Cebrino *et al*. (2012), who reported similar results in the HPP of red flesh and peel plum. Kaushik *et al*. (2014) also observed an 8% maximum reduction in YI during the HPP of mango pulp at 100 MPa for 20 min.



(a) **(b)**

Fig. 4.48 Effect of HPP on L * value of RJB and RJP respectively



(c) **(d)**

Fig. 4.49 Effect of HPP on BI, YI, ΔE of RJB and ΔE of RJP respectively

Table. 4.10 Colour characteristics of HPP ripe jackfruit samples

Treatments		RJB		RJP			
Pressure (MPa)	Holding time (min)	a*	b*	a*	b*	YI	BI
300	5	8.02±0.02	51.45±0.98	8.88±0.42	55.62±2.01	160.39±1.85	142.35±5.13
600	5	7.95±0.01	51.73±0.99	8.18±0.39	56.36±1.50	156.58±5.64	137.48±3.64
300	20	8.03±0.02	51.55±0.78	8.29±0.30	55.88±0.65	156.13±4.13	137.01±5.97
600	20	7.93±0.02	51.77±0.58	8.06±0.21	56.62±2.04	157.12±6.85	138.07±4.78
238	12.5	8.02±0.03	51.47±0.94	8.75±0.40	55.63±1.47	158.34±7.26	139.80±6.41
662	12.5	7.95±0.03	51.75±0.75	8.15±0.05	56.48±2.46	156.88±7.18	137.82±4.97
450	2	8.02±0.02	51.57±0.99	8.83±0.40	56.03±2.57	158.47±5.71	139.96±3.70
450	23	7.94±0.01	51.72±0.78	8.55±0.31	56.25±2.58	156.16±4.13	137.11±4.94
450	12.5	7.96±0.02	51.57±0.57	8.65±0.23	56.34±2.03	158.75±6.92	140.24±5.06
450	12.5	7.97±0.02	51.55±0.78	8.75±0.10	55.12±1.46	157.71±5.46	139.07±3.68
450	12.5	7.95±0.02	51.26±0.93	8.9±0.32	56.54±2.46	161.39±7.39	143.56±6.26
450	12.5	8.08±0.02	51.77±0.77	9.32±0.25	56.28±1.95	157.25±5.67	138.64±6.35
450	12.5	7.94±0.01	51.41±0.58	8.42±0.37	55.46±2.54	157.05±4.15	138.15±6.33

Where ΔE-Colour deviation, YI-yellowness index, and BI- browning index, RJB-Ripe jackfruit bulb, RJP-Ripe jackfruit pulp*
Data shown are the mean±SD of three treatment repetition

4.4.1.4 Effect of HPP on AA of ripe jackfruit

AA is a remarkably sensitive compound, and its stability is notably influenced by processing methods and environmental factors (Tewari *et al*., 2017). A significant ($p<0.05$) rise in the AA content was noted in ripe jackfruit samples subjected to HPP. When compared to the control sample (fresh RJB-13.68 ± 0.62 mg/100 g), the AA content in the treated RJB samples (ranging from 13.94 ± 0.63 to 16.82±0.82 mg/100 g) showed a maximum elevation of 23% in AA Notably, the highest content was observed at 600 MPa, 20-min holding time (Fig. 4.50).

It was noted that AA is susceptible to factors like heat, light, and oxygen exposure, commonly encountered in the pulping process during the conversion of fruits into pulp (Tewari *et al*., 2017). The statement indicated that mechanical processing could decrease AA content, leading to reduced AA levels in the RJP compared to RJBs (Arampath and Dekkera., 2019). In the case of HPP processed RJP, the AA content ranged from 7.85±0.35 to 9.91 ± 0.46 mg/100 g. The reported findings highlighted a similar trend to that observed in HPP treated RJBs, with a 17% increase in the processed RJP compared to the control sample value of 7.84 ± 0.37 mg/100 g. High retention of AA was noted at 300 MPa, 5 min and higher AA was observed at 600 MPa, 20 min condition. The quadratic polynomial model was developed for AA concerning process parameters, demonstrates the interaction between pressure and holding time as depicted in Equation (2). This interaction is also evident in the response surface plot, indicating that pressure had the most significant impact on AA extraction compared to holding time (Fig. 4.49a and b).

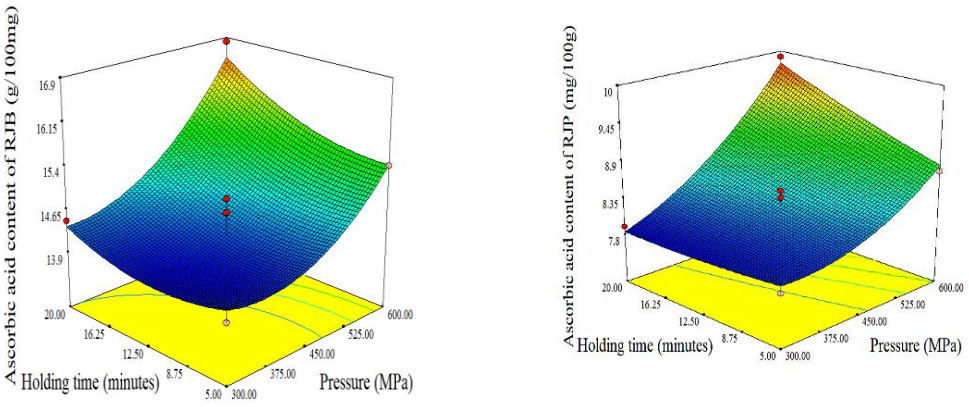
According to Landl *et al*. (2010), HPP generally has minimal effects on the AA content of fruits and vegetables, but it can be influenced by enzymatic reactions and chemical changes during pressurization. Briones-Labarca *et al*. (2013) noted that HPP might act as a facilitator for enhanced extraction of bioactive compounds from fruits. Kaushik *et al*. (2014) proposed that the increase in AA content in ripe jackfruit samples subjected to HPP might be attributed to cytoplasmic rupture and the subsequent release of contents into the extracellular space during compression. The regression model obtained can be written as follows. The R^2 values for AA_{RJB} and AA_{RJP} is 0.91 and 0.96

respectively. The ANOVA table for AA after HPP is given in Table C7 & C12 in Appendix C)

AA_{RJB} (mg/100 g) =14.28+0.87 P+0.33 Ht +0.22 P Ht +0.55 P^2+0.28 Ht^2 …(4.58)

AA_{RJP} (mg/100 g) =8.31+0.71 P+0.21 Ht +0.27 P Ht +0.27P^2+0.039 Ht^2 …(4.59)

Where, AA_{RJB}: AA of RJB; AA_{RJP}:AA of RJP; P: Pressure in MPa and Ht: Holding time in min



(a) **(b)**

Fig.4.50 Effect of HPP on AA of ripe jackfruit samples

4.4.1.5 Effect of HPP on TPC and TFC of ripe jackfruit

In previous studies, HPP impacted macromolecular structures in fruit and vegetable matrices (Gopal *et al*.,2017, Bansal *et al*., 2019, Nawawi *et al.*, 2023). The pressure difference generated by HPP across cell membranes enhances cell permeability, causing the breakdown of intracellular juice vesicles and releasing matrix-bound polyphenolic compounds, encompassing both flavonoids and non-flavanoids (Grunovaite *et al*., 2016).

This study revealed that the TPC in ripe jackfruit samples after pressure treatment ranged from 64.80 ± 2.96 to 66.02 ± 1.74 mg GAE/g for the RJB (Fig 4.51a) and 61.66 ± 1.63 to 70.12 ± 3.25 mg GAE/g for the RJP (Fig 4.51b). The results indicated a notable rise in TPC when the pressure was concurrently increased from 300 to 600 MPa, in comparison to the control samples (64.78 ± 2.96 mg GAE/g for both

RJP and RJB). The most significant ($p<0.05$) improvement, reflecting a 15.2% increase in TPC, occurred at 600 MPa for 20 min for the RJB, while the RJP experienced a 2% increase under the same conditions. Pressure had a significant effect on TPC of RJB and RJP. A non-significant lack of fit of the model suggests that the model is adequate for describing the relationship between the independent and dependent variables. The relationship between the dependent variable and the independent variables in terms of coded factors is given in Eqn (4.60 to 4.63). This improvement is credited to the increased extractability of specific antioxidant compounds at higher pressure levels, leading to the disruption of cell walls. According to Nayak *et al*. (2017), both elephant apple juice and strawberry puree exhibited comparable results when subjected to pressurization at 600 MPa, showing a rise in TPC of 9.8%. In a study by Fernández-Jalao *et al*. (2019) on the effects of HPP on flavonoids in Golden Delicious apples from Spain and Italy, it was found that treating Spain-apples at 400 MPa resulted in a notable increase of 22–35% in phenolics, specifically Q-3-galactoside, Q-3-glucoside, Q-3-arabinoside, Q-3-xyloside, and Q-3-Rhamnoside. This aligns with the general trend observed in various fruits and purees under high-pressure conditions

The extraction of flavonoids in all treatments exhibited a comparable pattern to the extraction of total phenols, indicating an elevation with increasing pressure levels (Fig. 4.52). In comparison to the control value of 33.89 ± mg RE/g, the TFC of HPP processed RJB rose from 35.12 ± 1.23 to 43.68 ± 1.57 mg RE/g. The maximum amounts of flavonoids were reported as 43.68 ± 1.57 mg RE/g at a higher pressure of 600 MPa for 20 min (Fig 4.52a). Concerning the RJP, the TFC ranged from 17.13 ± 0.45 to 22.85 ± 0.99 mg RE/g (Fig 4.52b), with the control sample showing a lower value of 17.06 ± 0.59 mg RE/g. Additionally, the highest extraction yields for flavonoids, specifically 25% for HP processed RJB and 22% for RJP, were noted at 600 MPa for 20 min. This aligns with the earlier observation by Abid *et al*. (2014) in apple juice subjected to 450 MPa treatment.

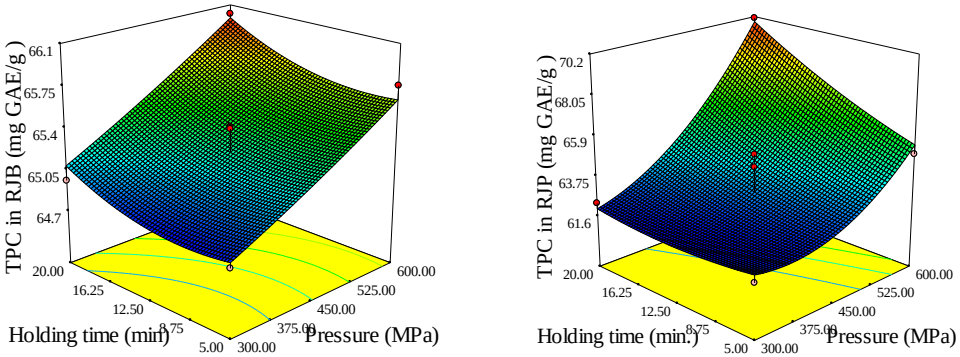
The statistical analysis indicated that both pressure and holding time, as well as their interactions, had a positive and significant effect on the HPP of ripe jackfruit samples. The regression equation derived from the model in terms of coded factors is given belowin Table 4.11 and ANOVA table is given in Appendix C. Flavanols

exhibited a comparable increase in multiple studies, such as in a soymilk beverage treated at 400 MPa (Rodríguez-Roque *et al*., 2016) and orange juice subjected to 550 MPa (Vieira *et al*., 2018). This underscores the importance of a well-balanced combination of high pressure and extraction time to improve extraction yields, consistent with prior research indicating the efficacy of HPP treatment in extracting phenols and flavonoids.

Table 4.11 Regression equation in terms of coded factors

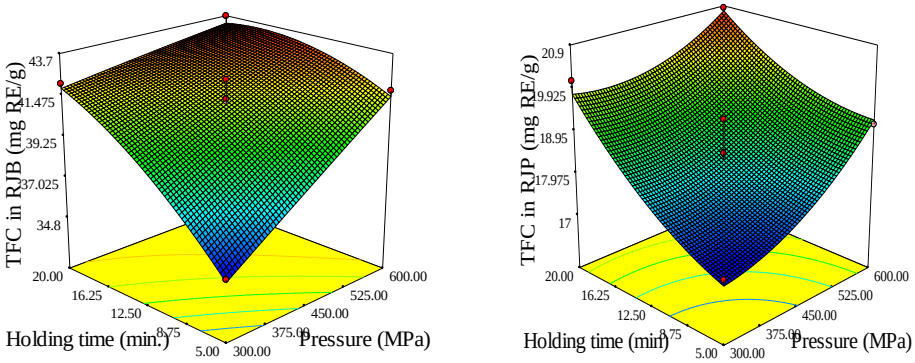
TPC_{RJB}= 65.24+0.42* P+0.15* Ht+0.025 *P* Ht +0.027* P^2+0.13* Ht^2	... (4.60)
TPC_{RJP}= 63.14+2.84* P+1.09* Ht +1.13* P * Ht +1.38* P^2+0.33* Ht^2	… (4.61)
TFC_{RJP}= 18.40+0.80* P+1.09* Ht -0.31* P * Ht +0.44* P^2+0.37* Ht^2	… (4.62)
TFC_{RJB}= 41.23+1.96* P+2.18* Ht -1.26* P * Ht -0.038* P^2-0.80* Ht^2	… (4.63)

Where TPC-Total phenolic compounds, TFC-Total flavonoid content, RJB: Ripe jackfruit bulb; RJP: Ripe jackfruit pulp; P: Pressure in MPa and Ht: Holding time in min



(a) **(b)**

Fig. 4.51 Effect of HPP on TPC of ripe jackfruit samples



(a) **(b)**

Fig. 4.52 Effect of HPP on TFC of ripe jackfruit samples

4.4.1.6 Effect of HPP on Total sugar of ripe jackfruit

Sugars play a crucial role as a sensory indicator influencing consumer perception (Liu *et al*., 2013). Typically, it is evaluated through total sugar, and reducing sugar levels. The assessment of total sugar in ripe jackfruit samples resulted in a range of 25.45 ± 0.91 to 25.50± 0.93 g/100 g for RJB (Table 4.12), while the control sample exhibited a total sugar content of 25.49 ± 0.85 g/100 g. The research indicates that there was a negligible variance in total sugar content before and after processing, and this difference was not statistically significant ($p>0.05$). Comparable outcomes were observed in the HPP processed RJP, where the total sugar content remained unchanged even post-processing. The initial total sugar content of the fresh RJP was 22.62 ± 0.62 g/100 g, and post-processing, it ranged from 22.62 ± 0.26 to 22.68 ± 0.99 g/100 g. This suggests that the pressure and holding time had no impact on the total sugars of ripe jackfruit samples. Similarly, Liu *et al*. (2016) found a non-significant effect on total sugars in both blanched and unblanched mango RJP after HP processing. Butz *et al*. (2002) reported that there were no significant differences in the sucrose, glucose, and fructose levels in HPP processed fresh juices from tomatoes, oranges, peaches, carrots, apples, and strawberries.

4.4.1.7 Effect of HPP on DPPH radical scavenging activity of ripe jackfruit

The control RJB and RJP were examined for antioxidant capacity through DPPH radical scavenging activity, yielding values of 88.55 ± 4.05 and 87.54 ± 3.1% DPPH radical scavenging activity, respectively. After processing, the DPPH radical scavenging activity in RJB ranged from 88.63 ± 2.34 to 91 ±1.04% (Fig 4.53a), while in RJP, it varied from 87.56 ± 3.15 to 89.92 ± 1.05% (Fig 4.53b). HPP had a notable impact ($p < 0.05$) on the antioxidant capacity of the treated ripe jackfruit samples. The application of elevated pressure at 600 MPa for 20 min. increased the DPPH radical scavenging activity in HPP processed RJB to 91 ± 1.04 % DPPH radical scavenging activity and in RJP to 90.45 ± 1.05% DPPH radical scavenging activity. In comparison to the control sample, there were respective increases of 2.7% and 2.8% in DPPH radical scavenging activity in RJP and RJB.

Table.4.12 Effect of HPP on Total sugar of ripe jackfruit

Treatment		Total sugar	
Pressure (MPa)	**Holding time (min)**	**RJB**	**RJP**
300	5	25.49±0.92	22.62±0.26
600	5	25.45±0.91	22.65±0.82
300	20	25.46±0.67	22.63±0.60
600	20	25.50±1.11	22.68±0.99
238	12.5	25.50±1.16	22.64±1.04
662	12.5	25.50±1.17	22.67±1.04
450	2	25.48±0.92	22.67±0.82
450	23	25.46±0.67	22.65±0.60
450	12.5	25.48±1.11	22.64±0.99
450	12.5	25.49±0.88	22.64±0.78
450	12.5	25.47±1.16	22.65±1.04
450	12.5	25.50±0.92	22.64±0.82
450	12.5	25.48±0.67	22.64±0.60

RJB: Ripe jackfruit bulb; RJP: Ripe jackfruit pulp;Data shown are the mean±SD of three treatment repetitions

Changes in antioxidant activity are connected to variations in bioactive compounds such as total phenols, vitamin C, and flavonoids. Elevated pressure levels in HPP contribute to the increased extractability of specific antioxidant compounds by disrupting cell walls and releasing bioactive compounds. These components, recognized as significant contributors to antioxidant activity, play a vital role in fruit and vegetable products, and their impact is shaped by factors like estimation methods, juice matrix nature, and HPP technique parameters (Andres *et al*., 2016). It was reported that the utilization of moderate pressures on pineapple by-products resulted in an 85% boost in antioxidant activity (DPPH method), a 79% increase in FRAP method, and a 76% rise in ABTS method (Santos *et al*., 2022). However, some studies, conducted by Sánchez-Moreno *et al*. (2005), indicated minimal effects of HPP on antioxidant capacity.

The outcomes of the two-way ANOVA revealed that pressure and holding time significantly influenced the DPPH radical scavenging activity of RJB and RJP, as indicated by DPPH values ($p<0.05$) (Table C9 & C21). In the regression analysis, it was found that a second-order model was a good fit for the antioxidant capacity following HPP. The determination coefficients were R^2=0.94 ($p<0.05$) and R^2= 0.92 ($p<0.05$) respectively for RJB and RJP. The experimental data were best described by a second-order polynomial model given by the equation given below and the 3D graphical illustration is depicted in Fig 4.53 a and b

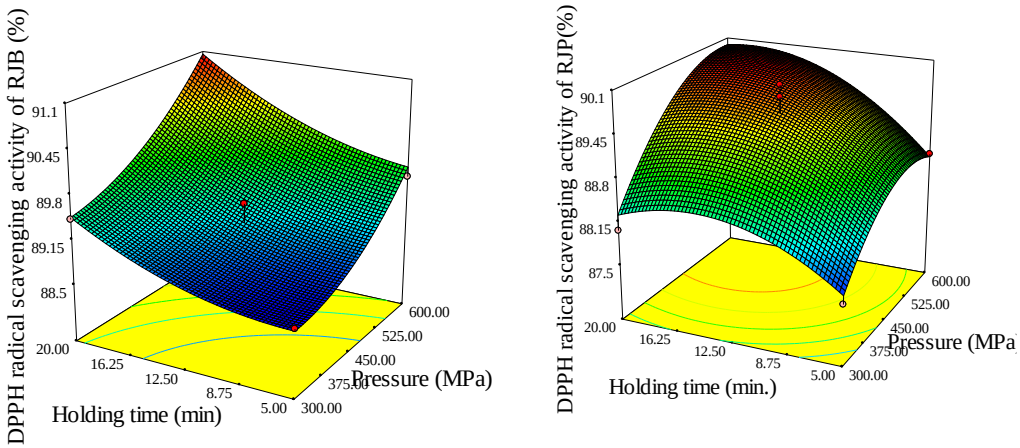
$DPPH_{RJB}$ radical scavenging activity (%)

$$= 89.23+0.69\ P+0.54Ht+0.093\ P\ Ht+0.29P^2+0.22\ Ht^2 \quad ..(4.64)$$

$DPPH_{RJP}$ radical scavenging activity (%)

$$=89.57+0.65\ P+0.50Ht+0.21\ P\ Ht-0.47\ P^2-0.47\ Ht^2 \quad \ldots(4.65)$$

Where RJB: jackfruit bulb; RJP: Ripe jackfruit pulp; P: Pressure in MPa and Ht: Holding time in min



(a) **(b)**

Fig.4.53 Effect of HPP on DPPH radical scavenging activity of RJB and RJP respectively

4.4.1.8 Effect of HPP on the firmness of RJB

The HPP had a significant impact ($p < 0.05$) on the firmness of the treated RJBs, as evident from Table 3. The initial hardness of untreated RJBs was 57.83 ± 2.6 N, while the hardness of those subjected to HPP increased from 57.16 ± 2.81 to 69 ± 3.16

N (Fig 4.54). In a two-way ANOVA, a notable impact of both pressure and holding time on sample hardness was identified (Table C10). However, there was no observed effect of the interaction between pressure and time. A nearly 19.31% increase was observed at 600 MPa, 20 mins. The model has an R^2 value of 0.97 ($P < 0.05$), showing a strong fit to the data. The significant variables are pressure and holding time. The F-value of 0.73 indicates that the lack of fit is not significant compared to the pure error, suggesting that the model sufficiently explains the relationship between the variables.

Following HPP, Pectin methylesterase (PME) is released and comes into contact with its substrate, which is highly methylated pectin. This results in de-esterification, occurring not only during the HPP but also after the pressure release. The texture firming was attributed to PME-initiated de-esterification, which facilitated the cross-linking of divalent metal ions with low-methoxyl pectins (Pérez-Pérez *et al*., 2019). It was noted that pressure treatment partially inactivated PME, enabling the interaction between the enzyme and substrate, initiating de-methylation and further contributing to textural firmness (Oey *et al*. 2008) Consequently, in the current study, the elevated treatment pressure exhibited a clear tendency toward creating a harder and firmer texture in RJBs. Ng *et al*. (2020) conducted similar studies on RJBs packed in vacuum skin (VS) and vacuum nylon (VN) packaging and observed an almost two-fold increase in hardness and chewiness after HPP. The regression equation for the texture of HPP-RJB is as follows:

Firmness of RJB (N) = $62.37+3.41\ P+2.15Ht+0.30\ PHt+0.69P^2-0.48Ht^2$… (4.66)

Where RJB: Ripe jackfruit bulb; RJP: Ripe jackfruit pulp; P: Pressure in MPa and Ht: Holding time in min

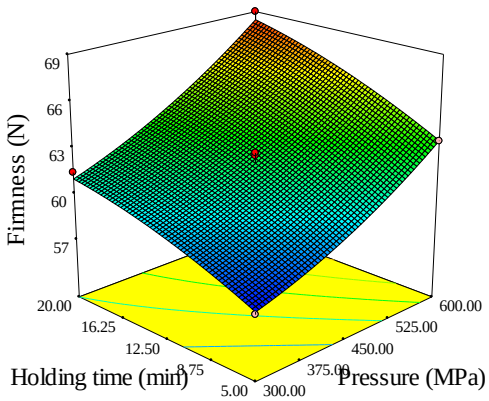


Fig .4.54 Effect of HPP on firmness of RJB

4.4.1.9 Effect of HPP on microbial activity of ripe jackfruit

The yeast and mould counts in untreated RJBs and RJP were 4.3 ± 0.15 and 4.4 ± 0.11 log CFU/g, respectively. However, for HP-treated samples, the microbial counts were all below the detection limit. The total log reduction in yeast and mold count varied from 3.87 ± 0.17 to 6.20 ± 0.035 log CFU/g for RJB (4.56a) and 4.3 ± 0.24 to 6.20 ± 0.14 log CFU/g for RJP (Fig 4.56b). After HPP at or over 600 MPa for 20 mins, the counts of microbial populations were significantly ($p<0.05$) reduced in treated RJB and RJP. Conversely, HPP treatments resulted in microbial counts (TAM) within allowable limits across all treatments (ie., <1 log CFU/g). The TAM in control samples were 4.51±0.16 and 4.73± 0.25 CFU/g, respectively in RJB and RJP. There was a significant decline in TAM observed in treated RJB and RJP concerning pressure and time ($p<0.05$). The total log reduction of TAM in the treated RJB and RJP was reported to be 4.1 ± 0.18 to 6.4 ± 0.23 log CFU/g (Fig 4.55a) and 4.1 ± 0.10 to 5.93 ± 0.0.23 log CFU/g (Fig 4.55b) from the initial population, respectively, in RJB and RJP. A substantial decline in cell counts occurred after pressurisation and was noticeable at 600 MPa, for 20 min ie., 6.4 ± 0.23 log CFU/g and 5.93 ± 0.0.23 log CFU/g respectively in RJB and RJP, and the least reduction, 4.1± 0.18 log CFU/g, was observed at a lower pressure of 300 MPa. According to Daher *et al*. (2017), HPP causes alterations in cellular membranes and interrupts cellular functions, specifically those associated with reproduction, resulting in bacterial death. Furthermore, pressure affects energy availability within cells by influencing biochemical reactions responsible for energy production. Li *et al*. (2010) reported a significant reduction in the total aerobic bacterial count at 400 MPa and 600 MPa in high-pressure treated sour Chinese cabbage for 10–30 min, while Kaushik *et al*. (2014) observed that microbial counts in mango pulp decreased to 4.6 ± 0.24 log cycles after applying 600 MPa for 5 min. In this investigation, microbial counts in both high-pressure processed RJB and RJP were detectable, confirming the effectiveness of HPP against microbial growth. The regression equation for the microbial activity of HPP-RJB is as follows:

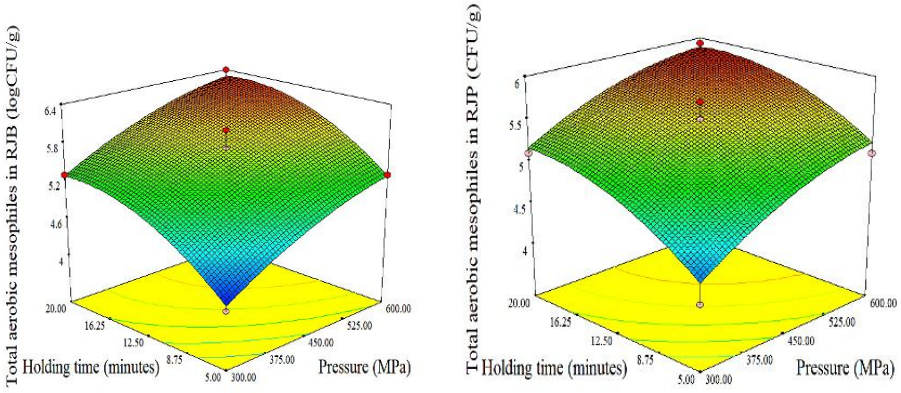
$$TAM_{RJB}\,(\log CFU/g) = 5.74 + 0.53P + 0.53Ht - 0.025PHt - 0.15P^2 - 0.32Ht^2 \quad \ldots (4.67)$$

$$TAM_{RJP}\,(\log CFU/g) = 5.51 + 0.40P + 0.37Ht - 0.042PHt - 0.15P^2 - 0.20Ht^2 \quad \ldots (4.68)$$

$Yeast/mold_{RJB}$ (log CFU/g) =5.10+0.55P+0.55Ht+0.22PHt-0.014P^2-0.24Ht^2 … (4.69)

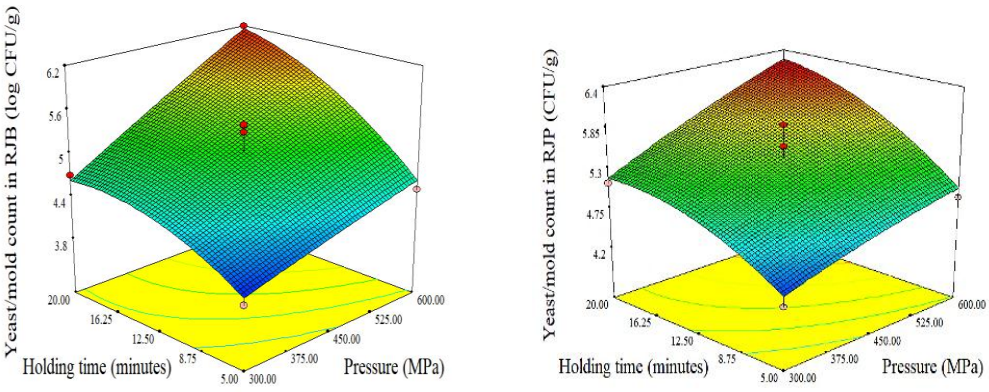
$Yeast/mold_{RJP}$ (log CFU/g) =5.50+0.42P+0.49Ht+0.13PHt-0.050P2-0.22Ht^2 … (4.70)

Where RJB: Ripe jackfruit bulb; RJP: Ripe jackfruit pulp; P: Pressure in MPa and Ht: Holding time in min; TAM-Total aerobic mesophiles. The R2 value and ANOVA table of HP processed ripe jackfruit is given in Appendix C)



(a) **(b)**

Fig.4.55 Effect of HPP on TAM of RJB and RJP respectively



(a) **(b)**

Fig .4.56 Effect of HPP on yeast/mold of RJB and RJP respectively

4.4.1.10 Effect of HPP on rheological property of ripe jackfruit

The rheological properties of RJP subjected to HPP were systematically evaluated under different treatment conditions, with a particular focus on viscosity and shear rate. The recorded viscosity of RJP varied within the range of 43.35 ± 0.85 to 60.53 ± 0.80 Pa.s, as depicted in Fig. 4.57 The experimental data were effectively analyzed using the power law model, yielding a consistency index (K) of 67.74 ± 0.58 and a flow behavior index (n) of 0.72. These values confirm the shear-thinning nature of RJP, classifying it as a non-Newtonian fluid due to its dependence on shear rate rather than maintaining a constant viscosity.

Fig. 4.58 presents the impact of HPP on viscosity (Pa.s) as a function of shear rate (1/s) for different treatment conditions (T1 to T9) alongside a control sample. The observed results clearly demonstrate the shear-thinning behavior of RJP, with viscosity increasing significantly post-HPP in comparison to fresh pulp, which had an initial viscosity of 42.77 ± 0.76 Pa.s. At lower shear rates, treatments T4 and T6 exhibited the most pronounced increase in viscosity relative to other conditions (Fig. 4.58). Notably, treatment T6 exhibited the highest viscosity of 60.53 ± 0.80 Pa.s, highlighting the synergistic effect of both pressure and holding time in enhancing viscosity. These findings are consistent with previous studies on pressurized apple purees, where viscosity initially increased and later stabilized at elevated shear rates

As the shear rate increased, the viscosities of all treated samples gradually converged toward lower values, reinforcing the shear-thinning behavior of RJP. It was observed that treatments processed under higher pressures and extended holding times resulted in greater viscosity enhancement, while lower-pressure treatments such as T1 and T3 exhibited relatively lower viscosity values. The general trend indicates that increasing both pressure and holding time leads to a viscosity increase, albeit with more complex interactions due to the presence of significant quadratic terms influencing the response.

Both untreated and treated RJP consistently exhibited shear-thinning characteristics, aligning with previously reported observations in fruit purees Steffe (1996) The increase in viscosity among treated samples may be attributed to the improved solubilization of polysaccharides such as starch and pectin, as suggested by

prior studies Zhou *et al*. (2017). Similar viscosity-enhancing effects have been documented by Krebbers *et al*. (2003) and Moussa-Ayoub *et al.* (2017), where HPP treatment contributed to structural modifications leading to viscosity enhancement. The observed viscosity changes could be attributed to reduced enzymatic activity, particularly a decline in polygalacturonase (PG) activity, which plays a role in cell wall degradation. A related study conducted by Hsu *et al*. (2008) demonstrated a strong association between PG activity and the viscosity of tomato juice subjected to HPP. The increase in viscosity following HPP is likely due to the release of cellular components as a result of cell wall permeabilization under high pressure, as previously noted by other researchers (Landl *et al*., 2010).

Statistical analysis using analysis of variance (ANOVA) confirmed a highly significant model ($F = 78.21$, $p < 0.0001$ and $R^2 = 0.98$), establishing a strong correlation between viscosity changes and both pressure and holding time. The final viscosity equation derived from the analysis is as follows:

$$\text{Viscosity (Pa.s)} = 49.06 + 4.05P + 4.07Ht - 0.46\,PHt + 1.03P^2 + 2.73\,Ht^2 \quad \ldots (4.71)$$

Where: P = Pressure (MPa) Ht = Holding time (min)

This equation illustrates that both pressure and holding time exert significant positive linear effects on viscosity. Furthermore, their quadratic terms contribute to the response surface curvature, indicating that viscosity undergoes more pronounced changes at extreme values of either factor. These findings emphasize the importance of optimizing HPP conditions to achieve the desired rheological properties in RJP, with potential implications for its application in food processing and formulation.

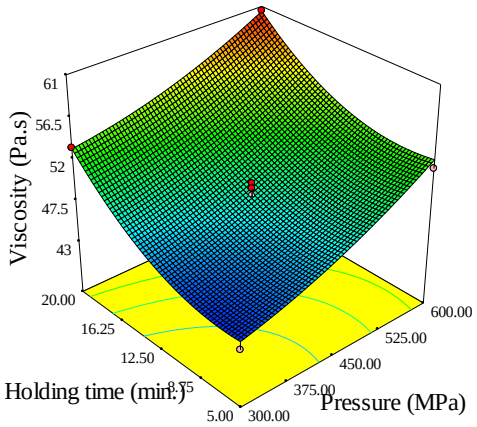
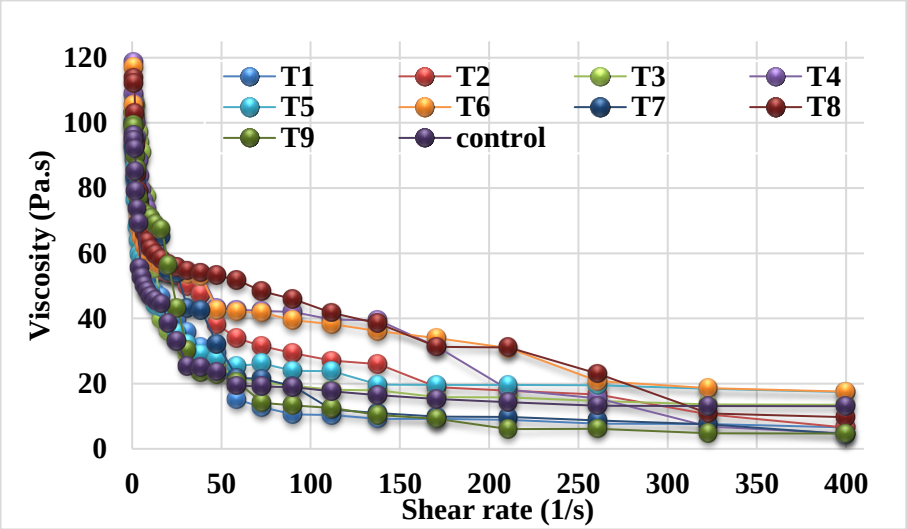


Fig. 4.57 Effect of HPP on viscosity of RJP



T1:300 MPa/5 min, T2:600 MPa /5 min, T3:300 MPa /20 min, T4:600 MPa /20 min, T5:238 MPa /12.5 min, T6:662 MPa /12.5 min, T7:450 MPa /2 min, T8:450 MPa /23 min, T9:450 MPa /12.5 min

Fig.4.58 Viscosity of HPP processed RJP as a function of shear rate

4.4.1.11 Sensory analysis

The results of the sensory evaluation of the samples are depicted in Fig.4.59 and 4.60. According to sensory analysis, treatment T_4 (600 MPa for 20 min) in high-pressure processed RJB achieved an overall acceptability score of 7.30, while T_6 (600 MPa for 12.5 min) scored the highest for RJP with an overall acceptability of 6.8, which was the highest score among other samples except for the control.

The control sample achieved the highest scores of 8.5 and 7, respectively for RJB and RJP. Lower scores in visual colour were observed in T_4 and T_6 for both RJB and RJP (Fig 4.60), attributed to a deviation from yellow to transparent colour due to the extraction of micelles post-processing. Textural scores were notably high for treatments with higher pressures, particularly at 600MPa/20 min, with a score of 7.2. Taste and aroma scores were nearly equivalent to the control for treated RJB and RJP, indicating that HPP did not significantly alter the taste and aroma of the treated jackfruit samples.

The sensory scorecard for the nine-point hedonic scale is provided in the appendix, along with a table displaying the sensory scores for each treatment. Statistical

analysis shows that all p-values are greater than 0.05, there is no statistically significant difference in sensory attributes across the different treatments. This suggests that high pressure processing do not significantly impact color, aroma, taste, texture, or overall acceptability in RJB and RJP.

Where T1:300 MPa/5 min, T2:600 MPa /5min, T3:300 MPa /20 min, T4:600 MPa /20 min, T5:238 MPa /12.5 min, T6:662 MPa /12.5 min, T7:450 MPa /2 min, T8:450 MPa /23 min, T9:450 MPa /12.5 min.

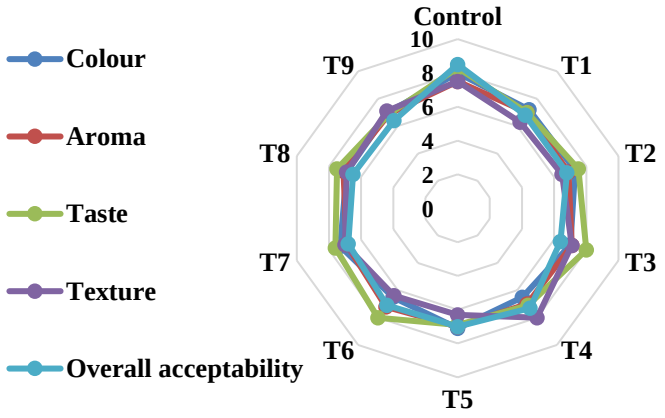


Fig. 4.59 Sensory score card for HP processed RJB

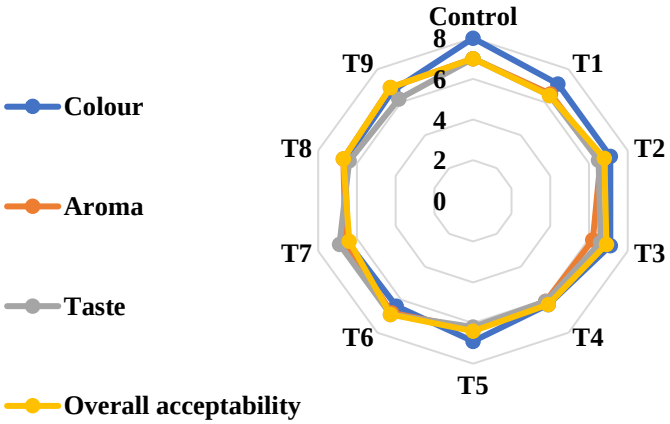


Fig.4.60 Sensory score card for HP processed RJP

4.4.2 Optimisation of the HPP ripe jackfruit

The numerical optimisation of the HPP of RJB and RJP was done based on the RSM approach. The optimization criteria for RJB were established to prioritize maximum preservation of bioactive compounds and minimal levels of microbial count and BI For the RJP, the focus was on maximizing bioactive compounds while minimizing microbial load. The remaining parameters were restricted to the limits observed in this study. The important values for bioactive compound retention and microbial stability were prioritized, aiming for a maximum desirability value, which was 0.952 for RJB and 0.839 for RJP. This suggests a stronger adherence to the established goals. At the optimized HPP conditions of 600 MPa/20 min. for RJB and 600 MPa/15 min for RJP, significant improvements were noted. For RJB, the bioactive compounds were effectively retained, with higher log reduction of TAM (6.3 log CFU/g) and yeast/mold count (6.1 log CFU/g), while firmness was enhanced. Similarly, for RJP, maximum bioactive compound retention and minimal microbial load (5.87 log CFU/g) and yeast/mold count (6.07 log CFU/g) were observed under the optimised conditions.

4.4.3 Cost analysis of high pressure processed ripe jackfruit

The production cost for HPP ripe RJBs and RJP was estimated by considering both fixed and variable costs. For HPP ripe RJBs, the cost was determined to be ₹3,758.62 per 500 g pack and ₹1,879.31 per 250 g pack. Similarly, for HPP ripe RJP, the production cost was calculated as ₹4,176.72 per 500 g pack and ₹2,088.36 per 250 g pack (Appendix G3 & G4). These costs include expenses related to fixed costs such as depreciation, interest, repairs, maintenance, insurance, and taxes, as well as variable costs including electricity, labour, raw materials, and packaging. However, these cost estimations are based on processing carried out using a lab-scale HPP machine with limited capacity. This significantly inflates the production cost and makes the benefit-cost ratio (BCR) calculation impractical for commercial comparison. A commercial-scale HPP system with higher throughput could substantially reduce the per-unit cost and improve economic feasibility.

4.5 Effect of storage on HPP of ripe jackfruit

The HPP of ripe jackfruit samples was conducted following established protocols, and the optimised samples were subsequently stored under refrigerated conditions for a storage study. The treatment conditions identified as optimal were 600 MPa for 20 min. for RJB and 600 MPa for 15 min. for RJP. To assess the quality changes of the stored samples, evaluations were performed over a 40-day period, with assessments occurring every 10 days. The results and discussions regarding these findings are elaborated in the following section.

4.5.1 Effect of storage on pH, TA, and TSS of ripe jackfruit

The pH variation in high-pressure processed ripe RJP and bulb over different storage periods was analysed. The pH of the fresh pulp dropped from 5 ± 0.2 to 3.2 ± 0.1 over 10 days of storage, and the pH of the fresh ripe RJB decreased from 5.1 ± 0.2 to 4 ± 0.1 in 15 days (Fig 4.61), and spoiled thereafter. As noted by Subasi *et al*., (2017), initial investigations revealed non significant ($p>0.05$) deviations in pH values during the first 40 days of storage. For the pulp, the pH values ranged from 4.66 ± 0.21 to 4.99 ± 0.17 during storage. Despite these fluctuations, the variations were not statistically significant ($p>0.05$), indicating that the pulp maintained a relatively stable pH over the 40-day storage period. Similarly, the bulb exhibited pH values ranging from 4.42 ± 0.14 to 4.59 ± 0.16 with no significant differences across the storage days. This stability suggests that high-pressure processing effectively preserves the pH of both the pulp and bulb, thereby potentially extending the shelf life without compromising quality. This phenomenon may be attributed to microbial metabolism in the pulp, as discussed by Liu *et al*. (2016) . The observed decrease in pH during storage of the HPP-treated RJP is consistent with findings in other HPP-treated fruit products, such as avocado paste and Maoberry juice, as reported by Jacobo-Velazquez and Hernandez-Brenes (2010) and Chaikham and Prangthip.(2015), respectively. These declines may be associated with the migration of organic acids and microbial activities during storage.

Similarly, the study investigated the TA of high-pressure processed ripe RJP and bulb over various storage periods. The TA of fresh pulp initially measured at 0.51±0.02%, increased to 0.68±0.04% within the first 10 days of storage, while the

bulb's TA was 0.50±0.01%, rising to 0.63±0.01% by the 15th day. For the bulb, the TA values ranged from 0.69±0.01% on the 0th day to 0.72±0.02% on the 40th day. The ANOVA results indicated that the differences in TA values over time were not statistically significant. For RJP, the Duncan post hoc test showed two homogeneous subsets—0th, 10th, and 20th days in the first, and 30th and 40th days in the second—suggesting a gradual increase in TA over time, while for RJB, it revealed that all storage periods formed a single homogeneous subset, indicating that the changes in TA were not substantial over time. Varela-Santos *et al*. (2012) also reported similar findings with high-pressure processed pomegranate juice, noting that both pH and TA remained stable during refrigerated storage over a period of 15 days.

The TSS ranged from 23.09±0.11 to 23.28±0.14 °Brix for high pressure processed RJP, and from 21.04±1.05 to 21.31±0.05 °Brix for RJB over the 0th to 40th day of storage, as shown in Table 1. ANOVA analysis indicated no significant ($p>0.05$) differences in TSS values among the storage periods, suggesting that the storage duration did not notably impact the TSS content of either RJP or RJB. This stability in TSS implies that both products maintained consistent quality and composition throughout the storage period, essential for product integrity and consumer satisfaction. According to Bi *et al*. (2020), high-pressure processing of mango smoothies resulted in a slight but statistically insignificant increase in TSS compared to untreated samples.

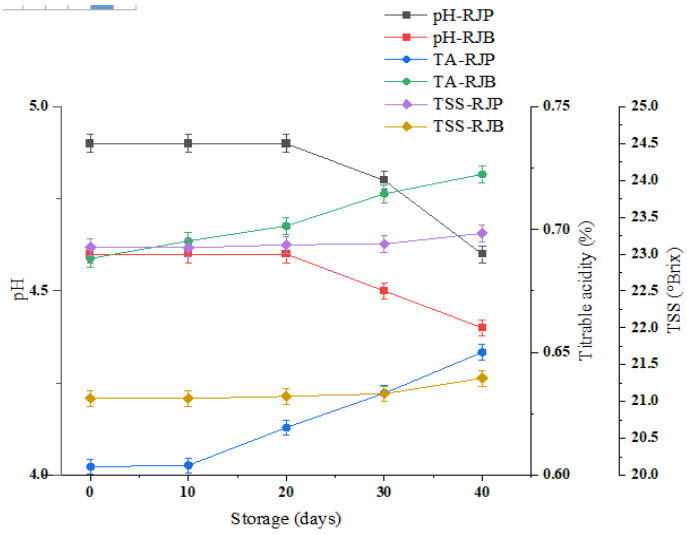


Fig. 4.61 Effect of storage on pH, TA, and TSS of HP processed RJP and RJB

4.5.2 Effect of storage on ΔE of ripe jackfruit

During storage, the ΔE of ripe RJB and pulp was observed. The colour deviation in the high-pressure processed RJP increased from an initial value of 2.78 ± 0.24 on the 0th day to 3.13 ± 0.06 on the 40th day. In the RJB, the colour deviation rose from 5.57 ± 0.11 on the 0th day to 6.21±0.72 on the 40th day. The control sample of fresh pulp exhibited an ΔE increase from 0 to 6.77 ± 1.11 (Fig. 4.62), while the fresh bulb showed an increase from 0 to 6.9 ± 2.16. Although there was an increase in ΔE in both the bulb and pulp during storage, the changes were not statistically significant. This indicates that the effect of storage on the ΔE of RJB and pulp, compared to the fresh samples, was minimal and did not result in significant variation. Ibarz *et al*. (2000) reported that various factors can contribute to these changes, including enzymatic and non-enzymatic browning, Maillard reactions occurring during storage, and the degradation or polymerisation of polyphenols. Szczepańska *et al*. (2022) observed similar results during the storage of HPP apple juice. Processed at 600 MPa for 5 minutes, the ΔE value of the juice increased from 4.14 to 10.53 after 12 weeks of storage.

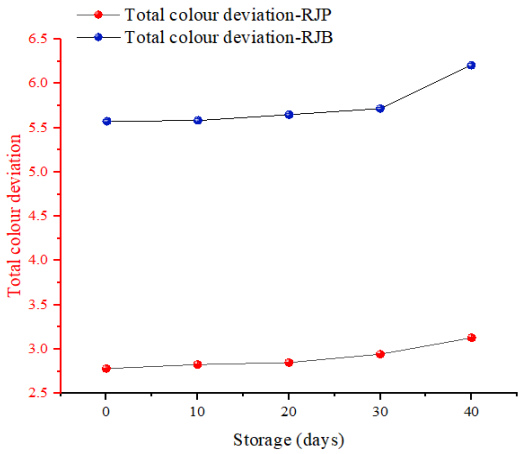


Fig. 4.62 Effect of storage on total colour deviation of High pressure processed RJP and RJB

4.5.3 Effect of storage on AA of ripe jackfruit

The initial AA content of fresh RJP and bulb were 7.84±0.19 mg/100 g and 13.68 ±0.43 mg/100 g, respectively. During the storage period, the AA content of the pulp varied from 7.62 ± 0.17 mg/100 g on the 40th day to 9.47±0.48 mg/100 g on the

0th day, while for the bulb, it ranged from 14.85±0.21 mg/100 g on the 40th day to 16.65±0.33 mg/100 g on the 0th day. The percentage retention of AA from the 0th day to the 40th day was also determined for both pulp and bulb. In the case of the pulp, where the AA content decreased from 9.46 ±0.48 mg/100 g on the 0th day to 7.62±0.17 mg/100 g on the 40th day, the retention of AA was approximately 80.45%. Similarly, for the bulb, with AA content decreasing from 16.65 ±0.33 mg/100 g to 14.85±0.21 mg/100 g over the same period, the retention of AA was approximately 89.14%. These findings illustrate the relative stability of ascorbic acid in RJP and bulb during the 40-day storage period under HPP, indicating that a significant portion of the initial AA content remains preserved despite storage-related losses. The deterioration of AA in stored fruits, including jackfruit, can be attributed to several factors as suggested by Sakhale *et al* (2012). These include exposure to light, oxidation of AA to dehydroascorbic acid, and the influence of enzymes such as cytochrome oxidase, ascorbic acid oxidase, and peroxidase. Additionally, both aerobic and anaerobic reactions play roles in AA degradation. According to Szczepanska *et al*. (2022), the concentration of vitamin C in cloudy apple juice treated at 600 MPa showed a significant degradation (60–80%) during storage after three weeks at 4°C. In industrial practice, the decline in AA content often determines the shelf life of juice samples, with a 50% decrease generally marking the point of reduced quality. Jackfruit samples treated with HPP can typically maintain acceptable quality for up to 40 days of refrigerated storage before reaching this critical threshold. This underscores the effectiveness of HPP in preserving AA levels compared to traditional methods, ensuring prolonged freshness and nutritional quality in stored ripe jackfruit.

The ANOVA revealed a highly significant effect of storage time on the AA content for both RJB and RJP ($p < 0.001$). Post hoc tests using Duncan's method demonstrated three distinct homogeneous subsets for both RJB and RJP , indicating that the rate of AA degradation differed significantly across storage times. For the RJP, the lowest AA content was observed on the 40th day, with a mean value of 7.62 ± 0.17 mg/100g, and the highest content on the 0th day, with a mean value of 9.47 ± 0.48 mg/100g. Similarly, for the RJB, the lowest AA content was recorded on the 40th day (14.85 ± 0.21 mg/100g) and the highest on the 0th day (16.65 ± 0.33 mg/100 g).

These findings indicate that HPP at 600 MPa for 20 min (RJP) and 15 minutes (RJB) effectively retained a significant portion of AA during the initial stages of storage but showed a marked decrease as the storage period extended to 40 days.

4.5.4 Effect of storage on TPC of ripe jackfruit

The TPC of high-pressure processed RJP and RJB was evaluated over a 40-day refrigerated storage period. The initial TPC for fresh jackfruit pulp was recorded at 64.78 ± 2.33 mg GAE/g, which decreased significantly to 52.14 ± 1.59 mg GAE/g by the 10^{th} day of storage. For the RJB, the initial TPC was 61.63 ± 0.34 mg GAE/g, which declined to 53.25 ± 0.25 mg GAE/g after 20 days of storage. The TPC values for the high-pressure processed RJP ranged from 70.08 ±0.37 mg GAE/g on the 0^{th} day to 61.15 ±3.29 mg GAE/g on the 40^{th} day. For the high-pressure processed RJB, the TPC values ranged from 66.03±0.64 mg GAE/g on the 0^{th} day to 62.72±0.62 mg GAE/g on the 40^{th} day (Fig 4.63). ANOVA analysis indicated a significant reduction in TPC in RJP and RJB respectively over the storage period ($p < 0.001$). Post hoc analysis with Duncan's test showed that the TPC on the 40^{th} day (61.15±3.29 mg GAE/g and 62.72±0.62 mg GAE/g) was significantly lower than that on the 0^{th} day (70.08±0.37 mg GAE/g and 66.03±0.64 mg GAE/g). This slight decrease could be attributed to the formation of partially soluble polymers during storage, which interact with the Folin–Ciocalteau reagent (Pérez-Vicente *et al*., 2004). These findings align with previous reports by Ozgen *et al*. (2008) and` *et al*. (2009) Varela-Santos *et al*. (2012), who observed similar levels of total phenols. The TPC values indicated a more pronounced reduction in the RJP compared to the RJB over the 40-day storage period. Specifically, the RJP showed a 13% reduction in TPC, whereas the RJB showed only a 5% reduction. The retention of phenolic content in the RJP was less compared to the bulb, suggesting different rates of phenolic degradation or stability between the two forms of jackfruit.

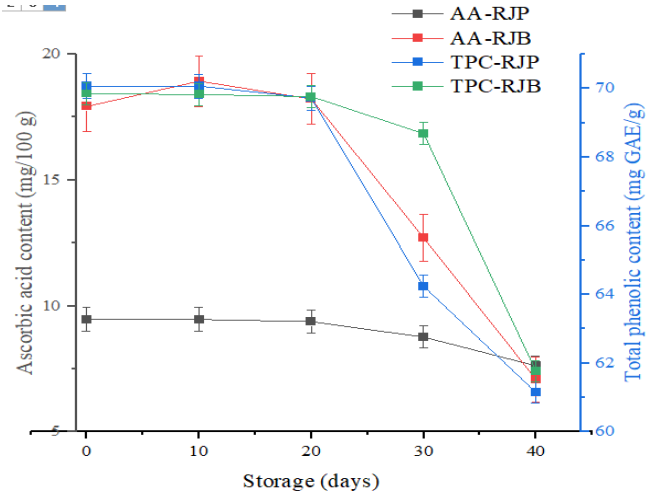


Fig. 4.63 Effect of storage on AA and TPC of HP processed RJP and RJB

4.5.5 Effect of storage on total sugar content of ripe jackfruit

The total sugar content in HP processed RJP and RJB was evaluated over a refrigerated storage period of 40 days, with initial values for the pulp and bulb being 22.62±0.72% and 25.01±0.68%, respectively. In the pulp, the total sugar content decreased from 22.68±0.14% on the 0^{th} day to 21.91±0.72% by the 40^{th} day (Fig 4.64), representing a 3% reduction. In contrast, the bulb exhibited a reduction in total sugar from 25.49± 0.70% initially to 24.66±0.75% after 40 days, a 3.26% decrease was observed, indicating a retention of around 96.71% of its initial sugar content. The variation in sugar content observed in the treated jackfruit samples can be attributed to the varying levels of surviving microbes. By the end of the storage period, the increased number of viable microbes likely led to a more pronounced decline in sugar content. This trend aligns with findings by Wu *et al*. (2021), who reported less than a 9% reduction in glucose and sucrose content in high-pressure processed pineapple juices stored under refrigerated conditions, consistent with previous observations by Huang *et al*. (2017).

ANOVA results showed no significant differences in the total sugar content between the storage intervals for both pulp ($F = 0.630$, $p = 0.652$) and bulb ($F = 1.174$, $p = 0.379$). Duncan's post hoc test further confirmed the homogeneity of total sugar content within each group, indicating consistent sugar levels across the different storage periods.

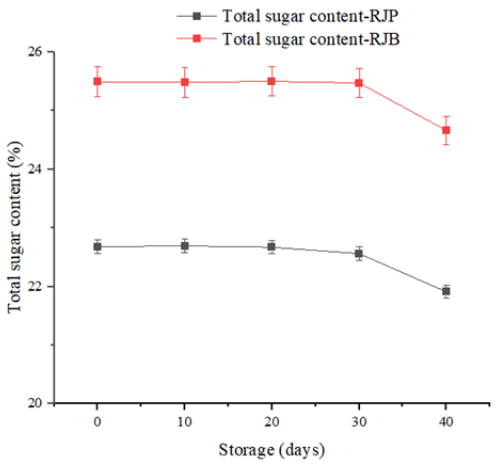


Fig. 4.64 Effect of storage on Total sugar content of HP processed RJP and RJB

4.5.6 Effect of storage on texture of ripe jackfruit

The firmness of RJB was measured as the textural property of the sample during its storage. The effect of HPP at 600 MPa for 20 minutes on the textural properties of RJBs during refrigerated storage was investigated and compared with a control sample. At the initial storage period of 0^{th} day, the texture of the HPP-treated sample (68.35±0.87 N) was significantly higher compared to the control (57.83±0.68 N). This trend continued throughout the storage period. After 10 days, the control sample showed a minor decrease in texture (57.64±0.76 N), whereas the HPP-treated sample maintained a relatively stable texture (68.35± 2.52 N) after 10 days. A marked decrease in texture was observed in the control sample by the 20^{th} day (46.85±1.47 N), indicating a significant loss in firmness of control sample. (Fig 4.65). In contrast, the HPP-treated sample retained its texture well (68.00±2.00 N) at the same time point. The observed reduction in texture in the RJB during storage can be attributed to enzymatic and non-enzymatic depolymerization of pectin and leaching from the RJP. Similar findings were reported by Gao *et al*. (2016), where pressurized strawberries, after storage for 45 and 60 days at 4°C, showed decreased hardness. Statistical analysis using Levene's test

confirmed the homogeneity of variances (p = 0.278), and ANOVA results indicated no significant differences in texture between the storage periods (F(4,10) = 0.095, p = 0.982). Post hoc tests using Duncan's method identified that all storage periods formed a single homogeneous subset, indicating no significant differences in texture between any of the storage periods. These results suggest that HPP treatment at 600 MPa for 20 minutes effectively preserves the textural quality of RJBs during extended refrigerated storage, highlighting its potential as a method for extending the shelf life of fresh produce.

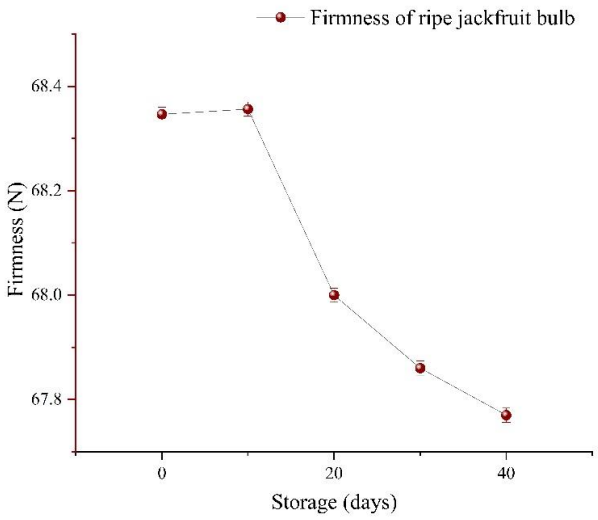


Fig.4.65 Effect of storage on firmness of High pressure processed RJB

4.5.7 Effect of storage on microbial analysis of ripe jackfruit

The microbiological quality of optimized samples of RJB and RJP after HPP and control was determined by monitoring the total aerobic bacteria and yeast and mould counts in the samples (Table 4.13). The mean initial populations of viable aerobic bacteria in RJP and RJB were 3.36±3.25 and 3.18±3.06 log CFU/g, respectively, while the initial populations of yeast and mold were 3.10 ±2.58 and 3.11± 2.11 log CFU/g, respectively. Over the storage period, the control samples showed a significant increase in microbial population and yeast and mold counts. The control samples of fresh pulp were stable up to 10 days, and the bulb was stable only up to 15 days under refrigerated storage. For the RJP control, the microbial population increased to an average of

8.18±3.26 log CFU/g by day 10. In the case of RJB control, the microbial population increased to an average of 8.76 ± 1.28 log CFU/g by day 15.

The HPP at 600 MPa for 15 and 20 min significantly reduced the microbial population. For RJP processed at 600 MPa for15 min, the microbial counts were <1 log CFU/g up to 20 days, and then increased to 2.48±1.02 log CFU/g by day 30 and 3.88±1.07 log CFU/g by day 40. Similarly, for RJB processed at 600 MPa/20 min, microbial counts remained <1 log CFU/g up to 20 days increasing to 2.55±1.74 log CFU/g on day 30 and 2.66±1.20 log CFU/g on day 40. The increase in the number of total aerobic bacteria (TAB) in ripe jackfruit samples is likely due to the reproduction of surviving cells and the recovery of injured cells (Wu *et al*., 2021).

The yeast and mold counts in control samples also increased over time, with RJP control showing an increase from 3.10 ±2.58 log CFU/ml on day after processing to 6.23±2.85 log CFU/ml on day 10,. RJB control samples showed an increase from 3.11±2.11 log CFU/g on day 0 to 6.38±2.07 log CFU/g on day 15. In contrast, HPP-treated samples showed significantly lower yeast and mold counts. For RJP processed at 600 MPa/15 min, counts remained <1 log cfu/ml up to 20 days, then increased to 2.50 ±2.78 log cfu/g on day 40. RJB processed at 600 MPa for 20 min also maintained counts of <1 log cfu/g up to 20 days, increasing to 2.79±2.09 log cfu/g by day 40. These results indicate that HPP at 600 MPa significantly reduces the microbial population and yeast and mold counts in RJP and RJB, maintaining lower levels over the storage period compared to the control samples. Similarly, Liu *et al*. (2016) reported that yeast and mold counts in cucumber juice treated by HPP (500 MPa/5 min) were undetectable during the first 20 days of storage at 4°C. However, a resurgence of yeast and mold counts and coliforms was noted in the end of storage period.

Wu *et al*. (2021) observed an upward trend in the counts of total aerobic bacteria (TAB) in high-pressure processed pineapple fruit juices during 28 days of storage, with counts reaching 2.02 log CFU/mL. The study also noted that yeast, mold, and coliforms were undetected in HPP- for the first 21 days, but were measurable by day 28, aligning with previous research on microbial resurgence during storage.

Table. 4.13 Effect of storage on microbial activity of HP processed RJP and RJB

Sample	Treatments	Storage time (days)	Total aerobic bacteria (log10 CFU/mL)	yeast and mould counts (log10 CFU/mL)
RJP	Control (Fresh RJP)	0	3.36±3.25	3.10±2.58
		10	8.18±3.26	6.23±2.85
	HPP (600MPa for 15 min)	0	<1	<1
		10	<1	<1
		20	<1	<1
		30	2.48±1.02	2.50±2.78
		40	3.88±1.07	3.05±1.78
RJB	Control (Fresh RJB)	0	3.18±3.06	3.11±2.11
		10	6.60±2.14	3.98±2.04
		15	8.76±1.28	6.38±2.07
	HPP (600MPa for 20 min)	0	<1	<1
		10	<1	<1
		20	<1	<1
		30	2.55±1.74	2.29±2.23
		40	2.66±1.20	2.79±2.09

Data shown are the mean±SD of three treatment repetitions

4.5.8 Effect of storage on sensory analysis of ripe jackfruit

The sensory analysis of high-pressure processed RJB and RJP was conducted over a storage period of 40 days, assessing attributes such as colour, aroma, consistency/texture, and overall acceptability.For RJB, the colour scores showed a slight decline from 6.5 ± 0.25 on day 1 to 6.04 ± 0.64 by day 40 (Fig 4.66). This decrease indicates a gradual loss of visual appeal, likely due to oxidative changes and pigment degradation, which are common in fruit products during storage (Cumplido-Laso *et al*., 2022). The aroma score also decreased from 7.00 ± 0.54 on day 1 to 6.31 ± 0.63 by day 40, suggesting a loss of volatile compounds responsible for the fresh aroma of the RJB,

potentially influenced by storage conditions and the high-pressure processing itself (Barros-Castillo *et al*, 2023). Consistency/texture scores declined from 7.1 ± 0.62 on day 1 to 6.11 ± 0.85 by day 40, with these changes attributed to enzymatic activities and moisture loss, impacting the structural integrity of the RJB (Ng *et al*., 2020). Consequently, the overall acceptability score dropped from 7.3 ± 0.88 on day 1 to 6.01 ± 0.76 by day 40, reflecting the cumulative effects of changes in colour, aroma, and texture on sensory appeal over time.Similarly, the colour scores for RJP decreased from 6.4±1.02 on day 1 to 5.9±1.11 by day 40, indicating pigment degradation and potential browning reactions that affect the visual quality of the pulp (Cumplido-Laso *et al*., 2022). The aroma scores also fell from 6.8±0.14 on day 1 to 6.00±1.03 by day 40, suggesting a loss of freshness and aromatic compounds, likely due to the volatilization of these substances and possible microbial activities during storage (Zhao *et al.*, 2024). The consistency/texture scores for RJP showed a notable decline from 6.9±0.89 on day 1 to 6.00±1.03 by day 40, linked to the breakdown of cell walls and pectin substances, resulting in a softer and less desirable texture (Wang *et al*., 2018).

Overall acceptability for RJP decreased from 6.8±0.15 on day 1 to 5.81±0.66 by day 40, indicating a significant decline in sensory appeal over the storage period due to combined changes in colour, aroma, and texture (Fig 4.67).The decreasing sensory scores for both RJB and RJP highlight the challenges in maintaining the sensory quality of HPP jackfruit products over time. The decline in colour can be attributed to oxidative reactions and enzymatic browning, while aroma loss is likely due to the volatilization of aroma compounds and potential microbial activities. Changes in consistency/texture are often a result of enzymatic breakdown of cell wall components and moisture migration, exacerbated by high-pressure processing. Overall, while HPP can extend the shelf life of jackfruit products by inactivating microorganisms and enzymes, the sensory quality deteriorates over time. This underscores the need for optimized storage conditions and the potential use of preservatives to maintain the sensory attributes and consumer acceptability of HPP jackfruit products over extended periods.

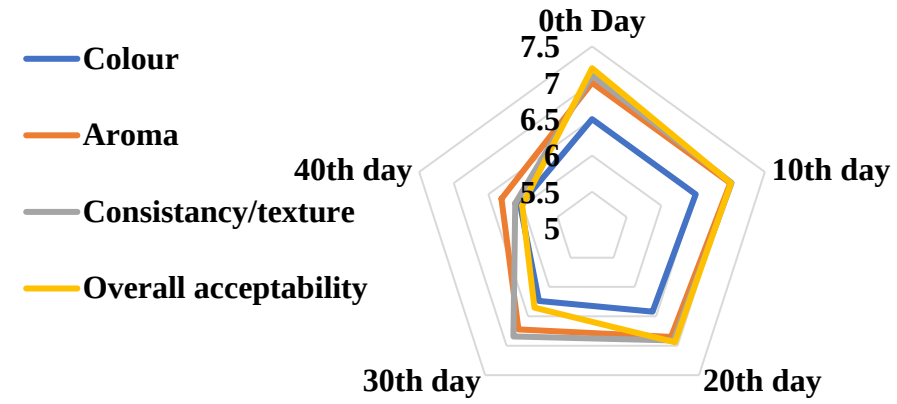


Fig.4.66 Effect of storage on sensory score of HP processed RJB

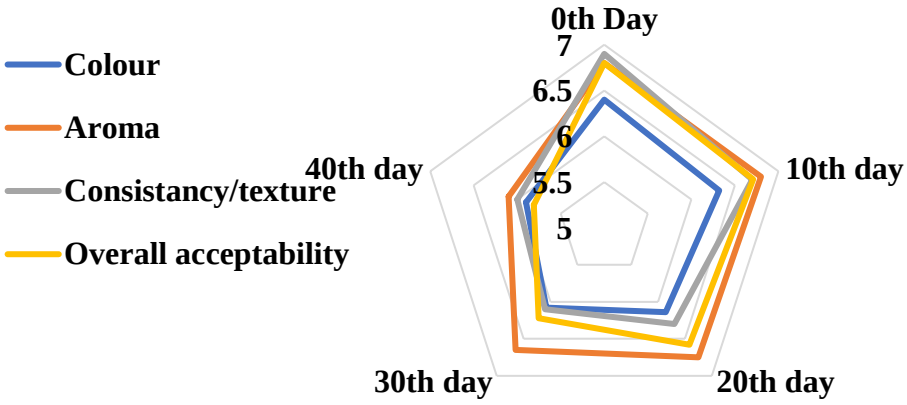


Fig.4.67 Effect of storage on sensory score of HP processed RJP

The study indicated that ripe jackfruit samples maintained their quality for over 40 days. The physicochemical properties exhibited minimal deterioration during storage, and the stored products were microbiologically safe, with microbial counts below 1 log CFU/g. The TPC decreased by only 13 and 5% after 40 days, comparable to the control. AA retention was approximately 80-89% in the stored samples. Sensory scores remained high for up to 30 days.

EXPERIMENT-III

4.6 STANDARDISATION OF PL FOR RJP

The collected ripe jackfruit intended for processing underwent a thorough analysis of its physico-chemical properties, and the results of this analysis have been systematically tabulated and detailed below (Table 4.13). This comprehensive examination involved assessing various physical and chemical attributes of the fruit, providing a detailed understanding of its composition and characteristics before further processing.

Table 4.14 Physico-chemical and microbial properties of fresh RJP prior to PL

Sl.No	Parameters		RJP
1	pH		5.31 ± 0.19
2	TSS (ºBrix)		23.80 ± 1.15
3	TA (%)		0.54 ± 0.02
4	Total sugar (%)		22.42 ± 0.98
5	AA (mg/100 g)		16.85 ± 0.45
		L*	58.69 ± 1.55
7	Colour	a*	7.63 ± 0.20
8		b*	57.45 ± 2.50
9	% DPPH scavenging activity		84.32 ± 3.68
10	TPC (mg GAE/g)		65.14 ± 2.89
11	TFC (mg RE/g)		20.54 ± 0.53

Where, TSS-Total soluble solids, TPC-Total phenolic content, TFC-Total flavonoid content; AA- Ascorbic acid; values are expressed in mean ±SD

4.6.1 Effect of PL on quality characteristics of ripe jackfruit

46.1.1 Effect of PL on pH, TA and TSS of RJP

In the investigation of PL treated RJP, standard analytical methodologies were employed to evaluate pH, TA, and TSS, as delineated in the preceding chapter. The control sample exhibited a pH value of 5.31 ± 0.19, a TA of 0.54 ± 0.02%, and a TSS value of 23.80 ± 1.15 °Brix (Table 4.15). Comparative analysis of PL-treated RJP

revealed pH values spanning from 5.28 ± 0.19 to 5.31 ± 0.13, indicating that the PL treatment did not induce statistically significant alterations in pH ($p > 0.05$). This observation corroborates findings reported by Chakraborty *et al*. (2022) in PL-treated mixed fruit beverages, where no appreciable impact on pH was observed post-treatment. Analogous conclusions were drawn by Teja *et al*. (2017) in UV-C-treated pineapple and apple juice, wherein negligible fluctuations in pH levels were documented. Similarly, Kwaw *et al*. (2018) reported non-significant variations in pH, TA, and TSS in PL-treated lactic acid-fermented mulberry juice.

The PL treatment yielded TA values within the range of 0.53 ± 0.02% to 0.55 ± 0.02%, as illustrated in Table 4.15. Notably, elevated TA values were observed at 2 kV under 200 and 125 pulse conditions. The statistical analysis elucidated that the applied voltage, pulse number, and vertical distance from the PL lamp to the sample did not exert a statistically significant influence ($p > 0.05$) on TA, suggesting that variations in these parameters did not induce substantial modifications in TA levels. These findings align with those of Shaik and Chakraborty (2022), who reported no significant alterations in the pH and TA of sweet lime juice following PL processing at 3 kJ/cm².

TSS levels in both fresh and PL-treated RJP were systematically assessed. The TSS values of the treated samples ranged from 23.70 ± 0.85 to 24.50 ± 0.64°Brix. In congruence with pH and TA findings, TSS exhibited no statistically significant modifications ($p > 0.05$) in response to treatment parameters, including applied voltage, pulse number, and vertical distance from the PL lamp to the sample. However, the highest TSS value (24.50 ± 0.64°Brix) was recorded in samples positioned closest to the lamp under applied voltages of 1.5 kV and 2 kV with corresponding pulse numbers of 200 and 125. This increase in TSS may be attributed to water loss via evaporation, consequently leading to a concentration effect. Comparable outcomes were reported by Palgan *et al*. (2011) in high-intensity PL-treated apple juice, orange juice, and milk. The results derived from the statistical confirmed that process parameters did not significantly influence ($p > 0.05$) the TSS of PL-processed RJP. Table 4.15, presented below, delineates the variations in these physicochemical parameters across different PL treatment conditions

4.6.1.2 Colour characteristics of PL-processed RJP

The untreated RJP exhibited a colorimetric profile characterized by L* = 58.69 ± 1.55, a* = 7.63 ± 0.20, and b* = 57.45 ± 2.50. The chromatic attributes of PL-processed RJP were meticulously assessed, with recorded values ranging from L* = 55.15 ± 1.42 to 56.47 ± 2.02, a* = 7.12 ± 0.31 to 9.04 ± 0.41, and b* = 56.18 ± 2.59 to 58.05 ± 1.53 (Table 4.16). As demonstrated in Table 4.16, subtle variations were observed in the color parameters (L*, a*, b*) of PL-treated RJP compared to the untreated control. The L* parameter, indicative of sample luminosity, decreased from 58.69 ± 1.55 to 55.15 ± 1.42 upon processing under intensified conditions (2.5 kV and 200 pulses) at a lamp-to-sample distance of 7 cm. The reduction in L* was statistically insignificant ($P > 0.05$), suggesting a perceptible darkening effect due to PL treatment. Furthermore, diminishing the lamp-to-sample distance was associated with a further decline in lightness.

Post-PL processing, a* values exhibited a minor increase, signifying a shift towards a redder hue; however, the increment remained statistically non-significant ($P > 0.05$). The most pronounced a* value (9.04 ± 0.41) was observed at 2 kV/200 pulses/4 cm lamp-to-sample distance. Likewise, the marginal increase in b* values was deemed statistically insignificant ($P > 0.05$). The maximum b* value (58.12 ± 1.53) was recorded under 2.5 kV/200 pulses at a 7 cm proximity to the lamp, indicating that PL-treated RJP exhibited a darker visual appearance due to elevated b* values. The observed variations in L*, a*, and b* values may be attributed to the photo-oxidative degradation of colour pigments within RJP during PL exposure (Chakraborty *et al*., 2020). Chia *et al*. (2012) postulated that non-enzymatic Maillard browning, exacerbated by high voltage and pulse intensity, may have contributed to the observed outcome. Comparable findings were reported by Donsingha and Assatarakul (2018), who noted a significant rise in a* values in UV-treated coconut water. Such variations can be ascribed to disparities in sample composition and processing methodologies. The perceptible alterations in yellowness and greenness may stem from pigment decomposition or isomerization, particularly of carotenoids and chlorophyll, as well as the genesis of dark-coloured compounds, potentially induced via photooxidation (Guerrero-Beltran and Barbosa-Cénovas, 2006).

The calculated ΔE values for PL-treated RJP spanned from 2.44 ± 0.11 to 3.59 ± 0.13. The control samples exhibited BI and YI values of 119.87 ± 3.17 and 139.84 ± 6.10, respectively. After PL treatment, BI values fluctuated between 122.88 ± 3.25 and 129.47 ± 5.69, while YI ranged from 142.89 ± 5.15 to 149.51 ± 3.98. The most pronounced ΔE value (3.59 ± 0.13) was registered under 2.5 kV, 200 pulses, and a 7 cm lamp-to-sample distance, conditions that also corresponded with the peak BI of 149.51 ± 3.98. The increased b* value at 2.5 kV/200 pulses accounted for the maximal YI observed under this treatment. Relative to the control, the augmented YI values signified an increase in BI, typically associated with the photodegradation of pigments, notably carotenoids and anthocyanins—although their presence in PL-treated RJP remains relatively limited. According to Cserhalmi *et al*. (2006), perceptible colour differences are classified as "noticeable" (ΔE = 1.5–3.0), "well visible" (ΔE = 3.0–6.0), and "significant" (ΔE = 6.0–12.0). Except for the most intense PL treatment, all PL-exposed samples exhibited a "noticeable" colour change, while the 2.5 kV/200 pulse treatment resulted in a "well visible" alteration (ΔE = 3.6). Elevated PL doses yielded more discernible colour transformations, particularly in conditions involving reduced lamp distances and higher pulse intensities, wherein the impact on chromatic attributes was more pronounced relative to alternative processing configurations (Teja *et al*., 2017).

Table 4.15 Effect of PL on pH, TA and TSS of RJP

Treatment	Voltage (kV)	Pulse number	Distance (cm)	pH	TSS (˚Brix)	TA (%)
PL1	1.5	50	7	5.30±0.23	24.40±0.14	0.54±0.02
PL2	2.5	50	7	5.31±0.24	24.00±1.0	0.55±0.02
PL3	1.5	200	7	5.29±0.13	24.40±0.28	0.54±0.01
PL4	2.5	200	7	5.28±0.19	23.90±0.63	0.55±0.02
PL5	1.5	125	4	5.29±0.19	24.50±0.64	0.54±0.12
PL6	2.5	125	4	5.31±0.13	24.40±1.12	0.55±0.15
PL7	1.5	125	10	5.29±0.24	23.70±0.85	0.54±0.24
PL8	2.5	125	10	5.29±0.19	23.90±0.63	0.55±0.02
PL9	2	50	4	5.30±0.14	23.90±1.29	0.54±0.01
PL10	2	200	4	5.29±0.19	24.50±0.64	0.54±0.12
PL11	2	50	10	5.30±0.23	24.40±0.14	0.53±0.02
PL12	2	200	10	5.29±0.19	23.90±0.63	0.55±0.02
PL13	2	125	7	5.29±0.18	23.80±0.85	0.55±0.20
PL14	2	125	7	5.31±0.19	23.90±0.63	0.54±0.18
PL15	2	125	7	5.31±0.14	24.00±1.04	0.54±0.03
PL16	2	125	7	5.31±0.23	24.30±0.84	0.55±0.02
PL17	2	125	7	5.31±0.24	24.40±1.11	0.54±0.02

Where,TSS-Total soluble solids, TA-Titrable acidity; values are expressed in mean ±SD

Table 4.16 Colour characteristics of PL-processed ripe jackfruit

Treatment	L*	a*	b*	ΔE	BI	YI
PL1	55.94±1.52	7.42±0.32	56.35±1.95	2.97±0.13	123.68±4.46	143.91±4.99
PL2	55.88±2.03	7.68±0.27	56.35±2.58	3.02±0.10	123.92±4.47	144.06±6.60
PL3	56.47±2.02	7.95±0.36	56.48±2.05	2.44±0.11	122.88±3.25	142.89±5.15
PL4	55.15±1.42	7.95±0.29	58.12±1.53	3.61±0.13	130.55±5.69	150.55±3.98
PL5	55.79±2.48	7.32±0.19	56.30±2.03	3.13±0.08	123.89±5.68	144.17±5.20
PL6	55.62±2.48	8.05±0.31	58.00±2.08	3.14±0.11	128.92±5.91	148.97±5.37
PL7	55.63±2.63	8.56±0.31	57.65±1.50	3.20±0.12	128.16±4.62	148.05±3.92
PL8	55.54±1.98	8.52±0.23	57.38±2.49	3.27±0.09	127.69±3.38	147.59±6.43
PL9	56.12±1.51	7.12±0.31	56.27±2.59	2.87±0.13	122.93±5.36	143.24±6.56
PL10	56.21±2.44	9.04±0.41	58.05±2.66	2.91±0.13	127.78±4.43	147.54±6.76
PL11	56.00±2.01	7.99±0.37	56.52±2.03	2.87±0.13	124.15±5.69	144.19±5.20
PL12	56.01±2.56	8.46±0.31	57.18±1.53	2.82±0.10	125.91±4.54	145.84±3.86
PL13	56.42±2.02	8.64±0.23	56.71±2.50	2.59±0.07	123.80±3.28	143.59±6.26
PL14	56.15±1.46	8.55±0.37	56.72±1.98	2.96±0.13	123.25±4.44	143.03±4.95
PL15	56.06±1.98	8.64±0.30	56.68±2.62	3.09±0.11	123.42±4.45	143.17±6.56
PL16	56.12±2.02	7.42±0.34	56.42±2.07	2.77±0.13	123.40±3.26	143.62±5.18
PL17	55.22±1.46	8.58±0.31	57.38±1.52	3.60±0.13	128.59±5.61	148.45±3.93

Where, BI: Browning index, YI: Yellowness index; values are expressed in mean ±SD

4.6.1.3 Effect of PL on the AA content

The untreated RJP reported an AA value of 16.85±0.45 mg/100g. The average AA of PL processed RJP ranged from 13.98±0.50 to 16.62±0.73. The AA retention in the PL processed ripe jackfruit is depicted in Fig 4.67 and shows a significant decline with voltage, pulse number and lamp to sample distance. Elevating the dose level to 2.5 kV/200 flashes led to a statistically significant decline in AA ($P \leq 0.05$). At this increased dose level, with a minimum distance of 7cm from the lamp, the AA content decreased from 16.74±0.73 to 13.98±0.50 mg/100g (Fig 4.68 a, b & c). This indicates that higher voltage doses, increased flashes, and reducing the distance between the lamp and the sample during treatment resulted in a significant reduction in the AA content in the RJP. There was a maximum reduction of 17% in AA reported in RJP at this condition. Chakraborty *et al*. (2014) reported that, as pulses and voltage levels increased during PL treatments, the extent of AA degradation increased as well.

The degradation of AA significantly contributes to non-enzymatic browning reactions in fruit juices. PL treatment can lead to variable AA loss in juices, with higher voltages potentially causing more significant losses due to a phenomenon known as a spectrum shift also known as blue shift or hypsochromic (Dhar and Chakraborty., 2023). The research conducted by Bhagat and Chakraborty (2022) provided strong evidence that higher voltages corresponded to greater depletion of AA.

The statistical analysis demonstrated that voltage, pulse number, and lamp-to-sample distance were significant model terms. Additionally, the interaction effects between voltage and lamp-to-sample distance, as well as between pulse number and lamp-to-sample distance, were also significant. The R^2 value indicates that approximately 98.99% of the variability in the data can be explained by the model. The adjusted R^2 value, which adjusts for the number of predictors in the model, suggests that about 97.69% of the variability is explained while considering the complexity of the model. The predicted R^2 value of 0.93 is reasonably close to the adjusted R^2 value of 0.98. This suggests that the model is performing well in predicting new observations, as the predicted R^2 is not substantially lower than the adjusted R^2. Additionally, the

adequate precision value of 27.51 indicates that the signal-to-noise ratio is sufficiently high, which implies that the model can be used to make reliable predictions (Table D2). The final regression equation for AA in terms of coded factors is given below:

$$AA\ (mg/100g) = 14.91 - 0.95V - 0.38P + 0.33D - 0.063VP - 0.18VD - 0.30PD + 0.047V^2 + 0.46P^2 + 0.20D^2 \quad \ldots. (4.72)$$

Where, V: Voltage (V), P: Number of Pulses, D: lamp to sample distance (cm)

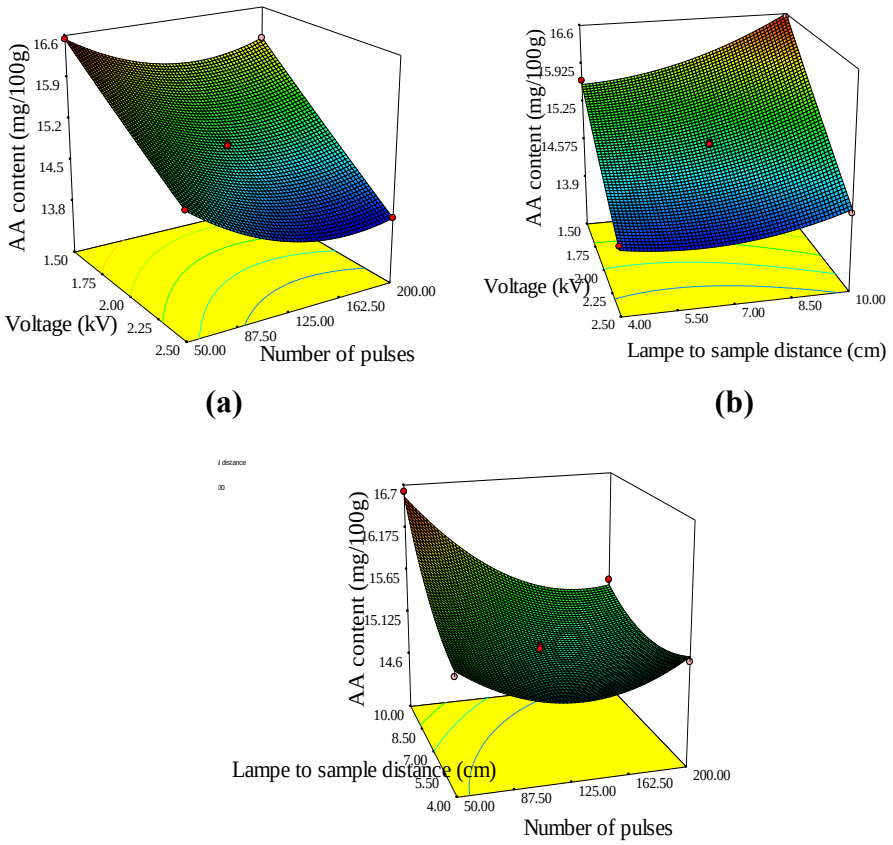


Fig.4.68 AA content of PL treated RJP

4.6.1.4 Effect of PL on the TPC and TFC of PL treated RJP

The fresh RJP exhibited a TPC of 65.14 ± 2.89 mg GAE/g and a TFC of 20.54 ± 0.53 mg RE/g. The treatment process resulted in a TPC range of 62.45 ± 1.65 to 66.10

± 2.87 mg GAE/g (Fig. 4.69 .69a, b & c), while TFC varied between 17.58 ± 0.77 and 21.12 ± 0.71 mg RE/g (Fig. 4 .70a, b & c) across all PL treatment conditions. The application of PL treatment either preserved or slightly enhanced TPC and TFC at lower dosages. However, a statistically significant decline ($P > 0.05$) was observed at higher intensities. Specifically, an increase of 1.58% in TPC was noted at 2 kV/200 pulses/4 cm lamp-to-sample distance, while TFC exhibited a 2.74% enhancement under identical conditions. Conversely, at 2.5 kV/200 pulses/7 cm, TPC and TFC demonstrated a maximum reduction of 4.14% and 14.4%, respectively.

Statistical analysis via ANOVA for the response surface quadratic model further validated these observations. The ANOVA results for TPC demonstrated a highly significant model ($P = 0.0002$), with voltage (A) ($P < 0.0001$), voltage-pulse number interaction ($P = 0.004$), and voltage squared ($P < 0.0001$) emerging as significant model terms (Table D3). The model exhibited an R-squared value of 0.97, with an adjusted R-squared of 0.93 and a predicted R-squared of 0.86, indicating a robust predictive capacity. The adequate precision of 15.14 further affirmed the model's reliability in navigating the design space. The lack of fit ($P = 0.80$) was non-significant, reinforcing the validity of the model.

For TFC, ANOVA results also indicated a significant model ($P < 0.0001$). Voltage (A) ($P < 0.0001$), vertical distance (C) ($P = 0.0095$), voltage-pulse number interaction (AB) ($P = 0.0002$), and pulse number-vertical distance interaction (BC) ($P = 0.0172$) were identified as significant contributors. The model's R^2 value stood at 0.9765, with an adjusted R^2 of 0.9463 and a predicted R^2 of 0.8406, suggesting a high degree of model accuracy (Table D4). The adequate precision value of 19.386 confirmed a strong signal-to-noise ratio, reinforcing the model's predictive capability. The lack of fit remained non-significant ($P = 0.5745$), ensuring the model's suitability for further application.

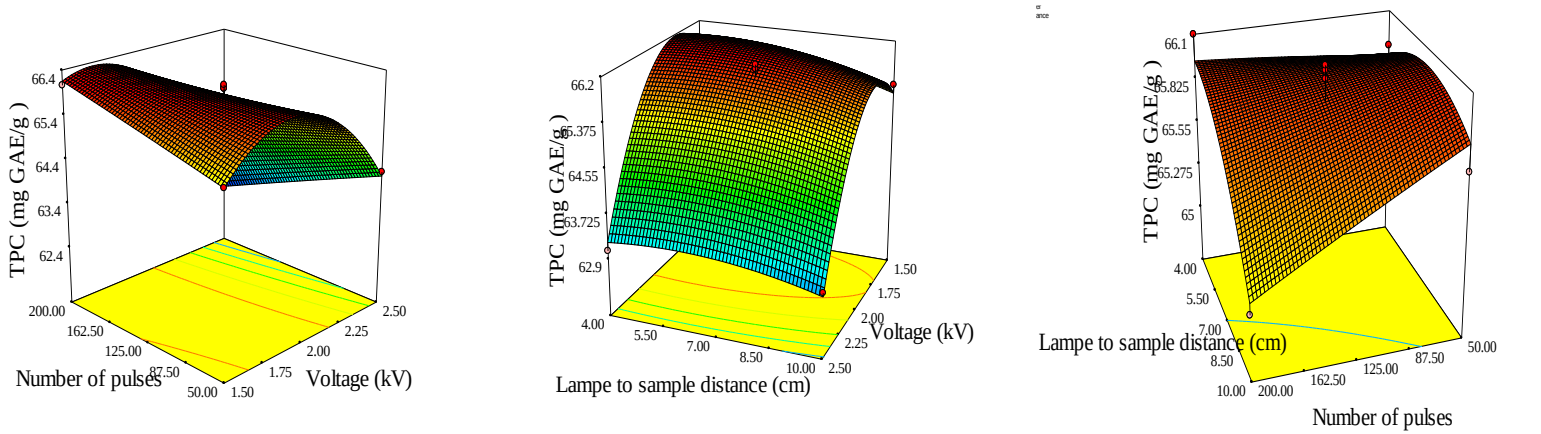
Previous literature corroborates these findings. Valdivia-Nájar *et al*. (2018) reported an increase in TPC in PL-treated tomato slices, while Agüero *et al*. (2016) noted enhanced phenolic and antioxidant activity in PL-treated spinach. Teja *et al*. (2017) documented a maximum reduction of 8% in TPC in PL-treated pineapple juice, aligning with the trends observed in the present study.

The preservation of bioactive compounds in RJP is attributed to the presence of complex protective compounds that mitigate oxidation processes, thermal degradation, and photodecomposition. These compounds act as natural safeguards against PL-induced degradation (Basak *et al*., 2022). Additionally, multiple studies have demonstrated that PL exposure stimulates phenolic biosynthesis via stress-response activation. However, certain investigations have reported negligible changes or negative effects at elevated PL intensities and prolonged pulse durations. Pataro *et al*. (2015) and Vargas-Ramella *et al*. (2021) posited that PL, being a surface treatment, potentially shields polyphenols, which are predominantly sequestered in vacuoles, thereby minimizing their degradation. The present study supports these findings, reinforcing the potential of PL treatment as a non-thermal technology for preserving the phenolic and flavonoid integrity of RJP.

$$\text{TPC (mg GAE/g)} = 65.86-1.20V-0.14P-0.21D-0.65\,VP+0.070\,VD-0.21P\,D1.40V^2-0.011P^2-0.19D^2 \quad \ldots (4.73)$$

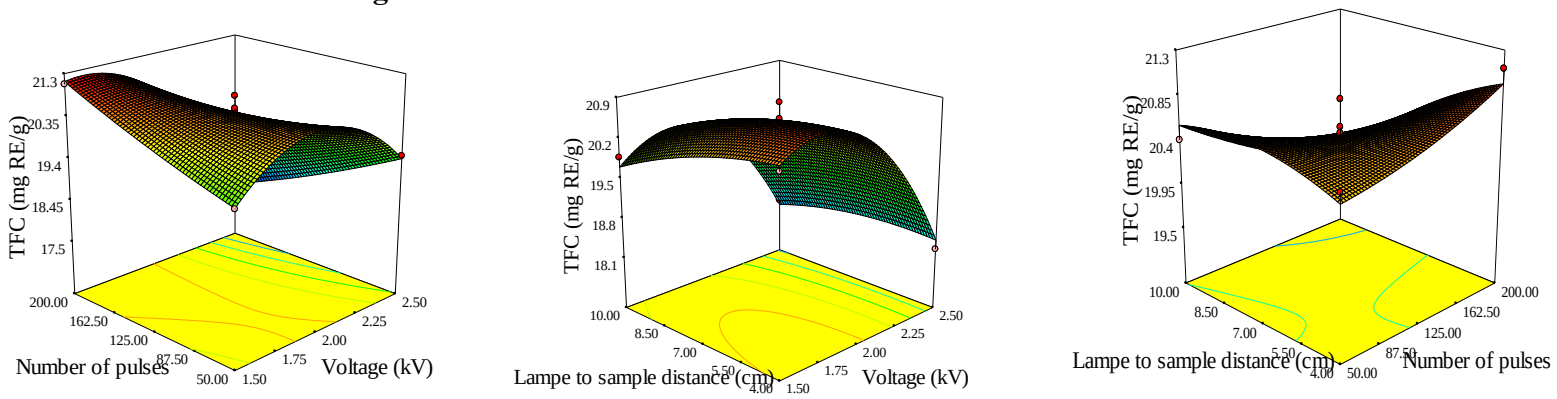
$$\text{TFC (mg RE/g)} =20.46-0.95V-0.094P-0.30D-0.84VP+0.14PD-0.37PD-1.10V^2+0.080P^2-0.15D^2 \quad \ldots (4.74)$$

Where, V: Voltage (V), P: Number of Pulses, D: lamp to sample distance (cm)



(a) **(b)** **(c)**

Fig 4.69 Effect of PL on the TPC of PL treated RJP



(a) **(b)** **(c)**

Fig 4.70 Effect of PL on the TFC of PL treated RJP

4.6.1.5 Effect of PL on the total sugar content

The total sugar concentration in the untreated RJP was initially recorded at 22.42 ± 0.98%. Following PL treatment, a slight increase in total sugar content was observed, ranging from 22.41 ± 1.03% to a maximum of 22.65%. However, this increase was determined to be statistically insignificant ($p>0.05$). Notably, the highest total sugar content was recorded at a PL treatment intensity of 1.5 kV with 125 pulses at a 10 cm lamp-to-sample distance. These findings are consistent with the observations reported by Ashitha and Prince (2020), who investigated the effect of PL treatment on pineapple and cashew apple juices under varying process conditions (PL dosage: 8-32 J/cm², sample source distance: 5-15 cm, and flow rate: 150-300 mL/min), concluding that no significant alterations were induced in the total sugar content of the treated samples.

The observed increment in total reducing sugars in bael fruit juice post-PL treatment has been attributed to enhanced extraction mechanisms, facilitated either by the liberation of sugars from the food matrix or through hydrolytic degradation processes (Dhar and Chakraborty, 2023). Similarly, Aguiló-Aguayo *et al*. (2015) documented a 19% increase in fructose at a PL dosage of 5.41 J/cm² and a 5.7% enhancement in β-glucose following a 2.26 J/cm² PL exposure in carrot slices. The variability in total sugar content observed across different PL process conditions applied to RJP is systematically presented in Table 4.3.

Statistical analysis of the data indicates the absence of significant model terms, as evidenced by "Prob > F" values exceeding the threshold of 0.1000. Moreover, the Lack of Fit F-value was calculated to be 1.23, signifying that the lack of fit is not statistically significant when compared to the pure error component. The probability of obtaining a Lack of Fit F-value of this magnitude purely due to noise was estimated at 45.99%. These statistical findings reinforce the conclusion that while PL treatment induces slight modifications in total sugar content, these alterations are not statistically significant and likely result from minor biochemical or physicochemical changes induced by PL exposure.

4.6.1.6 Effect of PL on the DPPH radical scavenging activity

The DPPH radical scavenging activity of fresh RJP was determined to be 84.32 ± 3.68%. Upon PL treatment, the DPPH radical scavenging activity exhibited a range between 83.15 ± 3.81% and 84.78 ± 2.94%, with the majority of treatment conditions leading to either full retention or a slight enhancement of DPPH radical scavenging activity. Notably, a maximal increase in DPPH radical scavenging activity was recorded at 1.5 kV/125 pulses/4 cm, whereas the most intense treatment at 2.5 kV resulted in a 1.40% reduction. These variations highlight the nuanced effects of PL treatment on antioxidant activity, with more severe intensities inducing minor degradative impacts.

A similar trend has been observed in PL-treated Amla juice, where Chakraborty *et al*. (2020) reported a peak increase of 4% at 2.8 kV/5 min, contrasted with a 3% decline at 2.9 kV/3 min. Additionally, Vollmer *et al*. (2020) demonstrated that PL treatments ranging from 160 to 375 J/cm² had no statistically significant impact on the antioxidant capacity of pineapple juice. The enhancement in antioxidant properties is potentially attributed to the activation of phenylalanine ammonia-lyase, which plays a crucial role in phenolic biosynthesis. Furthermore, light-induced modifications in the structural conformation of phenolic compounds, particularly benzoic ring transformations, coupled with the thermal effects of infrared radiation, may contribute to the observed variations in antioxidant efficacy, especially under more intense PL conditions (Chakraborty *et al*., 2020).

Comparative studies by Basak *et al*. (2022) evaluated the efficacy of PL treatment (3000 J/cm²) versus conventional thermal processing (90 °C for 5 minutes) on a mixed juice comprising apple bear, carambola, and black table grape. Their findings indicated a 12.8% reduction in antioxidant capacity following PL exposure, reinforcing the hypothesis that higher PL dosages may induce oxidative degradation in bioactive components.

The statistical analysis using three-way ANOVA revealed that the process parameters had no statistically significant effect ($p > 0.05$) on the DPPH radical scavenging activity of PL-processed RJP. The variations in antioxidant capacity under different PL treatment conditions are summarized in Table 4.17, underscoring the

complex interplay between PL intensity, exposure duration, and sample positioning in modulating the oxidative stability of bioactive compounds.

Table 4.17 Effect of PL on Total sugar and DPPH radical scavenging activity of RJP

Treatment	Total Sugar Content (%)	DPPH Scavenging activity
PL1	22.48±0.78	84.78±2.94
PL2	22.54±1.03	83.15±3.81
PL3	22.45±0.81	84.66±3.05
PL4	22.55±0.60	84.46±2.23
PL5	22.43±0.81	84.75±3.06
PL6	22.47±0.81	83.53±3.01
PL7	22.65±0.60	84.72±2.24
PL8	22.55±0.98	84.73±3.69
PL9	22.44±1.03	84.67±3.88
PL10	22.41±1.03	84.64±3.88
PL11	22.46±0.81	84.61±3.05
PL12	22.45±0.59	84.59±2.24
PL13	22.44±0.98	84.65±3.69
PL14	22.41±0.78	84.61±2.93
PL15	22.43±1.03	84.63±3.88
PL16	22.53±0.81	83.95±3.03
PL17	22.54±0.60	84.62±2.24

Values are expressed in mean ±SD

4.6.1.7 The rheological properties of PL processed jackfruit pulp

The viscosity of untreated (control) RJP was 61.89 ± 1.12 Pa.s. Following PL treatment, viscosity values ranged from 55.14 ± 1.02 Pa.s to 61.12 ± 0.15 Pa.s, (Fig 4.71), depending on the applied pulse number, lamp-to-sample vertical distance, and

voltage level. The results indicate a general reduction in viscosity with increasing pulse number, shorter vertical distances, and higher voltages.

At a constant voltage of 1.5 kV and vertical distance of 7 cm, increasing the pulse number from 50 to 200 led to a progressive decrease in viscosity from 61.12 ± 0.15 Pa.s to 58.47 ± 0.87 Pa.s. A similar pattern was observed at 2 kV, where viscosity decreased from 58.87 ± 0.76 Pa.s to 57.26 ± 0.81 Pa.s at 125 pulses. This trend suggests that higher pulse numbers facilitate greater structural degradation of the pulp matrix, leading to increased intracellular fluid release and reduced resistance to flow.

The effect of vertical distance was also evident, as reducing the distance from 10 cm to 4 cm at a pulse number of 125 and 1.5 kV resulted in a viscosity drop from 59.26 ± 0.88 Pa.s to 55.14 ± 1.02 Pa.s. This indicates that a shorter lamp-to-sample distance increases light intensity, leading to enhanced modification of pulp structure and a more fluid consistency. However, at shorter distances, the pulp generally displayed higher viscosities, suggesting that closer light exposure induced more structural changes in the pulp matrix (Bhavya and Hebbar, 2017).

Voltage played a role in further reducing viscosity, although its effect was dependent on the pulse number and vertical distance. At a fixed pulse number of 125 and vertical distance of 7 cm, increasing the voltage from 1.5 kV to 2 kV resulted in a viscosity change from 55.72 ± 0.77 Pa.s to 58.87 ± 0.76 Pa.s, respectively. Higher voltage resulted in a slight reduction in the internal structural resistance of the pulp, leading to a lower viscosity (Mandal *et al.,* 2020). While this suggests that higher voltage levels can facilitate structural breakdown, the impact appears to be more pronounced when combined with shorter distances and increased pulse numbers.

Compared to the control (61.89 Pa.s), most PL-treated samples exhibited a reduction in viscosity, with the highest decrease observed at 1.5 kV, 125 pulses, and 4 cm (55.14 ± 1.02 Pa.s), representing a 10.9% reduction. This suggests that higher energy exposure from a shorter distance and moderate pulse numbers maximizes viscosity reduction. The results demonstrate that pulsed light treatment significantly influences the rheological properties of ripe jackfruit pulp, which can be beneficial for processing applications requiring lower viscosity.

The jackfruit pulp consistently exhibited shear-thinning behavior, where its viscosity decreased as the shear rate increased, a hallmark of non-Newtonian fluids. This was evident across all processing conditions. For example, at 2kv and 125 pulses, reducing the shear rate from 1.609 s^{-1} to 1.094 s^{-1} (as the distance decreased) led to an increase in viscosity from 55.65 Pa·s to 62.12 Pa·s. The behavior supports the conclusion that the pulp becomes less viscous as the applied stress increases, making it easier to process.

Fig 4.72 depicts the relationship between shear rate (1/s) and viscosity (Pa.s) for PL-treated jackfruit pulp, along with the control sample. The data shows a clear shear-thinning behavior, where viscosity decreases as shear rate increases. This trend is typical for non-Newtonian fluids, particularly pseudoplastic fluids, where structural breakdown under shear stress leads to reduced viscosity. The power-law model parameters for the control and PL-treated jackfruit pulp were Control: k=255.42, n = 0.61 and PL-Treated: k=268.25, n=0.57. Since n < 1, both control and PL-treated pulp exhibit shear-thinning behavior. However, the PL-treated pulp has a slightly lower flow behavior index (n = 0.57), indicating an enhanced shear-thinning effect, likely due to structural modifications caused by pulsed light exposure. The lower viscosity at higher shear rates further confirms the effect of PL treatment on reducing the internal structural resistance of the pulp

The Analysis of Variance (ANOVA) Table D7 evaluates the significance of voltage (A), pulse number (B), and vertical distance (C) on the viscosity of pulsed-light-treated jackfruit pulp. The overall model is significant (p = 0.0051, F = 6.89 and R^2 = 0.61), meaning that at least one of the factors (A, B, or C) has a statistically significant effect on viscosity. The regression equation for the viscosity is given below

Viscosity= 57.77-1.30 V-1.01 P+1.19D …(4.75)

Where, V: Voltage (V), P: Number of Pulses, D: lamp to sample distance (cm)

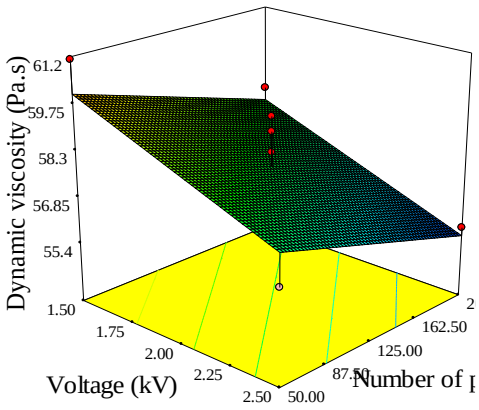


Fig.4.71 Viscosity of PL treated RJP

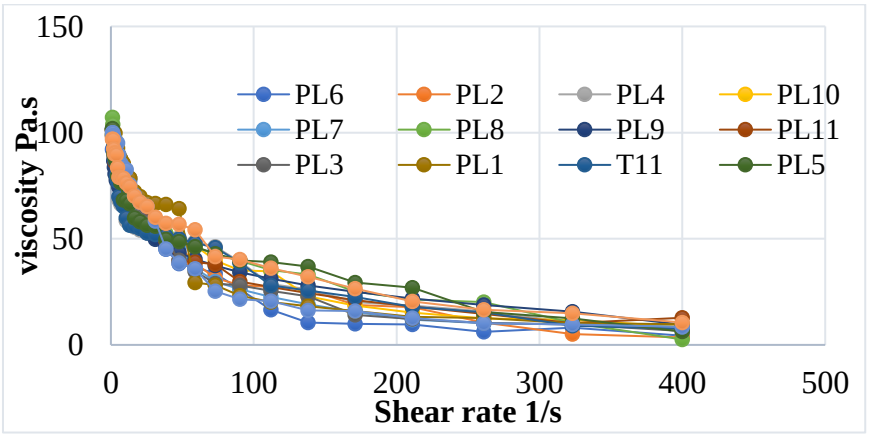


Fig.4.72 Viscosity of PL processed RJP as a function of shear rate

4.6.1.8 Effect of PL on microbial reduction

The study examined the microbial activity of PL processed RJP under various conditions of voltage, pulse number, and vertical distance. The control sample exhibited an initial population of 4.2 log CFU/g. The results revealed that an increase in voltage and pulse number generally led to a significant reduction in both TAM and yeast/mold counts. For TAM, the counts ranged from 1.04 to 6.68 log CFU/g (Fig 4.73). At 1.5 V and 50 pulses, the TAM count was reduced to 1.88 log CFU/g, while at 2.5 V and 200 pulses, the count was reduced to 6.68 log CFU/g. For yeast/mold, the counts ranged from 0.64 to 6.3 log CFU/g (Fig 4.74). At 1.5 V and 50 pulses, the yeast/mold count was 0.95 log CFU/g, and at 2.5 V and 200 pulses, the count was 6.3 log CFU/g. The results revealed that an increase in voltage and pulse number generally led to a significant reduction in both TAM and yeast/mold counts. For instance, at 1.5 V and 50

pulses, the TAM count was reduced to 1.88 log CFU/g and yeast/mold to 0.95 log CFU/g. At 2.5 V and 200 pulses, the reduction was more pronounced, with counts dropping to 6.68 log CFU/g for TAM and 6.3 log CFU/g for yeast/mold. Vertical distance also influenced the microbial reduction, with a distance of 10 cm generally showing lower microbial counts compared to shorter distances. For example, at 2 V, 50 pulses, and a 10 cm distance, the TAM count was 2.2 log cfu/g and yeast/mold were 1.9 log CFU/g. These findings suggest that higher voltages and pulse numbers, along with optimal vertical distances, enhance the effectiveness of PL treatment in reducing microbial populations in RJP. Preetha *et al*. (2016) demonstrated a maximum *E. coli* inactivation of 6.3 log CFU/ml under similar conditions.

The combined photochemical, photothermal, and photophysical mechanisms of PL result in efficient microbial reduction. Prolonged PL exposure can cause immediate microbial cell collapse (Ferrario *et al*., 2014). Increased PL intensity and pulse numbers improve inactivation and reduce the likelihood of photoreactivation. This comprehensive approach explains the enhanced microbial reduction observed in RJP treated with PL. In the study, Vollmer *et al*. 2020 demonstrated that PL treatment of pineapple juice significantly reduces microbial populations. Specifically, a treatment at 2.4 kV with 94 pulses achieved a 5-log cycle reduction in both aerobic mesophiles and yeast and mold counts. Furthermore, increasing the treatment to 2.4 kV with 187 pulses resulted in microbial levels dropping below detection limits.

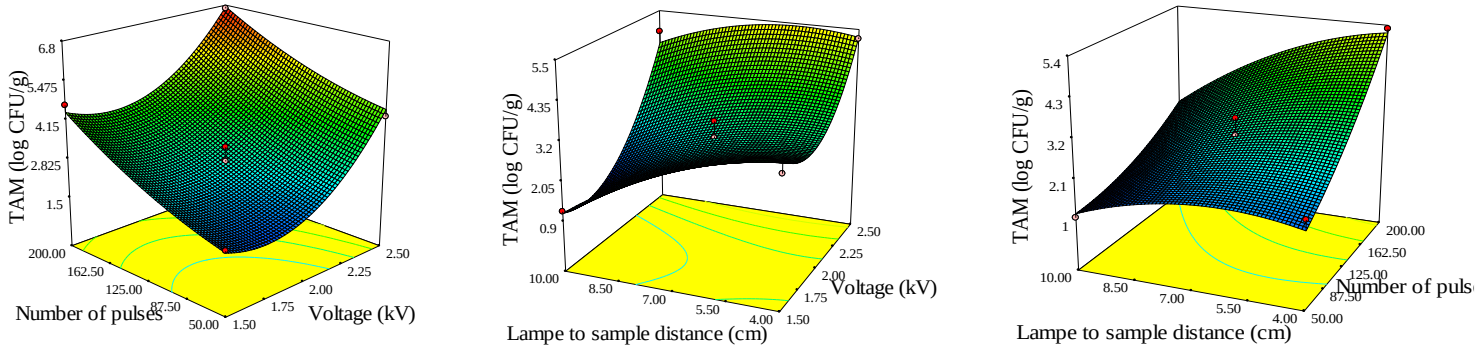
The ANOVA table for the reduction of TAM reveals significant insights into the effectiveness of the applied model. The overall model is statistically significant, indicated by an F-value of 36.04 and a p-value of less than 0.0001, suggesting a mere 0.01% likelihood that such a large F-value could arise from random noise. Significant factors influencing bacterial reduction include voltage V), pulse number (P), vertical distance (D), and the interaction terms VD and PD, along with the quadratic terms V^2 and D^2, all exhibiting p-values below 0.05. Conversely, the interaction term VP and the quadratic term B^2 are not significant, as indicated by their higher p-values. The lack of fit is also non-significant, with an F-value of 2.73 and a p-value of 0.1782, suggesting that the model adequately fits the data without substantial deviations.

The ANOVA results for the reduction in TAM and yeast and mold both demonstrate significant models with high F-values (36.04 and 63.75, respectively) and low p-values (< 0.0001) for the overall models, indicating their effectiveness in evaluating microbial reduction. Key factors such as voltage, pulse number, and vertical distance, along with relevant interaction and quadratic terms, exhibit p-values below 0.05 in both analyses, highlighting their significant influence on reducing total mesophilic bacteria and yeast and Mold. Both models show high R^2 values, with 0.9789 for TAM and 0.9879 for yeast and mold, suggesting strong correlations between observed and predicted values. The predicted R^2 values are also in reasonable agreement with the adjusted R^2 values for both analyses. However, a notable difference is observed in the lack of fit, which was non-significant for yeast and mold (p-value = 0.0900) but significant for total mesophilic bacteria, suggesting that the yeast and mold model better fits the data without substantial deviations. Overall, both models effectively assess microbial reduction, although the yeast and mold analysis demonstrate a stronger fit with a non-significant lack of fit.

$$TAM = 2.80+1.26V+1.21\ P-0.81D-0.11V\ P+0.42\ VD-0.54P\ D+1.29\ V^2+0.30P^2-0.47\ D^2 \quad \text{... (4.76)}$$

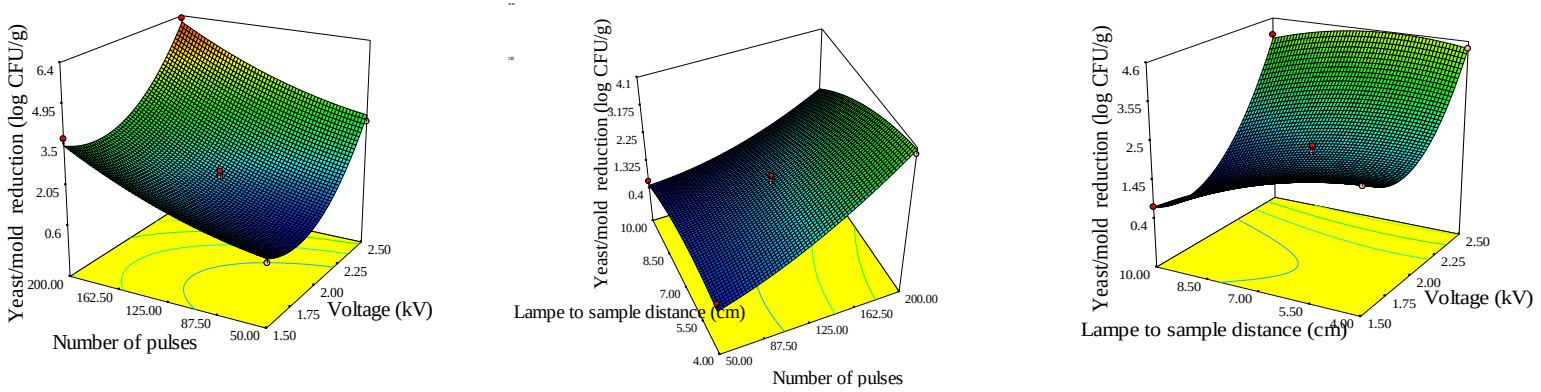
$$Yeast/mold=1.86+1.30V+1.23P-0.55D+0.025VP+0.34VD-0.40PD+1.39V^2+0.36P^2-0.34D^2 \quad \text{…(4.77)}$$

Where, V: Voltage (V), P: Number of Pulses, D: lamp to sample distance (cm)



(a) **(b)** **(c)**

Fig 4.73 Effect of PL on the TAM of PL treated RJP



(a) **(b)** **(c)**

Fig 4.74 Effect of PL on the yeast and mold of PL treated RJP

4.6.1.9 Sensory analysis

The control sample exhibited high scores across all sensory attributes, with colour rated at 8.7, aroma at 8.8, taste at 8.6, texture at 8.8, and overall acceptability at 8.7 (Fig 4.75). These scores set a benchmark for evaluating the effects of PL treatments. When PL was applied at a voltage of 1.5 Kv and a pulse number of 50 with a vertical distance of 7 cm (PL1), the scores for colour, aroma, taste, texture, and overall acceptability were 7, 6.8, 6.6, 8.4 and 6.3, respectively. This treatment showed a noticeable decline in sensory scores compared to the control, particularly in taste and overall acceptability. Increasing the pulse number to 200 under the same voltage and vertical distance (PL3) resulted in colour, aroma, taste, texture, and overall acceptability scores of 7.1, 6.8, 6.9, 8.6 and 7.4, respectively. This indicates a slight improvement in sensory attributes compared to PL1, particularly in taste and texture. When the vertical distance was increased to 10 cm, as seen in PL5 and PL7, the sensory scores generally declined further. For instance, PL5 had scores of 7.3 for colour, 6.8 for aroma, 6.5 for taste, 8.7 for texture, and 7.3 for overall acceptability. This suggests that increasing the vertical distance may negatively impact the sensory attributes of the pulp. For treatments involving varying voltages and pulse numbers with a vertical distance of 7 cm (PL9, PL10, PL11, PL12, PL13, PL14, PL15), the sensory scores varied. For example, PL9, with a voltage of 1.15 and a pulse number of 125, showed scores of 7.2 for colour, 7.1 for aroma, 6.6 for taste, 8.3 for texture, and 7.12 for overall acceptability. This treatment had relatively balanced scores across attributes, indicating a moderate level of acceptance. In contrast, PL11, which involved a voltage of 2 kv and a pulse number of 50, resulted in lower scores: 6.4 for colour, 5.9 for aroma, 5.1 for taste, 8.1 for texture, and 5.4 for overall acceptability. This suggests that inappropriate voltage and pulse number combinations can significantly degrade the sensory quality of the pulp. Overall, the data indicate that PL processing can influence the sensory attributes of RJP, with certain parameter combinations yielding better sensory quality than others. Further optimization of these parameters is necessary to enhance the sensory acceptance of PL processed jackfruit pulp.

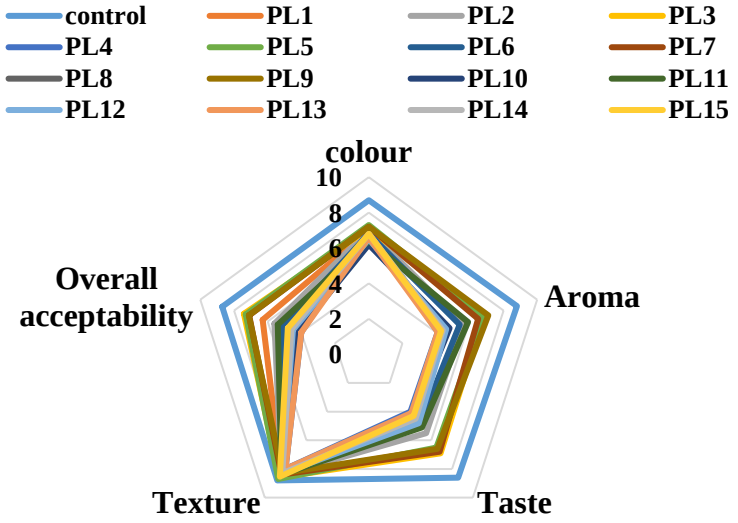


Fig.4.75 Sensory analysis of PL treated RJP

4.6.2 Numerical optimization

The optimization of PL processed RJP utilized a statistical model to balance multiple response variables: AA, TPC, TFC, reduction in microbial load, and yeast/mold count. The constraints were voltage (1.5 to 2.5 kV), pulse number (50 to 200 pulses), and vertical distance (4 to 10 cm). The goal was to maximize AA (13.98 to 16.62 mg/100 g), TPC (62.45 to 66.1 mg GAE/100g), TFC (17.58 to 21.12 mg RE/100 g), TAM (1.04 to 6.68 log CFU/g), and yeast/mold count (0.64 to 6.3 log CFU/g). The optimal solution, as determined by the desirability function, involved using a voltage of 1.50 kV, 200 pulses, and a vertical distance of 4.00 cm. This configuration resulted in AA of 16.067 mg/100 g, TPC of 66.459 mg GAE/100 g, TFC of 21.793 mg RE/100 g, a microbial reduction of 5.735 log CFU/g, and a yeast/mold count of 4.449 log CFU/g. The desirability score of 0.850 indicated the optimal balance across all variables, making this the selected process condition.

4.6.3 Cost analysis

The cost analysis for pulsed light-treated ripe jackfruit pulp was conducted based on the assumption of producing 2000 bottles (each containing 500 ml) annually. The cost per bottle for processing was calculated to be ₹778. Additionally, the cost of the

pulp and packaging was included, amounting to ₹62.5 for the pulp and ₹5 for packaging, bringing the total cost per bottle to ₹778 (Appendix G5). However, these cost estimations are based on processing carried out using a lab-scale PL machine with limited capacity, which significantly inflates the production cost and makes the benefit-cost ratio (BCR) calculation impractical for commercial comparison. A commercial-scale PL system with higher throughput could substantially reduce the per-unit cost and improve economic feasibility.

4.7 Effect of storage on PL processed RJP

PL processing was optimised prior to storage to establish the shelf life of the selected sample. The sample treated at 1.5 kV, with 200 pulses, and a lamp-to-sample distance of 4 cm, was identified as the best treatment based on quality analysis, sensory evaluation, and statistical results. The optimised sample was then stored under refrigerated conditions, with quality assessments conducted at 10-day intervals. The effect of storage on physicochemical parameters is discussed below.

4.7.1 Effect of storage on pH, Titratable acidity, and TSS of PL processed RJP

The study investigated the effects of PL treatment on the quality parameters of RJP under refrigerated storage over 35 days. The initial pH value of the fresh pulp was recorded at 5.31 ± 0.21, which decreased to 5.00 ± 0.19 by the 10^{th} day, and eventually, PL treated sample fluctuated between 5.27 ± 0.27 to 5.30 ± 0.20 after 35 days (Fig 4.76). The TA of the fresh pulp was initially 0.54 ± 0.02%, which increased slightly to 0.60±0.05% after 10 days, then ranged from 0.55 ± 0.04% to 0.58 ± 0.05% for the treated sample during 35th days of storage. The TSS of the fresh pulp was initially measured at 23.80 ± 0.49 °Brix, increasing to 24.10 ± 0.62 °Brix after 10 days and varying slightly from 24.49±0.55 °Brix on the 10th day to 24.59 ± 1.69°Brix on the 35^{th} day for optimised sample. The PL treatment helped maintain the pH, TA, and TSS of RJP during the 35-day refrigerated storage period, with only minor fluctuations observed. The stable pH and TA were likely due to the PL treatment's inhibition of lactic acid bacteria and spoilage microorganisms which prevents the production of acidic metabolites that could lower the pH. Moreover, the stable acidity during storage suggests negligible oxidative reactions, consistent with findings by Kwaw *et al*. (2018) who observed similar effects in PL-treated mulberry juice. In addition, Basak *et al*. (2022) reported that light pulses could not disrupt covalent bonds necessary for decomposition processes that alter pH, TA, and TSS. The hydrolysis of complex sugars into simple sugars facilitated microbial growth utilizing the simple sugars while maintaining pH stability. Chakraborty *et al*. (2020) also noted that the processing temperature, along with infrared and ultraviolet spectra from PL, could not dissociate sugar molecules into soluble fragments in juice.

The ANOVA results for pH indicated no significant differences among the storage days ($p = 1.000$). The homogeneity of variances was confirmed. The post hoc Duncan test further corroborated this by showing homogeneous subsets, with pH values ranging from 5.27 to 5.30 and a significance level of 0.92. For TA, ANOVA showed no significant differences between storage days ($p = 0.95$). The Duncan post hoc test indicated homogeneous subsets across all storage days, with TA values ranging from 0.54% to 0.58% and a significance level of 0.42 TSS levels analyzed using ANOVA also showed no significant differences between groups ($p = 1.000$). The Duncan post hoc test results for TSS demonstrated homogeneous subsets across all storage days, with TSS values remaining stable from 24.49 °Brix to 24.58 °Brix and a significance level of 0.92.

Overall, the study demonstrated that PL treatment effectively maintained the quality of jackfruit pulp during refrigerated storage, as indicated by the stable pH, TA, and TSS values over the 35-day period. This stability reflects the minimal impact of PL treatment on the chemical properties of the jackfruit pulp, aligning with previous studies on different fruit juices.

4.7.2 Effect of storage on ΔE of PL processed RJP

The **ΔE** data for PL treated RJP under refrigerated storage ranged from 2.30 ± 0.70 immediately after processing to 6.15 ± 0.28 on the 35th day (Fig 4.77), indicating a significant effect of storage duration on colour changes ($p < 0.001$).The redness value (a*) decreased for PL treated sample It is worth noting that low browning was observed in PL-treated juices, despite increasing enzyme activity with storage. This indicates non-enzymatic browning is the major mechanism of browning in the juice during storage. While maillard browning is responsible for browning in thermally treated juices, the degradation of AA and polyphenols also can contribute to browning (Hu *et al*., 2023). The high retention of AA and total phenolics in the PL-treated juice further confirms that the low browning in PL-treated juice was due to higher amounts of AA and total phenols, which were retained due to the non-thermal treatment. Donsingha and Assatarakul (2018) also observed changes in a* values when coconut water was treated with UV irradiation, increasing purpleness during storage. At the end of the storage period, ΔE was in the 'noticeable' range for the PL-treated juice

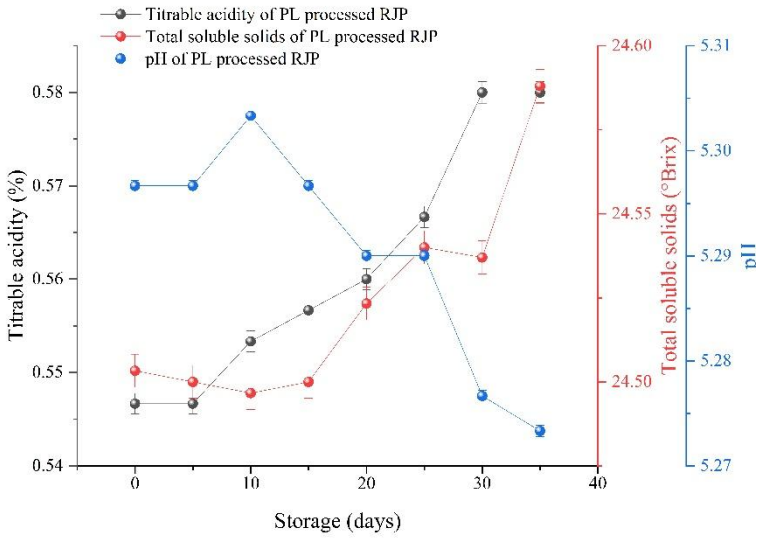


Fig.4.76 Effect of storage on pH, TA, and TSS of PL processed RJP

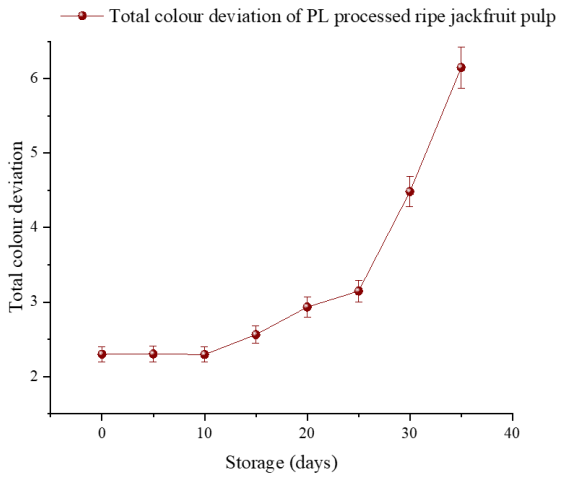


Fig.4.77 Effect of storage on total colour deviation of PL processed RJP

4.7.3 Effect of storage on AA content of PL processed RJP

The AA content in PL processed RJP was analyzed over a refrigerated storage period of 35 days. Initially, the AA content was 16.85 ± 0.01 g/100mg, which decreased to 13 ± 1.23 g/100 mg by the 10th day, indicating a significant reduction. Over the 35-day storage period, the AA content ranged from 16.00 ± 1.05 g/100 mg on the 5th day to 13.57 ±1.13 g/100 mg on the 35th day. The content on the intermediate days was 15.99 ± 1.03 g/100 mg on the 0th day and 14.88 ± 1.12 g/100mg on the 30th day. ANOVA results demonstrated significant differences in AA content between the different storage

intervals (p = 0.041). Post hoc analysis using Duncan's test revealed two homogeneous subsets, indicating a significant reduction in AA content, particularly after the 25th day of storage. Overall, the retention of AA was approximately 80.51% from the initial content to the 35th day, highlighting the impact of storage duration on the nutrient content in PL-treated jackfruit pulp.

In examining the impact of PL treatment on RJP, a notable reduction in antioxidant capacity occurred during storage, despite the treatment's initial efficacy in retaining antioxidants. This decline may be attributed to oxygen diffusion, albeit minimal, which could facilitate aerobic oxidation during refrigerated storage. Additionally, the presence of metal ions and dissolved oxygen concentration in the juice might have catalyzed the aerobic oxidation of AA, leading to its degradation over time (Vollmer *et al*., 2020).

Previous research by Denoya *et al*. (2020) on the quality of persimmons post-PL treatment showed no significant effect on AA during storage, suggesting variations in fruit types and processing methods. Similarly, studies by La-Cava and Sgroppo (2015) on grapefruit juice treated with UV-C light demonstrated a reduction of up to 30% in initial AA levels during refrigerated storage. Moreover, the degradation of AA following PL treatment can be attributed to the formation of ascorbyl radicals during the UV portion of PL, leading to subsequent reactions even in the absence of light. Factors such as pH, metal ion concentration, and the photothermal effect of PL are significant contributors to the oxidation of AA to its keto form (Chakraborty *et al*., 2020).

4.7.4 Effect of storage on TPC of PL processed RJP

The TPC of PL processed RJP, treated at 1.5 kV for 200 pulses with a 4 cm lamp-to-sample distance during 35 days of refrigerated storage, ranged from 66.08 ±0.075 mg GAE/g on the 0th day to 63.41 ± 0.41 mg GAE/g on the 35th day. Initially, the TPC of the fresh pulp was measured at 65.14 ± 0.08 mg GAE/g, which decreased to 13 ± 0.38 mg GAE/g by the 10th day. The ANOVA results revealed a significant difference in TPC across the storage period (p = 0.031). Duncan's multiple range test indicated two homogeneous subsets. The first subset, comprising the TPC from the 35th to the 30th

day, exhibited values ranging from 63.41 ± 0.41 to 64.76 ± 0.58 mg GAE/g. From the 25th to the 0th day, the second subset showed values from 65.12 ± 0.08 to 66.08 ± 0.07 mg GAE/g. These results indicate a notable retention of phenolic content over the storage period. The percentage retention of phenolic compounds from the initial to the final measurement was calculated to be approximately 95.96%, indicating a loss of 4.04%, which highlights the stability of these compounds during the storage period.

Basak *et al*. (2022) observed a significant decrease in TPC during storage of a mixed fruit beverage at refrigerated condition. The loss in TPC was mainly during storage may be due to the negligible antioxidant activity in the pulp during storage.

4.7.5 Effect of storage on Total sugar of PL processed RJP

The total sugar in the PL processed RJP were monitored over a 35-day refrigerated storage period. The initial total sugar value of the fresh pulp was measured at 22.42 ± 0.23%. Over the course of storage, the TSS showed a decrease, reaching a value of 20.12 ± 0.33% by the 10th day (Fig 4.78).

The ANOVA was performed to compare the TSS values across different storage days, yielding an F-value of 0.318 with a significance level of 0.935, indicating no statistically significant differences among the groups.

Post hoc analysis using Duncan's multiple range test identified a single homogeneous subset for alpha = 0.05. The total sugar values across the storage days ranged from 20.88 ± 1.79% on the 35th day to 22.44 ± 0.28% on the 0th day. On specific days, the total sugar values were observed as follows: 21.58 ± 1.42% on the 30th day, 21.66 ± 1.23% on the 25th day, 21.88 ± 1.30% on the 20th day, 21.95 ± 2.01% on the 15th day, 22.41±0.03% on the 5th day, and 22.44 ± 1.50% on the 0th day. The loss percentage of the total sugar over the 35 days ranged from 0.64% to 7.02%.

Overall, the results suggest that the total sugar values of PL processed jackfruit pulp experienced some loss during the 35 days of refrigerated storage, with minor fluctuations that were not statistically significant. The observed variation in sugar content in the treated jackfruit samples can be attributed to the differing levels of surviving microbes. As the storage period progressed, the increase in viable microbes likely caused a more pronounced decline in sugar content. This aligns with findings by

Pandiselvam *et al*. (2020), who reported a significant reduction in total sugar content in microwave-processed coconut inflorescence sap during a 16-day storage period.

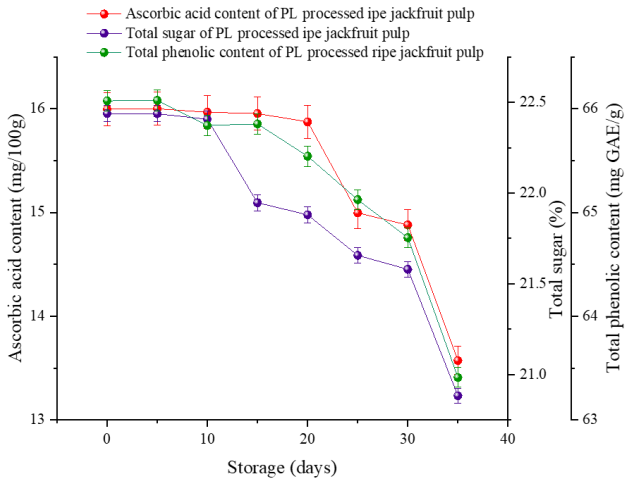


Fig 4.78 Effect of storage on AA, TPC and total sugar content of PL processed RJP

4.7.6 Effect of storage on Microbial activity of PL processed RJP

The initial microbial analysis of the control sample revealed a substantial load of microorganisms, with TAM present at 3.8 ± 1.20 log CFU/g and yeast and mold counts at 4 ± 1.30 log CFU/g. As the storage period progressed, the microbial counts exhibited a significant increase, reaching 6.2 ± 1.11log CFU/g for TAM (Table 4.18) and 6.5 ± 1.28 log CFU/g for yeast and mold by day 10. This rapid growth of microorganisms in the control sample suggests a lack of effective preservation methods, leading to a potential decrease in product quality and safety.

Similarly, the PL processed RJP demonstrated a remarkable reduction in initial microbial counts, with both TAM and yeast and mold counts being less than 1 log CFU/g at day 0. This significant decrease in microbial load was maintained up to 10 days of storage, indicating the effectiveness of PL processing in reducing the initial microbial burden in processed pulp. The low microbial counts observed in the PL processed RJP during the initial storage period suggest that this method can be a valuable tool in extending the shelf life of jackfruit bulbs.

However, from day 15 onward, a gradual increase in microbial counts was observed in the PL processed jackfruit pulp. By day 35, the TAM had reached 6.27 ± 1.33 log CFU/g, and yeast and mold counts were at 6.48 ± 2.14 log CFU/g, indicating a loss of effectiveness of the PL processing method over extended storage periods. This increase in microbial counts may be attributed to the potential re-contamination of the samples or the development of resistance to the PL treatment. Nevertheless, the PL processing method still demonstrated a significant delay in microbial growth compared to the control sample, highlighting its potential as a valuable preservation technique for jackfruit pulp. The study's results align with the results of Bask *et al*. (2022), who found that the TAM count and yeast and mold count remained low, below 1 log CFU/mL in mixed fruit beverage, for 45 days. In contrast, the PL-treated beverages showed a different pattern, with microbial counts starting to rise from day 40 and reaching 6.78 ± 0.26 TAM count by day 46. According to Ferrario *et al.* (2014), the microbial inactivation achieved by PL treatment is a result of the synergistic effects of photochemical, photothermal, and photophysical mechanisms.

The shelf-life of the PL processed jackfruit pulp was estimated based on the microbial count in the beverage. A threshold of 6 log CFU mL^{-1} was considered an indicator of microbial spoilage, and the microbial count was deemed unacceptable to consumption (Permanand, and Vos, 2010; Unluturk and Atilgan, 2015). In our study, the microbial counts exceeded this threshold by day 35, indicating that the shelf-life of the PL processed jackfruit pulp was approximately 30 days. This approach is consistent with previous studies, such as Unluturk and Atilgan (2015), who used a similar method to estimate the shelf-life of UV-C treated white grape juice.

Table 4.18 Effect of storage on Microbial activity of PL processed RJP

Sample	Storage period (days)	Total aerobic mesophiles (log CFU/g)	Yeast and mould count (log CFU/g)
Control sample	0	3.80 ± 1.20	4.00 ± 1.30
	5	4.60 ± 0.12	5.20 ± 0.41
	10	6.20 ± 0.45	6.50 ± 1.14
PL processed RJP	0	<1	<1
	5	<1	<1
	10	<1	<1
	15	1.77 ± 0.45	1.87 ± 0.95
	20	2.10 ± 1.04	2.42 ± 0.47
	25	2.43 ± 1.14	2.89 ± 1.04
	30	2.67 ± 1.04	2.98 ± 0.47
	35	6.27 ± 0.33	6.48 ± 1.14

values are expressed in mean ±SD

4.7.7 Effect of storage on sensory analysis of PL processed RJP

The sensory analysis of PL processed RJP was conducted over a storage period of 40 days, assessing attributes such as colour, aroma, consistency/texture, and overall acceptability. RJP colour scores showed a slight decline from 6.4 ± 0.25 after processing to 5.9 ± 1.11 by day 40, indicating pigment degradation and potential browning reactions that affect the visual quality of the pulp. This decrease could be linked to the PL treatment itself, potentially promoting oxidation and pigment degradation (Lee *et al*., 2023). The aroma scores also fell from 6.8 ± 0.14 on day 0 to 6.10 ± 1.03 by day 40, suggesting a loss of freshness and aromatic compounds, likely due to the volatilization of these substances and possible microbial activities during storage (Zhao *et al.*, 2024). The PL treatment might have influenced the volatilization of aroma compounds, particularly sensitive volatile compounds that contribute to the fresh aroma of jackfruit pulp. The consistency/texture scores for PL showed a notable decline from 6.9 ± 0.89 on day 1 to 6.00 ± 1.03 by day 40, linked to the breakdown of cell walls and pectin substances, resulting in a softer and less desirable texture (Wang *et al.*, 2019). The PL treatment might have affected the cell wall structure, leading to changes in texture over time. Overall acceptability for PL decreased from 6.8 ± 0.15 on day 1 to 5.81 ± 0.66 by day 40, indicating a significant decline in sensory appeal over the storage

period due to combined changes in colour, aroma, and texture. This suggests that PL processing, while potentially effective in extending shelf life, might negatively impact the sensory attributes of jackfruit pulp over time. The declining sensory scores for RJP highlight the challenges in maintaining the sensory quality of PL processed jackfruit products over time. The decline in colour can be attributed to oxidative reactions and enzymatic browning, while aroma loss is likely due to the volatilization of aroma compounds and potential microbial activities. Changes in consistency/texture are often a result of enzymatic breakdown of cell wall components and moisture migration, exacerbated by PL treatment. Overall, while PL processing can extend the shelf life of jackfruit products by inactivating microorganisms and enzymes, the sensory quality deteriorates over time. This underscores the need for optimized storage conditions and the potential use of preservatives to maintain the sensory attributes and consumer acceptability of PL processed jackfruit products over extended periods.

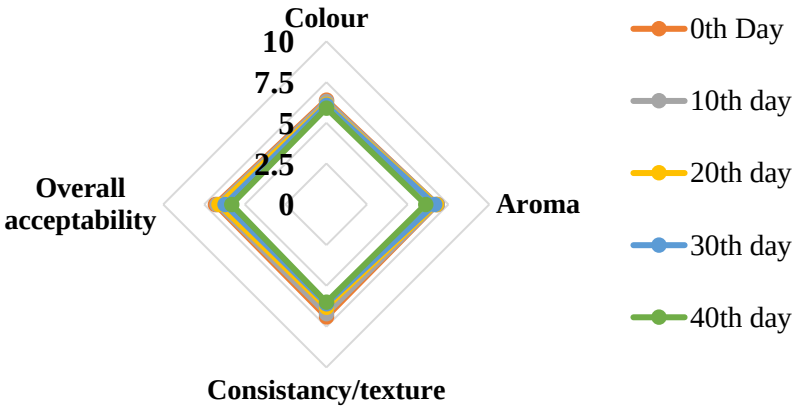


Fig. 4.79 Effect of storage on Sensory analysis of PL processed RJP

Summary and Conclusion

SUMMARY AND CONCLUSIONS

Jackfruit (*Artocarpus heterophyllus*) is recognised for its substantial nutrient density, comprising essential minerals and bioactive phytochemicals that confer various health benefits. Despite its potential, jackfruit's highly perishable nature poses a challenge, with substantial post-harvest losses due to inadequate storage and transportation infrastructure.

In this study, various advanced methodologies were employed to standardize the processing protocols for ripe jackfruit (*Varikka variety*), both in its bulb and pulp forms, with a focus on thermal techniques such as retort pouch processing and non-thermal techniques such as HPP and PL. For retort pouch processing, thermal treatments were carefully optimized through pasteurization, involving temperatures between 75-95°C for durations of 5-15 min, and sterilization, which ranged from 105-121°C for 5-15 min. These methods aimed to extend the shelf life of the fruit while ensuring microbial safety. On the non-thermal front, HPP was applied, using pressure levels between 300 and 600 MPa for 5-20 min. This technique preserved the fresh-like qualities of the jackfruit, including its texture, colour, and nutritional profile, while promoting the retention of bioactive compounds known for their health benefits. PL was also explored as an effective non-thermal method, utilizing a voltage range of 1-2.5 kV with 50-200 pulses, and maintaining a lamp-to-sample distance of 4-10 cm. During the preliminary study, a sample thickness of 1 mm was established as the standard for processing jackfruit pulp.

This study evaluated the effectiveness of three different processing techniques—retort pouch processing, HPP, and PL on ripe jackfruit, focusing on shelf-life extension, quality preservation, and food safety. The retort pouch processed ripe jackfruit samples (under both pasteurisation and sterilization treatments) exhibited significant differences in quality attributes such as colour, texture, AA, TFC, and TPC when compared to fresh samples. A significant reduction ($p<0.05$) in quality parameters was observed at elevated processing conditions (95°C/25 min. and 99°C/15 min.) in pasteurised and sterilised RJB and RJP. The elevation of a* and reduction in b* contributed to the higher total colour deviation in samples at higher process conditions due to Maillard browning. The results indicated that heating jackfruit pulp and bulbs to 99°C for 15 minutes led to a notable reduction in ascorbic acid content, with the RJP

experiencing a 33.72% decrease and the RJB a 23.56% decrease during pasteurisation and 41.60% in RJB and 20% in RJP respectively in sterilisation. Controlled heat treatments preserved desirable sensory characteristics in pasteurised and sterilised samples. The selection of the best processing method among the thermal and non-thermal techniques was primarily based on microbiological safety, followed by the retention of quality attributes in the processed samples. For retort pouch processing, the optimal conditions were determined to be pasteurization at 80°C for 5 minutes for ripe jackfruit pulp (RJP) and 80°C for 12 minutes for ripe jackfruit bulbs (RJB), yielding optimal desirability indices of 0.917 and 0.812, respectively. Sterilization at 106°C for 5 minutes (Desirability-0.956) for RJP and 106°C for 7 minutes (Desirability-0.825) for RJB was identified as the best treatment. This method offered a significant extension in shelf life, with processed pulp lasting up to 180 days, and ensured microbial safety. However, elevated temperatures led to heat-induced softening and pigment loss.

During the study the effect of applied pressure and holding time on different quality parameters of ripe jackfruit were studied. A significant increase in L* value observed in RJB and RJP resulted in the higher opacity of the product. The higher pressures not only maintained the fresh-like appearance of the fruit but also promoted cytoplasmic rupture and enhanced bioactive compound release resulted in a maximum AA content of 23% in RJB and 17% in RJP. In the case of HPP, the application of 600 MPa for 20 minutes extended the shelf life of ripe jackfruit bulb to 40 days, while 600 MPa for 15 minutes improved the retention of bioactive compounds in ripe jackfruit pulp. HPP at 600 MPa significantly reduced microbial populations in RJB and RJP, achieving log reductions of 6.4±0.23 and 5.93±0.068 log CFU/g, respectively, while maintaining total aerobic mesophiles within the allowable limit. A threefold increase in shelf life was observed for treated RJB compared to untreated samples.

During PL processing, a nonsignificant reduction in colour characteristics was observed, and higher dosages (2.5 kV/200 pulses kept at 4 cm lamp to sample distance) resulted in maximum AA degradation of 17%. The treatment at 2.4 kV with 94 pulses achieved a 5-log cycle reduction in both aerobic mesophiles and yeast and mold counts. Furthermore, increasing the treatment to 2.4 kV with 187 pulses resulted in microbial levels dropping below detection limits. The best results were achieved while applying

a voltage of 1.50 kV, 200 pulses, and a lamp-to-sample distance of 4.00 cm. This method effectively preserved the biochemical integrity of the jackfruit and ensured microbial safety, extending the shelf life of the processed pulp to over 30 days. A shear-thinning behaviour was observed in thermal processed and non-thermal processed RJP. Thermal and non-thermal process effectively inactivated the microorganisms to the below detection level in optimised samples. In conclusion, while non-thermal techniques like HPP and PL better preserve the quality and nutritional content of ripe jackfruit, retort pouch processing remains the most commercially viable option for ensuring long-term safety and shelf life.

Highlights

- Demonstrated that thermal and non-thermal processing effectively inactivated the microorganisms in optimized samples.
- The optimal pasteurisation conditions were established as 80°C for 5 minutes for ripe jackfruit pulp (RJP) and 80°C for 12 minutes for ripe jackfruit bulbs (RJB)
- Sterilisation at 106°C for 5 minutes for RJP and 106°C for 7 minutes for RJB was identified as the best treatment
- Retort pouch pasteurised and sterilised samples were shelf-stable and can be stored up to 150 and <180 days respectively.
- High pressure processed samples exhibited higher biochemical contents and maintained fresh-like quality in processed samples with higher sensory scores
- In the case of HPP, treatment at 600 MPa for 20 minutes effectively extended the shelf life of ripe jackfruit bulbs, while 600 MPa for 15 minutes enhanced the retention of bioactive compounds in ripe jackfruit pulp.
- PL helps to retain phenolic and flavonoid compounds at moderate dosages

- The optimal results in pulsed light (PL) treatment were obtained at a voltage of 1.50 kV, with 200 pulses and a lamp-to-sample distance of 4.00 cm
- Retort pouch processing technique shown to be commercially viable option for ensuring long-term safety and shelf life.

Future scope

- Further studies are needed for cost reduction and commercialization of HPP and PL
- Explore the possibility of improving the sensory quality of PL-processed ripe jackfruit pulp

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CHAPTER VI

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Appendix

APPENDIX A

RETORT POUCH PASTEURISED RIPE JACKFRUIT

Table.A1 Physicochemical properties of retort pouch pasteurised RJB

Temperature (°C)	**Time (**min)	**TA (**%)	**L***	**a***	**b***	**ΔE**
75	5	0.62±0.02	64.76±0.84	7.76±0.22	49.46±1.20	2.11±0.01
95	5	0.51±0.02	66.48±1.31	7.94±0.35	48.56±1.32	1.36±0.05
75	25	0.46±0.01	64.52±0.88	7.65±0.28	49.12±1.04	2.44±0.07
95	25	0.27±0.01	64.54±1.11	8.02±0.33	48.76±2.01	2.55±0.04
71	15	0.51±0.01	64.12±0.87	7.78±0.34	49.55±1.41	2.73±0.24
99	15	0.29±0.01	64.18±2.70	8.05±0.31	48.05±1.55	3.22±0.43
85	1	0.59±0.02	66.63±0.77	7.6±0.25	49.65±2.33	0.40±0.08
85	29	0.38±0.02	66.41±1.35	7.56±0.33	48.84±1.22	1.16±0.23
85	15	0.42±0.02	64.51±1.22	7.87±0.30	48.15±1.42	2.89±0.11
85	15	0.30±0.01	64.57±0.78	7.33±0.29	48.24±1.01	2.84±0.14
85	15	0.23±0.02	64.76±0.85	7.34±0.19	48.08±2.14	2.70±0.41
85	15	0.36±0.01	66.39±0.92	7.27±0.22	48.19±1.4	2.40±0.21
85	15	0.42±0.01	64.53±1.02	7.14±0.28	49.32±0.98	2.80±0.02

Data shown are the mean ± SD of three treatment repetition

Table.A1 Physicochemical properties of retort pouch pasteurised RJB

Temperature (°C)	Time (min)	AA (mg/100 g)	TPC (mg GAE/g)	TFC (mg RE/g)	DPPH radical scavenging activity (%)	Total sugar (%)	TAM (log CFU/g)	Yeast/Mold (log CFU/g)	Firmness (N)
75	5	14.24±0.45	70.46±1.87	39.72±1.23	86.45±2.45	20.14±0.63	5.61±1.23	5.95±1.45	53.84±0.32
95	5	13.45±0.55	63.28±2.01	36.47±1.45	84.63±2.14	17.33±0.45	7.12±1.87	7.85±1.27	48.23±0.54
75	25	13.25±0.61	68.97±1.25	38.84±1.11	85.25±3.01	19.82±0.88	5.89±0.98	6.25±1.36	52.85±0.31
95	25	11.16±0.58	59.51±2.10	34.14±1.75	82.33±2.80	15.53±0.56	7.85±1.45	8.25±1.75	46.06±0.77
71	15	14.32±0.62	70.53±2.54	40.02±1.44	86.55±3.12	20.22±0.92	5.42±1.29	5.35±1.82	54.16±0.54
99	15	11.03±0.51	58.96±2.12	34.02±1.22	82.41±3.11	15.42±0.53	7.86±1.70	8.85±1.32	45.85±0.25
85	1	14.06±0.55	69.26±2.31	39.33±1.64	85.98±2.74	19.15±0.68	6.46±1.35	5.95±1.62	52.76±0.65
85	29	12.56±0.51	65.84±1.54	35.95±1.75	84.02±2.41	18.71±1.24	6.99±1.42	7.55±1.46	51.46±0.35
85	15	13.84±0.67	68.46±1.42	38.48±1.32	84.17±3.17	19.05±0.87	6.87±1.33	6.65±1.24	52.05±0.75
85	15	14.22±0.63	67.58±1.88	38.22±1.85	84.12±3.25	19.32±0.92	6.77±1.54	6.41±1.34	52.13±0.65
85	15	14.24±0.67	68.46±2.43	38.34±1.55	83.46±2.46	18.95±0.99	6.80±1.25	6.62±1.54	52.00±0.25
85	15	14.06±0.68	69.56±2.01	38.12±1.64	82.42±2.22	19.05±1.02	7.05±1.45	5.65±.1.54	52.06±0.54
85	15	13.89±0.63	68.23±2.33	37.89±1.24	82.51±2.47	18.75±0.82	6.90±1.33	6.32±1.33	51.96±0.68

Data shown are the mean ± SD of three treatment repetition

Table.A2 Physicochemical properties of retort pouch pasteurised RJP

Temperature (°C)	Time (min)	BI	YI	TA (%)	L*	a*	b*	ΔE
75	5	109.27±4.38	126.83±5.74	0.628±0.02	65.88±2.14	8.56±0.52	58.49±0.78	2.07±0.23
95	5	103.16±4.74	118.01±5.82	0.502±0.01	67.56±1.85	8.83±0.34	55.85±0.64	2.74±0.47
75	25	108.86±4.50	126.26±5.69	0.430±0.02	65.51±2.31	8.56±0.25	57.90±0.35	2.52±0.89
95	25	104.03±4.60	119.27±5.56	0.222±0.01	66.51±1.54	8.94±0.22	55.53±0.50	3.36±0.47
71	15	107.63±4.70	124.66±5.89	0.538±0.03	66.72±2.14	8.55±0.35	58.22±0.53	1.28±0.65
99	15	105.65±3.51	121.52±5.72	0.304±0.01	65.43±1.59	9.04±0.33	55.66±1.25	3.86±0.78
85	1	106.82±2.45	123.55±4.45	0.628±0.02	67.63±3.08	8.32±0.41	58.49±1.92	0.32±0.10
85	29	105.99±4.40	122.45±3.19	0.344±0.01	67.29±1.25	8.41±0.42	57.68±1.45	1.12±0.45
85	15	107.61±0.54	124.66±5.70	0.432±0.02	65.87±2.14	8.36±0.75	57.48±1.44	2.36±0.38
85	15	105.95±4.64	122.24±0.70	0.321±0.02	66.10±1.25	8.58±0.43	56.56±1.02	2.72±0.28
85	15	106.31±3.66	122.77±5.62	0.364±0.02	66.35±1.55	8.56±0.28	57.02±0.87	4.00±0.01
85	15	106.67±2.61	123.21±4.33	0.411±0.01	66.09±2.04	8.67±0.22	57.00±1.29	3.00±0.24
85	15	109.74±1.05	127.54±3.43	0.275±0.01	64.00±1.25	8.16±0.23	57.23±1.77	4.19±0.34

Data shown are the mean ± SD of three treatment repetition

Table.A2 Physicochemical properties of retort pouch pasteurised RJP

Temperature (°C)	Time (min)	AA (mg/100 g)	TPC (mg GAE/g)	TFC (mg RE/g)	DPPH radical scavenging activity (%)	Total sugar (%)	TAM (log CFU/g)	Yeast/Mold (log CFU/g)	Firmness (N)
75	5	10.25±0.35	65.00±1.87	19.12±1.23	83.98±2.45	22.10±0.63	5.80±1.23	5.95±1.45	53.84±0.32
95	5	8.15±0.50	60.78±2.01	18.13±1.45	82.04±2.14	18.55±0.45	7.50±1.87	7.85±1.27	48.23±0.54
75	25	9.24±0.55	64.79±1.25	18.93±1.11	83.16±3.01	21.54±0.88	6.20±0.98	6.25±1.36	52.85±0.31
95	25	6.93±0.24	52.96±2.10	15.68±0.56	79.88±2.80	15.47±0.56	7.80±1.45	8.25±1.75	46.06±0.77
71	15	10.28±0.60	65.12±2.34	19.20±0.69	84.00±3.66	22.45±0.80	5.60±1.29	5.35±1.82	54.16±0.54
99	15	6.84±0.18	52.33±2.23	15.76±1.22	79.53±2.10	15.31±0.40	8.30±1.70	8.85±1.32	45.85±0.25
85	1	9.56±0.33	64.96±2.31	19.00±1.64	83.56±2.74	20.74±0.68	5.50±1.35	5.95±1.62	52.76±0.65
85	29	8.66±0.30	61.76±1.54	17.82±1.75	82.40±2.41	20.05±1.24	6.80±1.42	7.55±1.46	51.46±0.35
85	15	9.46±0.61	63.78±1.42	18.61±1.32	82.45±3.17	20.41±0.87	6.40±1.33	6.65±1.24	52.05±0.75
85	15	9.35±0.59	63.41±1.88	18.86±1.85	82.86±3.25	20.14±0.92	6.10±1.54	6.41±1.34	52.13±0.65
85	15	9.41±0.17	63.84±2.43	18.45±1.55	83.56±2.46	19.88±0.99	6.60±1.25	6.62±1.54	52.00±0.25
85	15	9.45±0.28	62.98±2.01	18.23±1.64	84.00±2.22	20.33±1.02	5.80±1.45	5.65±.1.54	52.06±0.54
85	15	8.96±0.63	63.00±2.33	17.99±1.24	83.16±2.47	20.45±0.82	5.90±1.33	6.32±1.33	51.96±0.68

Data shown are the mean ± SD of three treatment repetition

ANOVA for Response Surface Model
Table A3. TA of retort pouch pasteurised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.16	5	0.032	8.06	0.0081	significant
A-Temperature	0.049	1	0.049	12.28	0.0099	
B-Time	0.076	1	0.076	19.13	0.0033	
AB	1.76E-03	1	1.76E-03	0.45	0.5256	
A^2	8.66E-03	1	8.66E-03	2.19	0.1826	
B^2	0.028	1	0.028	7.15	0.0318	
Residual	0.028	7	3.96E-03			
Lack of Fit	2.53E-03	3	8.44E-04	0.13	0.9346	not significant
Pure Error	0.025	4	6.29E-03			
Cor Total	0.19	12				
R^2						0.8520
Adj R^2						0.7463
Pred R^2						0.6937
Adeq Precision						8.477

Table A4. TA of retort pouch pasteurised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.18	5	0.036	14.66	0.0014	significant
A-Temperature	0.055	1	0.055	22.23	0.0022	
B-Time	0.097	1	0.097	38.90	0.0004	
AB	1.681E-003	1	1.681E-003	0.68	0.4380	
A^2	5.532E-003	1	5.532E-003	2.23	0.1794	
B^2	0.026	1	0.026	10.31	0.0148	
Residual	0.017	7	2.486E-003			
Lack of Fit	8.581E-004	3	2.860E-004	0.069	0.9734	not significant
Pure Error	0.017	4	4.136E-003			
Cor Total	0.20	12				
R^2						0.9128
Adj R^2						0.8505
Pred R^2						0.8399
Adeq Precision						11.855

Table A5 b* value of retort pouch pasteurised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	9.84	2	4.92	17.85	0.0005	significant
A-Temperature	9.31	1	9.31	33.78	0.0002	
B-Time	0.53	1	0.53	1.92	0.1964	
Residual	2.76	10	0.28			
Lack of Fit	2.32	6	0.39	3.57	0.1194	not significant
Pure Error	0.43	4	0.11			
Cor Total	12.59	12	4.92			0.7812
R^2						0.7374
Adj R^2						0.5574
Pred R^2						12.099
Adeq Precision						0.7812

Table A6 ΔE **of retort pouch pasteurised RJB**

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	6.75	5	1.35	8.44	0.0071	significant
A-Temperature	1.821E-005	1	1.821E-005	1.138E-004	0.9918	
B-Time	0.84	1	0.84	5.23	0.0560	
AB	0.18	1	0.18	1.16	0.3180	
A^2	0.45	1	0.45	2.83	0.1363	
B^2	4.79	1	4.79	29.95	0.0009	
Residual	1.12	7	0.16			
Lack of Fit	0.35	3	0.12	0.60	0.6460	not significant
Pure Error	0.77	4	0.19			
Cor Total	7.87	12				
R^2						0.8577
Adj R^2						0.7560
Pred R^2						0.5313
Adeq Precision						9.679

Table A7 BI of retort pouch pasteurised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	6.75	2	11.83	5.77	0.0216	significant
A-Temperature	1.821E-005	1	23.61	11.50	0.0069	
B-Time	0.84	1	0.063	0.031	0.8647	
Residual	20.52	10	2.05			
Lack of Fit	11.27	6	1.88	0.81	0.6103	
Pure Error	9.25	4	2.31			
Cor Total	44.19	12				0.5356
R^2						0.4427
Adj R^2						0.2217
Pred R^2						0.7060
Adeq Precision						0.5356

Table A8 AA of retort pouch pasteurised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	14.90	5	2.98	29.91	0.0001	significant
A-Temperature	7.09	1	7.09	71.18	< 0.0001	
B-Time	3.65	1	3.65	36.60	0.0005	
AB	0.42	1	0.42	4.24	0.0785	
A^2	3.21	1	3.21	32.22	0.0008	
B^2	0.91	1	0.91	9.14	0.0193	
Residual	0.70	7	0.100			
Lack of Fit	0.56	3	0.19	5.57	0.0653	not significant
Pure Error	0.13	4	0.034			
Cor Total	15.60	12				
R^2						0.9553
Adj R^2						0.9233
Pred R^2						0.7299
Adeq Precision						15.077

Table A9 AA of retort pouch pasteurised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	13.66	5	2.73	49.11	< 0.0001	significant
A-Temperature	10.75	1	10.75	193.28	< 0.0001	
B-Time	1.53	1	1.53	27.57	0.0012	
AB	0.011	1	0.011	0.20	0.6696	
A^2	1.29	1	1.29	23.24	0.0019	
B^2	0.17	1	0.17	3.05	0.1243	
Residual	0.39	7	0.056			
Lack of Fit	0.21	3	0.072	1.64	0.3157	not significant
Pure Error	0.17	4	0.044			
Cor Total	14.05	12				
R^2						0.9723
Adj R^2						0.9525
Pred R^2						0.8720
Adeq Precision						21.588

Table A10 TPC of retort pouch pasteurised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	178.87	5	35.77	90.63	< 0.0001	significant
A-Temperature	136.11	1	136.11	344.82	< 0.0001	
B-Time	12.71	1	12.71	32.21	0.0008	
AB	1.29	1	1.29	3.28	0.1130	
A^2	27.93	1	27.93	70.77	< 0.0001	
B^2	2.52	1	2.52	6.37	0.0395	
Residual	2.76	7	0.39			
Lack of Fit	0.73	3	0.24	0.48	0.7165	not significant
Pure Error	2.04	4	0.51			
Cor Total	181.63	12				
R^2						0.9848
Adj R^2						0.9739
Pred R^2						0.9541
Adeq Precision						28.237

Table A11 TPC of retort pouch pasteurised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	219.65	5	43.93	110.62	< 0.0001	significant
A-Temperature	145.67	1	145.67	366.81	< 0.0001	
B-Time	19.71	1	19.71	49.62	0.0002	
AB	14.48	1	14.48	36.46	0.0005	
A^2	39.35	1	39.35	99.10	< 0.0001	
B^2	0.026	1	0.026	0.065	0.8058	
Residual	2.78	7	0.40			
Lack of Fit	2.11	3	0.70	4.16	0.1010	not significant
Pure Error	0.67	4	0.17			
Cor Total	222.43	12				
R^2						0.9875
Adj R^2						0.9786
Pred R^2						0.9279
Adeq Precision						30.254

Table A12TFC of retort pouch pasteurised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	45.14	5	9.03	115.50	< 0.0001	significant
A-Temperature	33.76	1	33.76	431.97	< 0.0001	
B-Time	7.98	1	7.98	102.09	< 0.0001	
AB	0.53	1	0.53	6.72	0.0358	
A^2	2.54	1	2.54	32.51	0.0007	
B^2	0.60	1	0.60	7.71	0.0274	
Residual	0.55	7	0.078			
Lack of Fit	0.35	3	0.12	2.31	0.2183	not significant
Pure Error	0.20	4	0.050			
Cor Total	222.43	12				
R^2						0.9880
Adj R^2						0.9795
Pred R^2						0.9392
Adeq Precision						32.149

Table A13 TFC of retort pouch pasteurised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	15.51	5	3.10	35.10	< 0.0001	significant
A-Temperature	10.36	1	10.36	117.22	< 0.0001	
B-Time	2.32	1	2.32	26.25	0.0014	
AB	1.28	1	1.28	14.44	0.0067	
A^2	1.53	1	1.53	17.31	0.0042	
B^2	1.113E-004	1	1.113E-004	1.259E-003	0.9727	
Residual	0.62	7	0.088			
Lack of Fit	0.17	3	0.056	0.49	0.7051	not significant
Pure Error	0.45	4	0.11			
Cor Total	16.13	12				
R^2						0.9616
Adj R^2						0.9342
Pred R^2						0.8824
Adeq Precision						17.171

Table A14 DPPH radical scavenging activity of retort pouch pasteurised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	25.27	5	5.05	11.49	0.0029	significant
A-Temperature	14.03	1	14.03	31.89	0.0008	
B-Time	4.92	1	4.92	11.18	0.0124	
AB	0.30	1	0.30	0.69	0.4344	
A^2	2.13	1	2.13	4.84	0.0637	
B^2	4.60	1	4.60	10.46	0.0144	
Residual	3.08	7	0.44			
Lack of Fit	0.23	3	0.078	0.11	0.9504	not significant
Pure Error	2.85	4	0.71			
Cor Total	28.35	12				
R^2						0.8914
Adj R^2						0.8137
Pred R^2						0.7847
Adeq Precision						9.357

Table A15 DPPH radical scavenging activity of retort pouch pasteurised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	23.67	5	4.73	17.93	0.0007	significant
A-Temperature	16.65	1	16.65	63.06	< 0.0001	
B-Time	2.67	1	2.67	10.11	0.0155	
AB	0.45	1	0.45	1.70	0.2335	
A^2	3.89	1	3.89	14.72	0.0064	
B^2	0.14	1	0.14	0.52	0.4960	
Residual	1.85	7	0.26			
Lack of Fit	0.40	3	0.13	0.37	0.7817	not significant
Pure Error	1.45	4	0.36			
Cor Total	25.52	12				
R^2						0.9276
Adj R^2						0.8758
Pred R^2						0.8000
Adeq Precision						12.413

Table A16 Total sugar content of retort pouch pasteurised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	28.49	5	5.70	76.72	< 0.0001	significant
A-Temperature	24.11	1	24.11	324.64	< 0.0001	
B-Time	0.94	1	0.94	12.66	0.0092	
AB	0.55	1	0.55	7.37	0.0300	
A^2	2.89	1	2.89	38.91	0.0004	
B^2	0.056	1	0.056	0.75	0.4151	
Residual	0.52	7	0.074			
Lack of Fit	0.35	3	0.12	2.76	0.1762	not significant
Pure Error	0.17	4	0.042			
Cor Total	29.01	12				
R^2						0.9821
Adj R^2						0.9693
Pred R^2						0.9050
Adeq Precision						26.521

Table A17 Total sugar content of retort pouch pasteurised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	56.72	5	11.34	64.28	< 0.0001	significant
A-Temperature	48.60	1	48.60	275.35	< 0.0001	
B-Time	2.66	1	2.66	15.09	0.0060	
AB	1.59	1	1.59	9.00	0.0200	
A^2	3.77	1	3.77	21.39	0.0024	
B^2	3.031E-003	1	3.031E-003	0.017	0.8994	
Residual	1.24	7	0.18			
Lack of Fit	1.01	3	0.34	6.13	0.0561	not significant
Pure Error	0.22	4	0.055			
Cor Total	57.96	12				
R^2						0.9787
Adj R^2						0.9635
Pred R^2						0.8695
Adeq Precision						24.425

Table A18 Firmness of retort pouch pasteurised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	86.75	5	17.35	75.55	< 0.0001	significant
A-Temperature	72.92	1	72.92	317.48	< 0.0001	
B-Time	3.12	1	3.12	13.60	0.0078	
AB	0.35	1	0.35	1.52	0.2580	
A^2	10.36	1	10.36	45.13	0.0003	
B^2	0.20	1	0.20	0.86	0.3856	
Residual	1.61	7	0.23			
Lack of Fit	1.59	3	0.53	127.80	0.0002	significant
Pure Error	0.017	4	4.150E-003			
Cor Total	88.36	12				
R^2						0.9818
Adj R^2						0.9688
Pred R^2						0.8717
Adeq Precision						26.632

Table A19 Dynamic viscosity of retort pouch pasteurised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	975.14	5	195.03	17.29	0.0008	significant
A-Temperature	322.56	1	322.56	28.60	0.0011	
B-Time	422.40	1	422.40	37.45	0.0005	
AB	117.33	1	117.33	10.40	0.0145	
A^2	9.78	1	9.78	0.87	0.3826	
B^2	109.70	1	109.70	9.73	0.0169	
Residual	78.95	7	11.28			
Lack of Fit	29.06	3	9.69	0.78	0.5650	not significant
Pure Error	49.89	4	12.47			
Cor Total	1054.09	12				
R^2						0.9251
Adj R^2						0.8716
Pred R^2						0.7300
Adeq Precision						13.498

Table A20 Reduction in TAM of retort pouch pasteurised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	6.59	5	1.32	17.29	0.0008	significant
A-Temperature	5.99	1	5.99	28.60	0.0011	
B-Time	0.39	1	0.39	37.45	0.0005	
AB	0.051	1	0.051	10.40	0.0145	
A^2	0.13	1	0.13	0.87	0.3826	
B^2	0.060	1	0.060	9.73	0.0169	
Residual	0.065	7	9.265E-003			
Lack of Fit	0.017	3	5.659E-003	0.78	0.5650	not significant
Pure Error	0.048	4	0.012			
Cor Total	6.66	12				
R^2						0.9903
Adj R^2						0.9833
Pred R^2						0.9706
Adeq Precision						37.671

Table A21 Reduction in TAM of retort pouch pasteurised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	9.07	5	1.81	22.73	0.0003	significant
A-Temperature	6.33	1	6.33	79.34	< 0.0001	
B-Time	0.81	1	0.81	10.09	0.0156	
AB	2.500E-003	1	2.500E-003	0.031	0.8646	
A^2	1.91	1	1.91	23.90	0.0018	
B^2	0.11	1	0.11	1.33	0.2859	
Residual	0.56	7	0.080			
Lack of Fit	0.35	3	0.12	2.18	0.2328	not significant
Pure Error	0.21	4	0.053			
Cor Total	9.63	12				
R^2						0.9420
Adj R^2						0.9005
Pred R^2						0.7095
Adeq Precision						15.058

A22 Reduction in Yeast and mould in retort pouch pasteurised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	12.39	5	2.48	15.17	0.0012	significant
A-Temperature	9.79	1	9.79	59.93	0.0001	
B-Time	1.10	1	1.10	6.72	0.0359	
AB	2.500E-003	1	2.500E-003	0.015	0.9050	
A^2	1.24	1	1.24	7.60	0.0282	
B^2	0.43	1	0.43	2.61	0.1503	
Residual	1.14	7	0.16			
Lack of Fit	0.49	3	0.16	0.99	0.4814	not significant
Pure Error	0.66	4	0.16			
Cor Total	13.54	12				
R^2						0.9155
Adj R^2						0.8552
Pred R^2						0.6680
Adeq Precision						11.622

Table A23 Reduction in Yeast and mould in retort pouch pasteurised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	9.75	5	1.95	19.93	0.0005	significant
A-Temperature	7.72	1	7.72	78.89	< 0.0001	
B-Time	1.19	1	1.19	12.20	0.0101	
AB	0.014	1	0.014	0.15	0.7127	
A^2	0.63	1	0.63	6.42	0.0390	
B^2	0.11	1	0.11	1.14	0.3202	
Residual	0.68	7	0.098			
Lack of Fit	0.35	3	0.12	1.36	0.3749	not significant
Pure Error	0.34	4	0.085			
Cor Total	10.44	12				
R^2						0.9344
Adj R^2						0.8875
Pred R^2						0.7136
Adeq Precision						11.622

APPENDIX B

RETORT POUCH STERILISATION OF RIPE JACKFRUIT

Table.B1 Physicochemical properties of retort pouch sterilised RJB

Temerature (°C)	Time (min)	pH	TSS (°Brix)	TA (%)	L*	a*	b*	ΔE	BI	YI
105	5	5.0±0.23	21.3±0.54	0.573±0.02	60.78±1.23	0.62±0.03	52.64±1.65	1.48±0.08	104.13±0.22	123.72±0.22
120	5	5.4±0.22	22.0±0.36	0.313±0.01	56.63±1.35	0.94±0.02	48.88±1.45	4.84±0.24	103.99±0.35	123.31±0.21
105	15	5.3±0.31	21.5±0.14	0.567±0.02	57.54±1.25	0.71±0.03	52.14±1.55	1.94±0.09	108.48±0.24	129.45±0.14
120	15	5.5±0.24	23.1±0.15	0.234±0.03	56.21±1.35	1.26±0.03	47.20±1.70	6.52±0.33	101.79±0.24	119.96±0.46
102	10	5.1±0.28	21.3±0.54	0.581±0.02	61.18±2.57	0.61±0.03	53.41±1.92	1.93±0.45	104.84±0.36	124.72±0.74
123	10	5.6±0.28	23.4±0.24	0.226±0.01	56.15±2.21	1.22±0.01	47.23±1.32	6.51±0.23	101.92±0.46	120.16±0.55
112.5	3	5.3±0.59	21.7±0.21	0.543±0.01	57.48±2.13	0.63±0.02	52.36±1.85	1.91±0.09	108.98±0.25	130.14±0.46
112.5	17	5.5±0.45	21.9±0.23	0.46±0.03	56.73±1.19	0.84±0.03	50.23±1.96	3.72±0.12	106.28±0.43	126.49±0.45
112.5	10	5.2±0.24	22.0±0.24	0.482±0.02	56.89±2.34	0.76±0.02	51.22±1.68	2.95±0.42	107.86±0.22	128.62±0.21
112.5	10	5.2±0.21	23.4±0.21	0.472±0.02	56.82±2.05	0.78±0.02	51.36±1.66	2.93±0.16	108.26±0.75	129.13±0.56
112.5	10	5.2±023	22.9±0.24	0.419±0.02	56.84±2.01	0.77±0.03	52.99±1.92	2.48±0.14	111.50±0.46	133.18±0.89
112.5	10	5.1±0.31	22.7±0.26	0.49±0.02	56.25±1.98	0.69±0.02	51.74±1.87	2.37±0.23	108.21±0.33	129.11±0.46
112.5	10	5.0±024	22.5±0.31	0.47±0.02	57.43±1.87	0.71±0.03	52.00±1.71	3.02±0.22	110.23±0.21	131.65±0.21

Data shown are the mean ± SD of three treatment repetition

Table.B1 Physicochemical properties of retort pouch sterilised RJB

Temerature (°C)	Time (min)	AA (mg/100 g)	TPC (mg GAE/g)	TFC (mg RE/g)	DPPH radical scavenging activity (%)	Total sugar (%)	Firmness (N)
105	5	13.56±0.62	68.51±3.14	38.80±1.03	86.52±3.12	18.86±0.25	51.43±1.12
120	5	11.20±0.56	62.41±2.15	34.58±1.02	83.95±3.62	17.54±0.35	45.65±1.11
105	15	12.81±0.54	67.58±2.11	38.23±1.16	86.22±3.21	18.33±0.68	52.68±2.13
120	15	9.98±0.45	58.51±2.11	31.50±1.09	82.60±3.79	15.80±0.56	42.85±1.35
102	10	13.29±0.62	68.16±3.06	38.56±1.18	86.42±2.87	18.59±0.55	53.65±1.93
123	10	10.02±0.71	58.43±2.16	31.54±1.33	82.63±2.14	15.84±0.47	40.15±1.80
112.5	3	13.11±0.87	68.21±3.42	38.64±2.05	86.38±1.56	18.72±0.65	51.47±2.03
112.5	17	11.49±0.55	65.84±2.10	36.52±1.35	87.41±1.54	17.68±0.54	48.73±2.14
112.5	10	12.34±0.62	67.12±1.01	37.12±1.19	87.52±1.44	18.44±0.63	50.64±1.16
112.5	10	12.28±0.84	67.21±1.18	38.01±2.31	87.54±1.65	18.41±0.87	50.08±1.12
112.5	10	12.31±0.74	67.35±1.11	36.95±1.25	86.84±1.47	18.40±0.95	50.05±1.85
112.5	10	12.45±0.66	67.08±2.13	37.05±1.14	85.42±1.65	17.99±0.84	50.65±2.05
112.5	10	12.38±0.53	68.00±2.25	36.93±1.19	87.45±2.31	18.35±0.63	48.88±2.04

Data shown are the mean ± SD of three treatment repetition

Table.B2 Physicochemical properties of retort pouch sterilised RJP

Temerature (°C)	Time (min)	pH	TSS (°Brix)	TA (%)	L*	a*	b*	ΔE
105	5	5.06±0.24	18.6±0.03	0.56±0.02	66.76±2.85	0.72±0.02	50.39±1.14	8.67±0.21
120	5	5.12±0.24	19.0±0.54	0.211±0.05	62.93±2.31	2.65±0.03	47.85±1.18	7.44±0.41
105	15	5.16±0.17	18.2±0.66	0.488±0.01	65.14±2.51	1.29±0.02	51.46±1.23	6.83±0.42
120	15	5.28±0.16	19.2±0.45	0.179±0.03	62.24±2.11	3.15±0.10	43.30±1.14	11.18±0.35
102	10	5.16±0.22	18.6±0.02	0.568±0.03	66.61±1.45	0.77±0.12	53.38±1.92	7.92±0.13
123	10	5.28±0.19	19.5±0.23	0.152±0.01	62.19±1.77	2.89±0.04	46.66±1.14	8.11±0.12
112.5	3	5.1±0.28	18.7±0.25	0.425±0.02	65.10±1.23	0.94±0.04	48.99±1.11	7.88±0.41
112.5	17	5.26±0.34	18.6±0.23	0.215±0.04	64.25±2.11	2.53±0.14	46.68±1.21	9.08±0.25
112.5	10	5.25±0.54	18.8±0.32	0.412±0.01	64.36±1.45	2.37±0.03	48.48±1.17	7.85±0.33
112.5	10	5.21±0.38	18.6±0.45	0.413±0.02	64.19±1.45	2.39±0.01	49.56±1.01	7.07±0.40
112.5	10	5.26±0.21	18.6±0.65	0.412±0.01	64.30±1.33	2.31±0.05	48.02±1.20	8.10±0.52
112.5	10	5.25±0.11	18.7±0.62	0.413±0.03	65.32±2.45	2.86±0.12	48.00±1.45	8.27±0.22
112.5	10	5.22±0.45	18.6±0.45	0.488±0.02	65.14±1.80	3.00±0.42	48.23±1.86	8.75±0.31

Data shown are the mean ± SD of three treatment repetition

Table.B2 Physicochemical properties of retort pouch sterilised RJP

Temerature (°C)	Time (min)	BI	YI	AA (mg/100 g)	TPC (mg GAE/g)	TFC (mg RE/g)	DPPH radical scavenging activity (%)	Total sugar (%)	Dynamic viscosity (Pa.s)
105	5	93.82±0.12	107.83±1.20	11.33±0.40	64.85±2.83	18.56±0.85	82.83±1.80	20.13±0.81	50.74±0.25
120	5	95.06±0.12	108.63±1.10	9.34±0.32	58.41±2.13	16.18±0.58	81.63±1.25	17.46±0.56	30.14±0.32
105	15	97.09±0.13	112.85±1.02	10.56±0.54	63.88±2.54	18.10±0.66	82.11±2.31	19.86±0.62	41.76±0.52
120	15	90.14±0.41	99.38±1.11	7.62±0.45	56.76±2.64	14.70±0.52	80.48±2.90	13.65±0.59	25.46±0.42
102	10	97.90±0.44	114.48±0.99	11.21±0.62	64.21±2.01	18.32±0.71	82.41±1.25	20.01±0.85	51.21±0.23
123	10	94.35±0.24	107.18±085	7.83±0.28	56.49±2.59	14.75±0.67	80.54±2.01	13.74±0.75	27.49±0.41
112.5	3	93.73±0.23	107.50±0.65	11.05±0.41	64.08±2.34	18.45±0.55	82.65±2.35	20.11±0.83	48.88±0.54
112.5	17	92.24±0.32	103.80±0.75	9.88±0.35	62.46±2.56	16.43±0.53	81.92±2.41	18.21±0.46	32.58±0.56
112.5	10	94.35±0.45	107.61±0.88	10.15±0.28	63.52±2.74	17.28±0.62	82.13±2.33	18.46±0.71	35.58±0.45
112.5	10	95.96±0.22	110.30±0.58	10.02±0.30	63.87±2.65	17.20±0.48	82.11±2.11	18.45±0.46	38.65±0.23
112.5	10	93.80±0.14	106.69±0.96	10.18±0.25	62.97±2.33	17.32±0.57	82.00±2.53	18.12±0.62	36.87±0.56
112.5	10	93.97±0.42	106.61±0.73	9.99±0.23	63.47±2.15	18.11±0.62	81.88±2.31	18.55±0.63	41.58±0.45
112.5	10	93.53±0.43	105.77±1.20	10.35±0.21	63.71±2.86	16.85±0.66	82.32±2.10	18.38±0.54	51.11±0.86

Data shown are the mean ± SD of three treatment repetition

ANOVA for Response Surface Model

Table B3 pH of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.40	5	0.081	12.20	0.0024	significant
A-Temperature	0.21	1	0.21	32.22	0.0008	
B-Time	0.058	1	0.058	8.79	0.0209	
AB	1.000E-002	1	1.000E-002	1.51	0.2590	
A^2	0.052	1	0.052	7.81	0.0267	
B^2	0.086	1	0.086	12.99	0.0087	
Residual	0.046	7	6.629E-003			
Lack of Fit	0.014	3	4.800E-003	0.60	0.6483	not significant
Pure Error	0.032	4	8.000E-003			
Cor Total	0.45	12				
R^2						0.8971
Adj R^2						0.8235
Pred R^2						0.6619
Adeq Precision						9.127

Table B5 pH of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.059	5	0.012	13.48	0.0018	significant
A-Temperature	0.015	1	0.015	17.58	0.0041	
B-Time	0.030	1	0.030	34.00	0.0006	
AB	9.000E-004	1	9.000E-004	1.04	0.3428	
A^2	2.853E-003	1	2.853E-003	3.28	0.1130	
B^2	0.011	1	0.011	12.96	0.0087	
Residual	6.085E-00	7	8.693E-004			
Lack of Fit	4.205E-003	3	1.402E-003	2.98	0.1593	not significant
Pure Error	1.880E-003	4	4.700E-004			
Cor Total	0.065	12				
R^2						0.9791
Adj R^2						0.9641
Pred R^2						0.9107
Adeq Precision						24.623

Table B6 TSS of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5.69	5	0.012	13.48	0.0018	significant
A-Temperature	3.47	1	0.015	17.58	0.0041	
B-Time	0.31	1	0.030	34.00	0.0006	
AB	0.20	1	9.000E-004	1.04	0.3428	
A^2	0.28	1	2.853E-003	3.28	0.1130	
B^2	1.57	1	0.011	12.96	0.0087	
Residual	1.27	7	8.693E-004			
Lack of Fit	0.21	3	1.402E-003	2.98	0.1593	not significant
Pure Error	1.06	4	4.700E-004			
Cor Total	6.96	12				
R^2						0.8181
Adj R^2						0.6882
Pred R^2						0.5520
Adeq Precision						6.552

Table B7 TSS of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.22	5	0.24	31.31	0.0001	significant
A-Temperature	0.89	1	0.89	114.80	< 0.0001	
B-Time	0.015	1	0.015	1.87	0.2134	
AB	0.090	1	0.090	11.57	0.0114	
A^2	0.20	1	0.20	25.85	0.0014	
B^2	6.261E-003	1	6.261E-003	0.80	0.3994	
Residual	0.054	7	7.779E-003			
Lack of Fit	0.022	3	7.484E-003	0.94	0.5018	not significant
Pure Error	0.032	4	8.000E-003			
Cor Total	1.27	12				
R^2						0.9572
Adj R^2						0.9266
Pred R^2						0.8352
Adeq Precision						20.015

Table B8 TPC of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.17	5	0.034	38.40	< 0.0001	significant
A-Temperature	0.15	1	0.15	170.68	< 0.0001	
B-Time	5.120E-003	1	5.120E-003	5.83	0.0465	
AB	1.332E-003	1	1.332E-003	1.52	0.2578	
A^2	0.011	1	0.011	12.20	0.0101	
B^2	6.630E-004	1	6.630E-004	0.75	0.4137	
Residual	6.147E-003	7	8.782E-004			
Lack of Fit	3.056E-003	3	1.019E-003	1.32	0.3851	not significant
Pure Error	3.091E-003	4	7.728E-004			
Cor Total	0.17	12				
R^2					0.9648	
Adj R^2					0.9397	
Pred R^2					0.8480	
Adeq Precision					19.230	

Table B9 TPC of retort pouch sterilised RJ

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	100.32	5	20.06	51.19	< 0.0001	significant
A-Temperature	74.89	1	74.89	191.09	< 0.0001	
B-Time	3.01	1	3.01	7.69	0.0276	
AB	0.12	1	0.12	0.29	0.6039	
A^2	22.23	1	22.23	56.73	0.0001	
B^2	0.75	1	0.75	1.91	0.2098	
Residual	2.74	7	0.39			
Lack of Fit	2.28	3	0.76	6.57	0.0503	not significant
Pure Error	0.46	4	0.12			
Cor Total	103.07	12				
R^2						0.9734
Adj R^2						0.9544
Pred R^2						0.8356
Adeq Precision						21.844

Table B10TFC of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	72.17	5	14.43	63.90	< 0.0001	significant
A-Temperature	54.49	1	54.49	241.20	< 0.0001	
B-Time	5.52	1	5.52	24.46	0.0017	
AB	1.58	1	1.58	6.97	0.0334	
A^2	10.28	1	10.28	45.49	0.0003	
B^2	0.017	1	0.017	0.076	0.7910	
Residual	1.58	7	0.23			
Lack of Fit	0.76	3	0.25	1.24	0.4059	not significant
Pure Error	0.82	4	0.20			
Cor Total	73.75	12				
R^2						0.9786
Adj R^2						0.9632
Pred R^2						0.9092
Adeq Precision						24.061

Table B11 TFC of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	19.14	5	3.83	25.56	0.0002	significant
A-Temperature	14.66	1	14.66	97.83	< 0.0001	
B-Time	2.88	1	2.88	19.20	0.0032	
AB	0.26	1	0.26	1.74	0.2291	
A^2	1.31	1	1.31	8.75	0.0212	
B^2	2.349E-003	1	2.349E-003	0.016	0.9039	
Residual	1.05	7	0.15			
Lack of Fit	0.19	3	0.064	0.30	0.8246	not significant
Pure Error	0.86	4	0.21			
Cor Total	20.19	12				
R^2						0.9481
Adj R^2						0.9110
Pred R^2						0.8658
Adeq Precision						15.458

Table B12 AA of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	15.30	5	3.06	65.03	< 0.0001	significant
A-Temperature	11.79	1	11.79	250.37	< 0.0001	
B-Time	2.15	1	2.15	45.65	0.0003	
AB	0.23	1	0.23	4.79	0.0647	
A^2	1.00	1	1.00	21.23	0.0025	
B^2	0.061	1	0.061	1.30	0.2922	
Residual	0.33	7	0.047			
Lack of Fit	0.25	3	0.082	3.98	0.1077	not significant
Pure Error	0.083	4	0.021			
Cor Total	15.63	12				
R^2						0.9789
Adj R^2						0.9639
Pred R^2						0.8795
Adeq Precision						24.992

Table B13 AA of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	15.32	5	3.06	247.89	< 0.0001	significant
A-Temperature	12.04	1	12.04	973.94	< 0.0001	
B-Time	2.27	1	2.27	183.58	< 0.0001	
AB	0.055	1	0.055	4.47	0.0724	
A^2	0.96	1	0.96	77.45	< 0.0001	
B^2	0.016	1	0.016	1.32	0.2877	
Residual	0.087	7	0.012			
Lack of Fit	0.069	3	0.023	5.27	0.0711	not significant
Pure Error	0.017	4	4.370E-003			
Cor Total	15.41	12	3.06			
R^2						0.9944
Adj R^2						0.9904
Pred R^2						0.9664
Adeq Precision						48.975

Table B14 Viscosity of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	810.55	5	162.11	6.14	0.0170	significant
A-Temperature	620.31	1	620.31	23.49	0.0019	
B-Time	168.47	1	168.47	6.38	0.0395	
AB	4.62	1	4.62	0.18	0.6882	
A^2	14.78	1	14.78	0.56	0.4787	
B^2	4.10	1	4.10	0.16	0.7053	
Residual	184.82	7	26.40			
Lack of Fit	30.61	3	10.20			not significant
Pure Error	154.21	4	38.55			
Cor Total	995.37	12				
R^2						0.8143
Adj R^2						0.6817
Pred R^2						0.5392
Adeq Precision						7.910

Table B15 L* value of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	31.40	5	6.28	28.79	0.0002	significant
A-Temperature	19.82	1	19.82	90.87	< 0.0001	
B-Time	2.79	1	2.79	12.77	0.0091	
AB	1.99	1	1.99	9.11	0.0194	
A^2	6.76	1	6.76	30.99	0.0008	
B^2	0.29	1	0.29	1.35	0.2834	
Residual	1.53	7	0.22			
Lack of Fit	1.20	3	0.40	4.82	0.0814	not significant
Pure Error	0.33	4	0.083			
Cor Total	32.93	12				
R^2						0.9536
Adj R^2						0.9205
Pred R^2						0.7260
Adeq Precision						14.797

Table B16 L* value of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	22.91	5	4.58	34.87	< 0.0001	significant
A-Temperature	21.06	1	21.06	160.30	< 0.0001	
B-Time	1.54	1	1.54	11.73	0.0111	
AB	0.22	1	0.22	1.65	0.2404	
A^2	0.068	1	0.068	0.51	0.4963	
B^2	0.011	1	0.011	0.080	0.7853	
Residual	0.92	7	0.13			
Lack of Fit	0.33	3	0.11	0.74	0.5816	not significant
Pure Error	0.59	4	0.15			
Cor Total	23.83	12				
R^2						0.9614
Adj R^2						0.9338
Pred R^2						0.8633
Adeq Precision						19.192

Table B17a* value of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.52	5	0.10	50.40	< 0.0001	significant
A-Temperature	0.38	1	0.38	181.22	< 0.0001	
B-Time	0.062	1	0.062	30.17	0.0009	
AB	0.013	1	0.013	6.39	0.0394	
A^2	0.071	1	0.071	34.18	0.0006	
B^2	8.227E-004	1	8.227E-004	0.40	0.5485	
Residual	0.014	7	2.071E-003			
Lack of Fit	8.216E-003	3	2.739E-003	1.74	0.2960	not significant
Pure Error	6.280E-003	4	1.570E-003			
Cor Total	0.54	12				
R^2						0.9730
Adj R^2						0.9537
Pred R^2						0.8728
Adeq Precision						20.823

Table B18 b* value of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	48.30	5	9.66	24.51	0.0003	significant
A-Temperature	38.02	1	38.02	96.45	< 0.0001	
B-Time	3.37	1	3.37	8.55	0.0222	
AB	0.35	1	0.35	0.88	0.3787	
A^2	5.88	1	5.88	14.91	0.0062	
B^2	1.30	1	1.30	3.29	0.1127	
Residual	2.76	7	0.39			
Lack of Fit	0.79	3	0.26	0.53	0.6834	not significant
Pure Error	1.97	4	0.49			
Cor Total	51.06	12				
R^2						0.9460
Adj R^2						0.9074
Pred R^2						0.8298
Adeq Precision						14.456

Table B19 b* value of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	94.03	5	18.81	35.88	< 0.0001	significant
A-Temperature	79.98	1	79.98	152.58	< 0.0001	
B-Time	5.69	1	5.69	10.86	0.0132	
AB	7.90	1	7.90	15.06	0.0060	
A^2	0.028	1	0.028	0.053	0.8240	
B^2	0.46	1	0.46	0.87	0.3823	
Residual	3.67	7	0.52			
Lack of Fit	2.00	3	0.67	1.60	0.3227	not significant
Pure Error	1.67	4	0.42			
Cor Total	97.69	12				
R^2						0.9624
Adj R^2						0.9356
Pred R^2						0.8277
Adeq Precision						20.482

Table B20 ΔE value of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	33.37	5	6.67	65.53	< 0.0001	significant
A-Temperature	26.03	1	26.03	255.63	< 0.0001	
B-Time	2.75	1	2.75	26.96	0.0013	
AB	0.37	1	0.37	3.68	0.0967	
A^2	4.21	1	4.21	41.35	0.0004	
B^2	0.039	1	0.039	0.38	0.5564	
Residual	0.71	7	0.10			
Lack of Fit	0.35	3	0.12	1.27	0.3978	not significant
Pure Error	0.37	4	0.091			
Cor Total	34.08	12				
R^2						0.9791
Adj R^2						0.9641
Pred R^2						0.9107
Adeq Precision						24.623

Table B21 ΔE value of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	11.52	5	2.30	5.94	0.0185	significant
A-Temperature	1.44	1	1.44	3.70	0.0956	
B-Time	1.62	1	1.62	4.18	0.0801	
AB	7.79	1	7.79	20.08	0.0029	
A^2	0.040	1	0.040	0.10	0.7574	
B^2	0.66	1	0.66	1.71	0.2318	
Residual	2.71	7	0.39			
Lack of Fit	1.19	3	0.40	1.04	0.4663	not significant
Pure Error	1.53	4	0.38			
Cor Total	14.23	12				
R^2	11.52	5				0.8093
Adj R^2						0.6731
Pred R^2						0.2389
Adeq Precision						8.725

Table B22 YI value of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	155.39	5	31.08	14.19	0.0015	significant
A-Temperature	66.12	1	66.12	30.19	0.0009	
B-Time	11.19	1	11.19	5.11	0.0583	
AB	50.89	1	50.89	23.23	0.0019	
A^2	14.67	1	14.67	6.70	0.0360	
B^2	9.05	1	9.05	4.13	0.0816	
Residual	15.33	7	2.19			
Lack of Fit	3.11	3	1.04	0.34	0.7998	not significant
Pure Error	12.23	4	3.06			
Cor Total	170.72	12				
R^2	155.39	5				0.9102
Adj R^2						0.8460
Pred R^2						0.7588
Adeq Precision						14.206

Table B23 YI value of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	185.71	5	37.14	9.45	0.0051	significant
A-Temperature	33.40	1	33.40	8.50	0.0225	
B-Time	0.96	1	0.96	0.25	0.6357	
AB	20.58	1	20.58	5.24	0.0559	
A^2	126.54	1	126.54	32.20	0.0008	
B^2	12.28	1	12.28	3.13	0.1204	
Residual	27.50	7	3.93			
Lack of Fit	11.79	3	3.93	1.00	0.4787	not significant
Pure Error	15.71	4	3.93			
Cor Total	213.22	12				
R^2	185.71	5				0.8710
Adj R^2						0.7789
Pred R^2						0.4915
Adeq Precision						8.480

Table B24 BI value of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	97.43	5	19.49	8.01	0.0082	significant
A-Temperature	15.04	1	15.04	6.18	0.0418	
B-Time	0.35	1	0.35	0.14	0.7153	
AB	10.71	1	10.71	4.41	0.0740	
A^2	68.70	1	68.70	28.25	0.0011	
B^2	7.21	1	7.21	2.96	0.1289	
Residual	17.03	7	2.43			
Lack of Fit	7.01	3	2.34	0.93	0.5029	not significant
Pure Error	10.02	4	2.50			
Cor Total	114.45	12				
R^2	97.43	5				0.8512
Adj R^2						0.7450
Pred R^2						0.6878
Adeq Precision						7.762

Table B25 BI value of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	42.84	5	8.57	13.83	0.0016	significant
A-Temperature	14.35	1	14.35	23.16	0.0019	
B-Time	1.78	1	1.78	2.88	0.1337	
AB	16.85	1	16.85	27.20	0.0012	
A^2	4.14	1	4.14	6.69	0.0362	
B^2	4.43	1	4.43	7.16	0.0317	
Residual	4.34	7	0.62			
Lack of Fit	0.62	3	0.21	0.22	0.8753	not significant
Pure Error	3.71	4	0.93			
Cor Total	47.17	12				
R^2						0.9081
Adj R^2						0.8424
Pred R^2						0.7830
Adeq Precision						13.704

Table B26 DPPH radical scavenging activity of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5.72	5	1.14	35.33	< 0.0001	significant
A-Temperature	3.75	1	3.75	115.68	< 0.0001	
B-Time	1.05	1	1.05	32.51	0.0007	
AB	0.046	1	0.046	1.43	0.2711	
A^2	0.78	1	0.78	24.23	0.0017	
B^2	0.033	1	0.033	1.03	0.3447	
Residual	0.23	7	0.032			
Lack of Fit	0.12	3	0.040	1.49	0.3452	not significant
Pure Error	0.11	4	0.027			
Cor Total	5.95	12				
R^2						0.9619
Adj R^2						0.9347
Pred R^2						0.8288
Adeq Precision						18.914

Table B27 DPPH radical scavenging activity of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	31.34	5	6.27	7.14	0.0113	significant
A-Temperature	16.67	1	16.67	19.00	0.0033	
B-Time	4.674E-003	1	4.674E-003	5.325E-003	0.9439	
AB	0.28	1	0.28	0.31	0.5927	
A^2	14.35	1	14.35	16.35	0.0049	
B^2	0.44	1	0.44	0.50	0.5020	
Residual	6.14	7	0.88			
Lack of Fit	2.87	3	0.96	1.17	0.4260	not significant
Pure Error	3.28	4	0.82			
Cor Total	37.48	12				
R^2						0.8361
Adj R^2						0.7190
Pred R^2						0.6193
Adeq Precision						7.722

Table B28 Total sugar content of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	11.86	5	2.37	72.23	< 0.0001	significant
A-Temperature	7.49	1	7.49	227.89	< 0.0001	
B-Time	1.75	1	1.75	53.24	0.0002	
AB	0.37	1	0.37	11.14	0.0125	
A^2	2.26	1	2.26	68.86	< 0.0001	
B^2	0.042	1	0.042	1.28	0.2952	
Residual	0.23	7	0.033			
Lack of Fit	0.091	3	0.030	0.88	0.5237	not significant
Pure Error	0.14	4	0.035			
Cor Total	12.09	12				
R^2						0.9810
Adj R^2						0.9674
Pred R^2						0.9284
Adeq Precision						24.480

Table B29 Total sugar content of retort pouch sterilised RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	54.20	5	10.84	162.40	< 0.0001	significant
A-Temperature	39.37	1	39.37	589.79	< 0.0001	
B-Time	5.72	1	5.72	85.75	< 0.0001	
AB	3.13	1	3.13	46.93	0.0002	
A^2	4.67	1	4.67	69.92	< 0.0001	
B^2	0.73	1	0.73	10.90	0.0131	
Residual	0.47	7	0.067			
Lack of Fit	0.36	3	0.12	4.48	0.0906	not significant
Pure Error	0.11	4	0.027			
Cor Total	54.67	12				
R^2						0.9915
Adj R^2						0.9853
Pred R^2						0.9501
Adeq Precision						37.707

Table B30 Firmness of retort pouch sterilised RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	177.60	5	35.52	54.47	< 0.0001	significant
A-Temperature	150.27	1	150.27	230.45	< 0.0001	
B-Time	3.64	1	3.64	5.58	0.0502	
AB	4.16	1	4.16	6.38	0.0394	
A^2	19.37	1	19.37	29.71	0.0010	
B^2	0.033	1	0.033	0.050	0.8287	
Residual	4.56	7	0.65			
Lack of Fit	2.49	3	0.83	1.60	0.3232	not significant
Pure Error	2.08	4	0.52			
Cor Total	182.16	12				
R^2						0.9749
Adj R^2						0.9570
Pred R^2						0.8851
Adeq Precision						22.620

APPENDIX C

HP PROCESSED RIPE JACKFRUIT

Table.C1 Physicochemical properties of HP processed RJB

Pressure (MPa)	Holding time (min)	L*	ΔE	BI	YI
300	5	34.09±1.15	2.18±0.09	268.04±1.41	215.58±1.32
600	5	40.05±1.86	7.26±0.26	179.80±1.62	184.52±2.01
300	20	35.63±1.10	4.06±0.10	235.25±2.33	206.65±1.87
600	20	42.64±1.35	12.64±0.55	160.49±2.04	173.44±1.56
238	12.5	34.83±1.51	2.61±0.09	250.44±2.47	211.07±2.67
662	12.5	42.59±1.47	11.70±0.53	160.67±1.74	173.55±2.30
450	2	36.02±1.55	3.53±0.12	228.47±2.03	204.49±1.80
450	23	38.11±1.87	6.36±0.16	199.89±1.75	193.87±1.93
450	12.5	36.13±1.99	3.65±0.13	226.68±1.38	203.89±2.30
450	12.5	35.52±1.37	3.14±0.11	237.53±1.88	207.33±2.00
450	12.5	35.24±1.20	2.97±0.07	239.07±1.47	207.80±2.05
450	12.5	36.16±1.75	3.60±0.15	228.55±1.55	204.53±1.54
450	12.5	35.98±1.02	3.54±0.16	227.39±1.68	204.12±2.64

Data shown are the mean ± SD of three treatment repetition

Table.C1 Physicochemical properties of HP processed RJB

Data shown are the mean ± SD of three treatment repetition

Pressure (MPa)	Holding time (min)	AA (mg/100 g)	TPC (mg GAE/g)	Firmness (N)	TFC (mg RE/g)	DPPH radical scavenging activity (%)	Total aerobic mesophiles (log CFU/g)	Yeast/mold (log CFU/g)	Total sugar (%)
300	5	13.94±0.63	64.80±2.80	57.16±2.81	35.12±1.23	88.63±2.34	4.10±0.18	3.87±0.17	25.49±0.92
600	5	15.42±0.58	65.76±1.25	63.51±2.14	41.75±1.20	89.65±1.18	5.30±0.23	4.50±0.18	25.45±0.91
300	20	14.45±0.74	64.96±1.35	61.46±2.17	42.11±1.45	89.46±1.25	5.30±0.41	4.70±0.18	25.46±0.67
600	20	16.82±0.82	66.02±1.74	69.00±3.16	43.68±1.57	90.43±1.04	6.40±0.23	6.20±0.03	25.50±1.11
238	12.5	14.25±0.86	64.81±2.03	58.84±3.02	38.22±1.65	88.79±1.03	4.74±0.18	4.30±0.01	25.50±1.16
662	12.5	16.44±0.63	65.78±1.48	68.28±3.05	43.53±2.03	91.00±0.98	6.10±0.22	5.90±0.06	25.50±1.17
450	2	14.56±0.41	65.23±1.65	58.59±2.01	36.34±1.45	88.95±1.02	4.40±0.24	4.00±0.03	25.48±0.92
450	23	15.06±0.68	65.76±2.04	63.84±2.15	42.36±1.18	90.56±0.87	5.76±0.23	5.30±0.04	25.46±0.67
450	12.5	14.84±0.46	65.42±2.0	62.74±2.01	41.31±1.04	89.46±1.25	5.68±0.18	4.90±0.02	25.48±1.11
450	12.5	14.05±0.88	65.41±1.87	62.70±2.54	40.19±1.35	88.98±1.41	6.00±0.19	5.40±0.03	25.49±0.88
450	12.5	13.94±0.76	65.00±1.16	62.54±3.16	41.29±1.42	88.79±1.02	5.70±0.20	5.30±0.02	25.47±1.16
450	12.5	14.59±0.42	65.40±1.84	61.14±2.45	41.02±1.33	89.46±1.45	5.70±0.26	5.00±0.01	25.50±0.92
450	12.5	13.99±0.91	64.95±1.90	62.74±2.53	42.33±1.54	89.46±1.65	5.60±0.21	4.90±0.02	25.48±0.67

Table.C2 Physicochemical properties of HP processed RJP

Pressure (MPa)	**Holding time (min)**	**L***	ΔE*	**Total aerobic mesophiles (log CFU/g)**	**Yeast/mold (log CFU/g)**	**Total sugar (%)**
300	5	49.54±2.27	1.54±0.06	4.10±0.18	4.30±0.24	22.62±0.26
600	5	51.42±1.24	2.86±0.13	5.10±0.17	4.90±0.18	22.65±0.82
300	20	51.13±1.74	2.66±0.13	5.10±0.21	5.10±0.19	22.63±0.60
600	20	51.58±1.85	2.92±0.14	5.93±0.23	6.20±0.54	22.68±0.99
238	12.5	50.19±1.65	1.97±0.09	4.82±0.23	4.90±0.14	22.64±1.04
662	12.5	51.43±2.01	2.87±0.08	5.80±0.31	6.10±0.20	22.67±1.04
450	2	50.51±1.65	2.13±0.11	4.80±0.35	4.50±0.23	22.67±0.82
450	23	51.46±2.04	2.94±0.11	5.60±0.36	5.80±0.17	22.65±0.60
450	12.5	50.52±2.31	2.06±0.11	5.45±0.35	5.40±0.22	22.64±0.99
450	12.5	49.93±1.74	2.07±0.01	5.70±0.28	5.90±0.16	22.62±0.78
450	12.5	50.05±1.18	1.67±0.05	5.50±0.18	5.60±0.13	22.65±1.04
450	12.5	51.13±1.62	2.84±0.11	5.50±0.24	5.40±0.12	22.64±0.82
450	12.5	50.45±1.63	2.20±0.01	5.40±0.21	5.20±0.22	22.64±0.60

Data shown are the mean ± SD of three treatment repetition

Table.C2 Physicochemical properties of HP processed RJP

Pressure (MPa)	Holding time (min)	AA (mg/100 g)	TPC (mg GAE/g)	Viscosity (Pa.s)	TFC (mg RE/g)	DPPH radical scavenging activity (%)
300	5	7.85±0.35	61.66±1.63	43.35±0.85	17.13±0.45	87.56±2.34
600	5	8.76±0.25	64.97±1.20	52.30±0.71	19.12±0.35	88.62±2.13
300	20	7.92±0.14	62.28±2.13	53.41±0.56	20.10±0.54	88.03±2.01
600	20	9.91±0.46	70.12±3.25	60.53±0.80	22.85±0.45	89.92±2.39
238	12.5	7.85±0.54	61.92±2.41	45.77±0.85	17.88±0.65	87.92±2.14
662	12.5	9.84±0.53	70.08±1.87	57.31±0.46	20.46±0.42	89.53±2.20
450	2	8.22±0.57	62.84±1.53	49.89±0.75	17.62±0.46	87.95±2.14
450	23	8.56±0.21	64.94±1.56	60.00±0.62	20.46±0.34	89.51±2.18
450	12.5	8.46±0.32	64.94±2.03	48.64±0.71	18.45±0.74	89.46±2.17
450	12.5	8.12±0.12	64.25±1.42	50.12±0.62	17.86±0.65	89.95±2.16
450	12.5	8.46±0.45	61.951±2.01	49.56±0.88	18.45±0.41	89.77±2.34
450	12.5	8.36±0.75	62.54±1.53	48.75±1.20	19.23±0.75	89.46±1.89
450	12.5	8.14±0.35	62.00±2.08	48.25±1.11	17.99±0.46	89.23±2.01

Data shown are the mean ± SD of three treatment repetition

ANOVA for Response Surface Model

Table C3 L* value of HP processed RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	95.68	5	19.14	93.84	< 0.0001	significant
A-Pressure	71.63	1	71.63	351.23	< 0.0001	
B-Holding time	6.27	1	6.27	30.75	0.0009	
AB	0.28	1	0.28	1.35	0.2831	
A^2	15.83	1	15.83	77.61	< 0.0001	
B^2	3.26	1	3.26	15.97	0.0052	
Residual	1.43	7	0.2			
Lack of Fit	0.76	3	0.25	1.53	0.3367	not significant
Pure Error	0.66	4	0.17			
Cor Total	97.11	12				0.9853
R^2						0.9748
Adj R^2						0.9335
Pred R^2						28.263
Adeq Precision						0.9853

Table C4 L* value of HP processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	4.43	5	0.89	6.65	0.0137	significant
A-Pressure	1.98	1	1.98	14.90	0.0062	
B-Holding time	1.12	1	1.12	8.41	0.0230	
AB	0.59	1	0.59	4.40	0.0743	
A^2	0.27	1	0.27	2.00	0.2000	
B^2	0.56	1	0.56	4.19	0.0798	
Residual	0.93	7	0.13			
Lack of Fit	0.040	3	0.013	0.060	0.9782	not significant
Pure Error	0.89	4	0.22			
Cor Total	5.36	12				0.8260
R^2	4.43	5				0.7018
Adj R^2						0.6866
Pred R^2						7.549
Adeq Precision						0.8260

Table C5 ΔE value of HP processed RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	94.46	5	18.89	100.04	< 0.0001	significant
A-Pressure	70.62	1	70.62	373.96	< 0.0001	
B-Holding time	6.12	1	6.12	32.42	0.0007	
AB	0.31	1	0.31	1.64	0.2408	
A^2	15.78	1	15.78	83.58	< 0.0001	
B^2	3.17	1	3.17	16.78	0.0046	
Residual	1.32	7	0.19			
Lack of Fit	0.74	3	0.25	1.69	0.3058	not significant
Pure Error	0.58	4	0.15			
Cor Total	95.78	12				0.9862
R^2	94.46	5				0.9763
Adj R^2						0.9356
Pred R^2						29.132
Adeq Precision						0.9862

Table C6 ΔE value of HP processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	2.29	5	0.46	4.39	0.0396	significant
A-Pressure	1.02	1	1.02	9.75	0.0168	
B-Holding time	0.67	1	0.67	6.41	0.0391	
AB	0.28	1	0.28	2.69	0.1449	
A^2	0.11	1	0.11	1.10	0.3298	
B^2	0.25	1	0.25	2.36	0.1687	
Residual	0.73	7	0.10			
Lack of Fit	0.013	3	4.257E-003	0.024	0.9943	not significant
Pure Error	0.72	4	0.18			
Cor Total	3.02	12				0.7581
R^2	2.29	5				0.5853
Adj R^2						0.5986
Pred R^2						6.286
Adeq Precision						0.7581

Table C7 AA of HP processed RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	9.51	5	1.90	14.32	0.0015	significant
A-Pressure	6.02	1	6.02	45.36	0.0003	
B-Holding time	0.85	1	0.85	6.42	0.0390	
AB	0.20	1	0.20	1.51	0.2586	
A^2	2.11	1	2.11	15.91	0.0053	
B^2	0.56	1	0.56	4.21	0.0792	
Residual	0.93	7	0.13			
Lack of Fit	0.26	3	0.087	0.52	0.6890	not significant
Pure Error	0.67	4	0.17			
Cor Total	97.11	12				0.9109
R^2						0.8473
Adj R^2						0.7215
Pred R^2						9.956
Adeq Precision						0.9853

Table C8 TPC of HP processed RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.72	5	0.34	8.19	0.0077	significant
A-Pressure	1.44	1	1.44	34.14	0.0006	
B-Holding time	0.17	1	0.17	4.06	0.0838	
AB	2.500E-003	1	2.500E-003	0.059	0.8145	
A^2	5.071E-003	1	5.071E-003	0.12	0.7388	
B^2	0.11	1	0.11	2.66	0.1467	
Residual	0.29	7	0.042			
Lack of Fit	0.066	3	0.022	0.39	0.7694	not significant
Pure Error	7.58	4	1.89			
Cor Total	101.11	12				0.8540
R^2						0.7497
Adj R^2						0.5897
Pred R^2						9.287
Adeq Precision						0.8540

Table C9 DPPH radical scavenging activity of HP processed RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	6.99	5	1.40	17.81	0.0007	significant
A-Pressure	3.83	1	3.83	48.80	0.0002	
B-Holding time	2.32	1	2.32	29.54	0.0010	
AB	0.034	1	0.034	0.44	0.5302	
A^2	0.58	1	0.58	7.36	0.0301	
B	0.33	1	0.33	4.22	0.0791	
Residual	0.55	7	0.078			
Lack of Fit	0.13	3	0.045	0.43	0.7414	not significant
Pure Error	0.41	4	0.10			
Cor Total	97.11	12				0.9271
R^2						0.8751
Adj R^2						0.7871
Pred R^2						12.928
Adeq Precision						0.9271

Table C10 Firmness of HP processed RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	135.79	5	27.16	63.96	< 0.0001	significant
A-Pressure	92.75	1	92.75	218.44	< 0.0001	
B-Holding time	37.04	1	37.04	87.24	< 0.0001	
AB	0.35	1	0.35	0.83	0.3916	
A^2	3.34	1	3.34	7.86	0.0264	
B^2	1.60	1	1.60	3.77	0.0933	
Residual	2.97	7	0.42			
Lack of Fit	1.05	3	0.35	0.73	0.5874	not significant
Pure Error	0.41	4	0.10			
Cor Total	97.11	12				0.9786
R^2						0.9633
Adj R^2						0.9246
Pred R^2						25.406
Adeq Precision						0.9786

Table C11 TAM in HP processed RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5.27	5	1.05	56.44	< 0.0001	significant
A-Pressure	2.23	1	2.23	119.47	< 0.0001	
B-Holding time	2.23	1	2.23	119.47	< 0.0001	
AB	2.500E-003	1	2.500E-003	0.13	0.7252	
A^2	0.16	1	0.16	8.58	0.0220	
B^2	0.72	1	0.72	38.59	0.0004	
Residual	0.13	7	0.019			
Lack of Fit	0.037	3	0.012	0.52	0.6903	not significant
Pure Error	0.094	4	0.023			
Cor Total	5.40	12				0.9758
R^2						0.9585
Adj R^2						0.9244
Pred R^2						22.753
Adeq Precision						0.9758

Table C12 AA in HP processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5.23	5	1.05	40.27	< 0.0001	significant
A-Pressure	4.08	1	4.08	157.15	< 0.0001	
B-Holding time	0.36	1	0.36	13.92	0.0073	
AB	0.29	1	0.29	11.23	0.0122	
A2	0.49	1	0.49	19.04	0.0033	
B2	0.011	1	0.011	0.41	0.5424	
Residual	0.18	7	0.026			
Lack of Fit	0.069	3	0.023	0.82	0.5460	not significant
Pure Error	0.11	4	0.028			
Cor Total	5.41	12				0.9664
R^2						0.9424
Adj R^2						0.8764
Pred R^2						18.453
Adeq Precision						0.9664

Table C13 TPC in HP processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	92.47	5	18.49	14.97	0.0013	significant
A-Pressure	64.33	1	64.33	52.06	0.0002	
B-Holding time	9.58	1	9.58	7.75	0.0271	
AB	5.10	1	5.10	4.12	0.0818	
A^2	13.30	1	13.30	10.77	0.0135	
B^2	0.76	1	0.76	0.61	0.4592	
Residual	8.65	7	1.24			
Lack of Fit	1.07	3	0.36	0.19	0.8993	not significant
Model	92.47	5	18.49	14.97	0.0013	significant
Cor Total	97.11	12				0.9145
R^2						0.8534
Adj R^2						0.8076
Pred R^2						10.621
Adeq Precision						0.9145

Table C14TFC in HP processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	79.73	5	15.95	36.76	< 0.0001	significant
A-Pressure	30.85	1	30.85	71.12	< 0.0001	
B-Holding time	37.99	1	37.99	87.58	< 0.0001	
AB	6.40	1	6.40	14.76	0.0064	
A^2	0.010	1	0.010	0.024	0.8822	
B^2	4.46	1	4.46	10.29	0.0149	
Residual	3.04	7	0.43			
Lack of Fit	0.69	3	0.23	0.39	0.7658	not significant
Pure Error	2.35	4	0.59			
Cor Total	82.77	12				0.9633
R^2						0.9371
Adj R^2						0.8964
Pred R^2						19.997
Adeq Precision						0.9633

Table C15 TAM in HP processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	2.79	5	0.56	18.13	0.0007	significant
A-Pressure	1.29	1	1.29	41.96	0.0003	
B-Holding time	1.10	1	1.10	35.58	0.0006	
AB	7.225E-003	1	7.225E-003	0.23	0.6430	
A^2	0.16	1	0.16	5.04	0.0597	
B^2	0.29	1	0.29	9.43	0.0180	
Residual	0.22	7	0.031			
Lack of Fit	0.16	3	0.055	4.20	0.0998	not significant
Model	0.052	4	0.013	0.052	4	significant
Cor Total	3.01	12		3.01	12	0.9283
R^2						0.8771
Adj R^2						0.5862
Pred R^2						12.950
Adeq Precision						0.9283

Table C16 Yeast and mold in HP processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	3.80	5	0.76	14.43	0.0014	significant
A-Pressure	1.44	1	1.44	27.40	0.0012	
B-Holding time	1.94	1	1.94	36.83	0.0005	
AB	0.063	1	0.063	1.19	0.3120	
A^2	0.017	1	0.017	0.33	0.5835	
B^2	0.35	1	0.35	6.69	0.0361	
Residual	0.37	7	0.053			
Lack of Fit	0.089	3	0.030	0.42	0.7480	not significant
Pure Error	0.28	4	0.070	14.43	0.0014	
Cor Total	4.17	12				0.9116
R^2						0.8484
Adj R^2						0.7439
Pred R^2						12.273
Adeq Precision						0.9116

Table C17 Yeast and mold in HP processed RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5.39	5	1.08	26.13	0.0002	significant
A-Pressure	2.41	1	2.41	58.51	0.0001	
B-Holding time	2.39	1	2.39	57.86	0.0001	
AB	0.19	1	0.19	4.59	0.0694	
A^2	1.438E-003	1	1.438E-003	0.035	0.8572	
B^2	0.40	1	0.40	9.67	0.0171	
Residual	0.29	7	0.041			
Lack of Fit	0.069	3	0.023	0.42	0.7516	not significant
Model	0.22	4	0.055			
Cor Total	5.68	12				0.9492
R^2						0.9128
Adj R^2						0.8535
Pred R^2						16.745
Adeq Precision						0.9492

Table C18 Dynamic viscosity of HP processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	319.72	5	63.94	78.11	< 0.0001	significant
A-Pressure	131.14	1	131.14	160.20	< 0.0001	
B-Holding time	132.74	1	132.74	162.16	< 0.0001	
AB	0.84	1	0.84	1.02	0.3455	
A^2	7.33	1	7.33	8.96	0.0201	
B^2	51.82	1	51.82	63.30	< 0.0001	
Residual	5.73	7	0.82			
Lack of Fit	3.43	3	1.14	1.99	0.2584	not significant
Model	2.30	4	0.58			
Cor Total	325.45	12				
R^2						0.9824
Adj R^2						0.9698
Pred R^2						0.9140
Adeq Precision						26.428

Table C19 BI of HP processed RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	13116.51	5	2623.30	56.74	< 0.0001	significant
A-Pressure	10509.05	1	10509.05	227.32	< 0.0001	
B-Holding time	1070.03	1	1070.03	23.15	0.0019	
AB	45.43	1	45.43	0.98	0.3546	
A^2	1155.71	1	1155.71	25.00	0.0016	
B^2	511.48	1	511.48	11.06	0.0127	
Residual	323.61	7	46.23			
Lack of Fit	181.71	3	60.57	1.71	0.3025	not significant
Model	141.91	4	35.48			
Cor Total	13440.13	12				
R^2						0.9759
Adj R^2						0.9587
Pred R^2						0.8874
Adeq Precision						23.110

Table C20 YI of HP processed RJB

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	2238.39	5	447.68	92.42	< 0.0001	significant
A-Pressure	1720.59	1	1720.59	355.20	< 0.0001	
B-Holding time	153.36	1	153.36	31.66	0.0008	
AB	1.15	1	1.15	0.24	0.6417	
A^2	320.32	1	320.32	66.13	< 0.0001	
B^2	78.04	1	78.04	16.11	0.0051	
Residual	33.91	7	4.84			
Lack of Fit	19.84	3	6.61	1.88	0.2740	not significant
Model	14.07	4	3.52			
Cor Total	2272.30	12				
R^2						0.9851
Adj R^2						0.9744
Pred R^2						0.9282
Adeq Precision						28.548

Table C21 DPPH radical scavenging activity of HP processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	8.31	5	1.66	24.19	0.0003	significant
A-Pressure	3.42	1	3.42	49.74	0.0002	
B-Holding time	1.98	1	1.98	28.79	0.0010	
AB	0.17	1	0.17	2.51	0.1572	
A^2	1.56	1	1.56	22.69	0.0021	
B^2	1.54	1	1.54	22.45	0.0021	
Residual	0.48	7	0.069			
Lack of Fit	0.16	3	0.052	0.64	0.6263	not significant
Model	0.32	4	0.081			
Cor Total	8.79	12				
R^2						0.9453
Adj R^2						0.9062
Pred R^2						0.8157
Adeq Precision						12.925

APPENDI D

PL PROCESSING OF RJP

Table.D1 Physicochemical properties of PL processed RJP

Voltage (Kv)	Pulse number	Vertical distance (cm)	AA (mg/100 g)	TPC (mg GAE/g)	TFC (mg RE/g)
1.5	50	7	16.74±0.73	65.14±1.25	19.63±0.87
2.5	50	7	14.92±0.68	64.14±1.71	19.48±0.65
1.5	200	7	16.05±0.58	66.07±1.84	21.07±0.75
2.5	200	7	13.98±0.50	62.45±1.65	17.58±0.77
1.5	125	4	15.64±0.54	65.68±1.35	20.51±0.61
2.5	125	4	14.15±0.63	63.05±1.54	18.25±0.74
1.5	125	10	16.54±0.81	65.36±1.53	19.88±0.83
2.5	125	10	14.32±0.55	63.01±1.85	18.19±0.28
2	50	4	15.24±0.62	65.88±1.76	20.52±0.45
2	200	4	15.13±0.71	66.10±2.87	21.12±0.71
2	50	10	16.62±0.46	65.65±2.15	20.41±0.63
2	200	10	15.32±0.54	65.04±3.01	19.52±0.52
2	125	7	14.68±0.72	66.00±1.02	20.82±0.56
2	125	7	15.00±0.66	66.05±1.05	20.48±0.86
2	125	7	14.98±0.62	66.00±1.23	20.35±0.45
2	125	7	14.95±0.61	66.08±1.54	20.13±0.72
2	125	7	14.96±0.63	65.19±1.67	20.54±0.44

Data shown are the mean ± SD of three treatment repetition

Table.D1 Physicochemical properties of PL processed RJP

Voltage (Kv)	Pulse number	Vertical distance (cm)	Viscosity (Pa.s)	TAM (log CFU/g)	Yeast and mold count (log CFU/g)
1.5	50	7	61.12±0.15	1.88±1.02	0.95±0.03
2.5	50	7	56.47±0.12	4.30±2.04	3.40±1.02
1.5	200	7	58.47±0.11	4.68±2.14	3.75±2.10
2.5	200	7	55.72±0.16	6.68±2.11	6.30±2.45
1.5	125	4	55.74±0.14	3.23±1.87	2.39±2.45
2.5	125	4	55.14±1.02	5.22±1.65	4.40±2.35
1.5	125	10	59.26±0.53	1.18±1.54	0.72±2.45
2.5	125	10	56.85±0.42	4.84±1.62	4.10±2.45
2	50	4	59.19±0.33	1.98±1.44	1.05±1.83
2	200	4	55.65±0.72	5.30±1.35	3.90±1.75
2	50	10	60.12±0.25	1.04±1.42	0.64±1.20
2	200	10	58.97±0.14	2.20±1.55	1.90±1.32
2	125	7	58.22±0.56	3.25±1.75	2.01±1.47
2	125	7	59.34±0.75	2.55±1.53	1.83±1.53
2	125	7	55.68±0.66	2.69±1.23	1.76±1.23
2	125	7	58.87±0.52	2.77±1.45	2.03±2.15
2	125	7	57.26±0.46	2.75±1.55	1.65±1.35

Data shown are the mean ± SD of three treatment repetition

ANOVA for Response Surface Model

Table D2 ANOVA for AA in PL processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	10.343	9	1.14925758	79.439153	< 0.0001	significant
A-voltage	6.845	1	6.845	473.14111	< 0.0001	
B-pulse number	1.0082	1	1.0082	69.68895	< 0.0001	
C-vertical distance	0.8712	1	0.8712	60.219216	0.0001	
AB	0.050625	1	0.050625	3.4993088	0.1036	
AC	0.133225	1	0.133225	9.2087983	0.0190	
BC	0.354025	1	0.354025	24.470969	0.0017	
A^2	0.001991842	1	0.00199184	0.1376804	0.7216	
B^2	0.803160263	1	0.80316026	55.516163	0.0001	
C^2	0.216486579	1	0.21648658	14.964018	0.0061	
Residual	0.10127	7	0.01446714			
Lack of Fit	0.03135	3	0.01045	0.5978261	0.6494	not significant
Pure Error	0.06992	4	0.01748			
R-Squared						0.9903
Adj R-Squared						0.9778
Pred R-Squared						0.9415
Adeq Precision						28.401

Table D3 ANOVA for TPC in PL processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	22.55	9	2.51	24.57	0.0002	significant
A-voltage	11.52	1	11.52	112.95	< 0.0001	
B-pulse number	0.17	1	0.17	1.62	0.2436	
C-vertical distance	0.34	1	0.34	3.34	0.1105	
AB	1.72	1	1.72	16.83	0.0046	
AC	0.020	1	0.020	0.19	0.6743	
BC	0.17	1	0.17	1.69	0.2349	
A^2	8.29	1	8.29	81.29	< 0.0001	
B^2	4.866E-004	1	4.866E-004	4.771E-003	0.9469	
C^2	0.15	1	0.15	1.42	0.2716	
Residual	0.71	7	0.10			
Lack of Fit	0.14	3	0.047	0.33	0.8058	not significant
Pure Error	0.57	4	0.14			
R-Squared						0.9693
Adj R-Squared						0.9299
Pred R-Squared						0.8643
Adeq Precision						15.147

Table D4 ANOVA for TFC in PL processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	16.74	9	1.86	32.31	< 0.0001	significant
A-voltage	7.20	1	7.20	125.08	< 0.0001	
B-pulse number	0.070	1	0.070	1.22	0.3056	
C-vertical distance	0.72	1	0.72	12.51	0.0095	
AB	2.79	1	2.79	48.44	0.0002	
AC	0.081	1	0.081	1.41	0.2736	
BC	0.56	1	0.56	9.64	0.0172	
A^2	5.14	1	5.14	89.22	< 0.0001	
B^2	0.027	1	0.027	0.47	0.5133	
C^2	0.097	1	0.097	1.69	0.2348	
Residual	0.40	7	0.058			
Lack of Fit	0.15	3	0.049	0.75	0.5745	not significant
Pure Error	0.26	4	0.064			
R-Squared						0.9765
Adj R-Squared						0.9463
Pred R-Squared						0.8406
Adeq Precision						19.386

Table D5 ANOVA for TAM in PL processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	39.62	9	4.40	36.04	< 0.0001	significant
A-voltage	12.68	1	12.68	103.79	< 0.0001	
B-pulse number	11.66	1	11.66	95.51	< 0.0001	
C-vertical distance	5.23	1	5.23	42.85	0.0003	
AB	0.044	1	0.044	0.36	0.5668	
AC	0.70	1	0.70	5.71	0.0482	
BC	1.17	1	1.17	9.55	0.0176	
A^2	6.96	1	6.96	56.95	0.0001	
B^2	0.37	1	0.37	3.06	0.1239	
C^2	0.93	1	0.93	7.61	0.0282	
Residual	0.85	7	0.12			
Lack of Fit	0.57	3	0.19	2.73	0.1782	not significant
Pure Error	0.28	4	0.070			
R-Squared						0.9789
Adj R-Squared						0.9517
Pred R-Squared						0.7621
Adeq Precision						20.945

Table D6 ANOVA for Yeast and mold in PL processed RJP

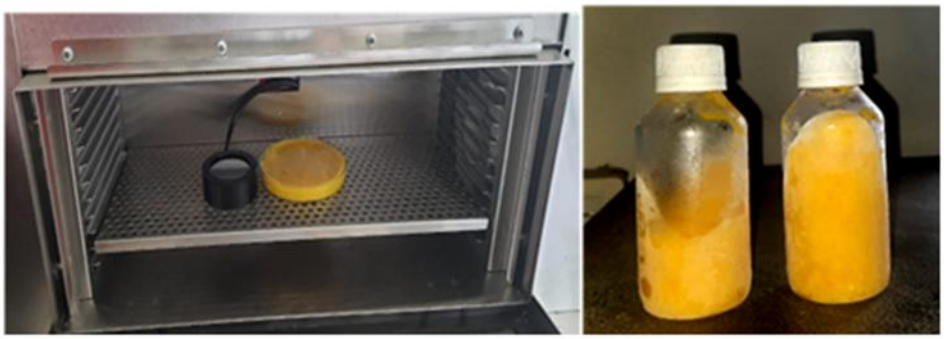
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	38.16	9	4.24	63.75	< 0.0001	**significant**
A-voltage	13.49	1	13.49	202.90	< 0.0001	
B-pulse number	12.03	1	12.03	180.88	< 0.0001	
C-vertical distance	2.40	1	2.40	36.06	0.0005	
AB	2.500E-003	1	2.500E-003	0.038	0.8518	
AC	0.47	1	0.47	7.06	0.0326	
BC	0.63	1	0.63	9.50	0.0177	
A^2	8.10	1	8.10	121.79	< 0.0001	
B^2	0.54	1	0.54	8.07	0.0250	
C^2	0.49	1	0.49	7.34	0.0302	
Residual	0.47	7	0.067			
Lack of Fit	0.36	3	0.12	4.50	0.0900	**not significant**
Pure Error	0.11	4	0.027			
R-Squared						0.9879
Adj R-Squared						0.9724
Pred R-Squared						0.8469
Adeq Precision						28.584

Table D7 ANOVA for viscosity in PL processed RJP

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	32.96	3	10.99	6.89	0.0051	**significant**
A-voltage	13.55	1	13.55	8.50	0.0121	
B-pulse number	8.18	1	8.18	5.13	0.0412	
C-vertical distance	11.23	1	11.23	7.05	0.0198	
Residual	20.73	13	1.59			
Lack of Fit	12.28	9	1.36	0.65	0.7316	**not significant**
Pure Error	8.45	4	2.11			
Cor Total	53.69	16				
R-Squared						0.6139
Adj R-Squared						0.5248
Pred R-Squared						0.3447
Adeq Precision						8.118

Table D8 PL setting and energy calculation

Voltage (kV)	No. of Pulses	Distance (cm)	Average Fluence/Pulse ($J \cdot cm^{-2}$)	Total Fluence ($J \cdot cm^{-2}$)	Estimated Temp Rise (°C)
1.5	50	7	3.4	170	1.8 ± 0.1
2.5	50	7	7	350	2.5 ± 0.2
1.5	200	7	3.4	680	4.5 ± 0.3
2.5	200	7	7	1400	7.0 ± 0.3
1.5	125	7	3.4	425	3.0 ± 0.2
2.5	125	4	7	875	5.8 ± 0.2
1.5	125	10	3.4	425	3.0 ± 0.2
2.5	125	10	7	875	5.8 ± 0.2
2	50	4	5.4	270	2.3 ± 0.2
2	200	4	5.4	1080	6.0 ± 0.3
2	50	10	5.4	270	2.3 ± 0.2
2	200	10	5.4	1080	6.0 ± 0.3
2	125	7	5.4	675	4.5 ± 0.3
2	125	7	5.4	675	4.5 ± 0.3
2	125	7	5.4	675	4.5 ± 0.3
2	125	7	5.4	675	4.5 ± 0.3



(a) **(b)**

Plate D1 PL processed RJP (a) before processing and (b) after processing

APPENDIX E

STORAGE STUDYOF THERMAL AND NON-THERMAL PROCESSED RIPE JACKFRUIT

Table E1 ANOVA for retort pouch pasteurisation of RJB

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.330	6	.055	1.698	.194
	Within Groups	.453	14	.032		
	Total	.783	20			
TSS	Between Groups	1.680	6	.280	.608	.720
	Within Groups	6.447	14	.460		
	Total	8.127	20			
TA	Between Groups	.003	6	.001	2.215	.103
	Within Groups	.004	14	.000		
	Total	.007	20			
Colourdeviation	Between Groups	19.787	6	3.298	233.010	.000
	Within Groups	.198	14	.014		
	Total	19.985	20			
BI	Between Groups	34.647	6	5.775	.263	.945
	Within Groups	307.866	14	21.990		
	Total	342.513	20			
AA	Between Groups	4.430	6	.738	2.613	.065
	Within Groups	3.955	14	.283		
	Total	8.386	20			
totalsugar	Between Groups	3.212	6	.535	1.099	.410
	Within Groups	6.816	14	.487		
	Total	10.028	20			
firmness	Between Groups	84.968	6	14.161	5.651	.004
	Within Groups	35.083	14	2.506		
	Total	120.051	20			
TPC	Between Groups	103.555	6	17.259	3.659	.021
	Within Groups	66.044	14	4.717		
	Total	169.599	20			

Table E2 ANOVA for retort pouch pasteurisation of RJP

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.330	6	.055	1.698	.194
	Within Groups	.453	14	.032		
	Total	.783	20			
TSS	Between Groups	1.680	6	.280	.608	.720
	Within Groups	6.447	14	.460		
	Total	8.127	20			
TA	Between Groups	.003	6	.001	2.215	.103
	Within Groups	.004	14	.000		
	Total	.007	20			
Colourdeviation	Between Groups	19.787	6	3.298	233.010	.000
	Within Groups	.198	14	.014		
	Total	19.985	20			
BI	Between Groups	34.647	6	5.775	.263	.945
	Within Groups	307.866	14	21.990		
	Total	342.513	20			
AA	Between Groups	4.430	6	.738	2.613	.065
	Within Groups	3.955	14	.283		
	Total	8.386	20			
totalsugar	Between Groups	12.156	6	2.026	2.615	.065
	Within Groups	10.845	14	.775		
	Total	23.001	20			
TPC	Between Groups	192.891	6	32.149	5.803	.003
	Within Groups	77.558	14	5.540		
	Total	270.449	20			

Table E3 ANOVA for retort pouch sterilisation of RJB

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.034	6	.006	.048	.999
	Within Groups	1.689	14	.121		
	Total	1.724	20			
TSS	Between Groups	.271	6	.045	.165	.982
	Within Groups	3.847	14	.275		
	Total	4.118	20			
TA	Between Groups	.000	6	.000	.002	1.000
	Within Groups	.037	14	.003		
	Total	.037	20			
Colourdeviation	Between Groups	.012	6	.002	.015	1.000
	Within Groups	1.787	14	.128		
	Total	1.798	20			
firmness	Between Groups	22.420	6	3.737	.583	.738
	Within Groups	89.700	14	6.407		
	Total	112.120	20			
AA	Between Groups	14.981	6	2.497	16.349	.000
	Within Groups	2.138	14	.153		
	Total	17.119	20			
totalsugar	Between Groups	.011	6	.002	.001	1.000
	Within Groups	30.277	14	2.163		
	Total	30.288	20			
TPC	Between Groups	92.726	6	15.454	2.701	.059
	Within Groups	80.096	14	5.721		
	Total	172.823	20			

Table E4 ANOVA for retort pouch sterilisation of RJP

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.027	6	.005	.027	1.000
	Within Groups	2.337	14	.167		
	Total	2.364	20			
TSS	Between Groups	.158	6	.026	.072	.998
	Within Groups	5.100	14	.364		
	Total	5.258	20			
TA	Between Groups	.000	6	.000	.001	1.000
	Within Groups	.082	14	.006		
	Total	.082	20			
Colourdeviation	Between Groups	.217	6	.036	.251	.951
	Within Groups	2.015	14	.144		
	Total	2.231	20			
AA	Between Groups	14.345	6	2.391	5.705	.003
	Within Groups	5.868	14	.419		
	Total	20.213	20			
Total sugar	Between Groups	.009	6	.002	.001	1.000
	Within Groups	18.754	14	1.340		
	Total	18.763	20			

TableE5 ANOVA for processed RJB

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.057	4	.014	.595	.674
	Within Groups	.238	10	.024		
	Total	.295	14			
TSS	Between Groups	.161	4	.040	.057	.993
	Within Groups	7.040	10	.704		
	Total	7.201	14			
TA	Between Groups	.002	4	.001	1.170	.381
	Within Groups	.005	10	.001		
	Total	.008	14			
Colourdeviation	Between Groups	.799	4	.200	1.363	.314
	Within Groups	1.466	10	.147		
	Total	2.265	14			
Texture	Between Groups	.893	4	.223	.095	.982
	Within Groups	23.592	10	2.359		
	Total	24.485	14			
AA	Between Groups	8.527	4	2.132	11.319	.001
	Within Groups	1.883	10	.188		
	Total	10.410	14			
totalsugar	Between Groups	1.637	4	.409	1.174	.379
	Within Groups	3.484	10	.348		
	Total	5.121	14			
TPC	Between Groups	24.723	4	6.181	14.434	.000
	Within Groups	4.282	10	.428		
	Total	29.005	14			

TableE6 ANOVA for processed RJP

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.180	4	.045	1.351	.318
	Within Groups	.333	10	.033		
	Total	.513	14			
TSS	Between Groups	.077	4	.019	1.607	.247
	Within Groups	.120	10	.012		
	Total	.196	14			
TA	Between Groups	.002	4	.001	3.315	.057
	Within Groups	.002	10	.000		
	Total	.004	14			
Colourdeviation	Between Groups	.228	4	.057	1.147	.389
	Within Groups	.498	10	.050		
	Total	.727	14			
AA	Between Groups	7.577	4	1.894	32.926	.000
	Within Groups	.575	10	.058		
	Total	8.152	14			
totalsugar	Between Groups	1.354	4	.338	.630	.652
	Within Groups	5.371	10	.537		
	Total	6.725	14			
TPC	Between Groups	332.587	4	83.147	9.348	.002
	Within Groups	88.942	10	8.894		
	Total	421.529	14			

TableE7 ANOVA for PL processed RJP

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.002	7	.000	.003	1.000
	Within Groups	1.838	16	.115		
	Total	1.840	23			
TSS	Between Groups	.020	7	.003	.003	1.000
	Within Groups	14.896	16	.931		
	Total	14.916	23			
TA	Between Groups	.004	7	.001	.277	.954
	Within Groups	.031	16	.002		
	Total	.034	23			
Colourdeviation	Between Groups	39.652	7	5.665	65.809	.000
	Within Groups	1.377	16	.086		
	Total	41.029	23			
AA	Between Groups	16.011	7	2.287	2.811	.041
	Within Groups	13.020	16	.814		
	Total	29.031	23			
totalsugar	Between Groups	6.096	7	.871	.318	.935
	Within Groups	43.849	16	2.741		
	Total	49.944	23			

APPENDIX F

SENSORY EVALUATION OF THERMAL AND NON-THERMAL PROCESSING OF RJB AND RJP

SENSORY SCORE CARD

Date:

Name of judge:

You are requested to assess the product in terms of general acceptability on a 9 point hedonic scale

Score system:

Like extremely 9

Like very much 8

Like moderately 7

Like slightly 6

Neither like nor dislike 5

Dislike slightly 4

Dislike moderately 3

Dislike very much 2

Dislike extremely 1

Characteristics	Sample code					
	A	B	C	D	E	F
Colour & appearance						
Flavor						
Taste						
Overall acceptability						

Comments if any: Signature

Table F1 Sensory score for retort pouch pasteurised ripe jackfruit samples

Treatment	Colour		Aroma		Taste		Texture		Overall acceptability	
	RJB	RJP	RJB	RJP	RJB	RJP	RJB	RJP	RJP	RJB
Control	8.0^{b}	8.0^{b}	8.4^{b}	7.5^{a}	8.8^{b}	8.3^{b}	8.0^{a}	7.5^{a}	8.5^{b}	8.3^{b}
R1	7.4^{a}	7.0^{a}	7.2^{a}	7.0^{a}	7.2^{a}	7.0^{a}	7.6^{a}	6.8^{a}	7.0^{a}	7.1^{a}
R2	6.0^{a}	7.0^{a}	6.2^{a}	6.9^{a}	5.8^{a}	7.5^{a}	6.0^{a}	6.5^{a}	6.8^{a}	6.3^{a}
R3	6.8^{a}	7.0^{a}	6.6^{a}	7.1^{a}	6.5^{a}	6.5^{a}	6.5^{a}	6.6^{a}	6.4^{a}	6.4^{a}
R4	5.1^{c}	6.3^{a}	5.8^{c}	6.6^{a}	5.0^{c}	6.3^{a}	5.0^{b}	6.4^{a}	6.4^{a}	5.1^{b}
R5	7.0^{a}	7.1^{a}	6.2^{a}	7.0^{a}	6.4^{a}	6.9^{a}	6.3^{a}	6.5^{a}	6.3^{a}	6.6^{a}
R6	5.8^{c}	6.1^{a}	6.0^{a}	6.4^{a}	5.3^{c}	6.6^{a}	5.0^{c}	6.4^{a}	7.1^{a}	5.4^{b}
R7	6.5^{a}	7.1^{a}	6.3^{a}	7.0^{a}	6.7^{a}	7.4^{a}	6.2^{a}	7.0^{a}	6.8^{a}	6.7^{a}
R8	6.0^{a}	6.9^{a}	5.8^{c}	7.1^{a}	5.5^{c}	7.5^{a}	5.0^{b}	6.9^{a}	6.5^{a}	5.6^{b}
R9	6.2^{a}	7.0^{a}	6.0^{a}	6.9^{a}	6.0^{a}	6.9^{a}	6.1^{a}	7.1^{a}	6.4^{a}	6.0^{a}

Table F2 Sensory score for retort pouch sterilised ripe jackfruit sample

Treatment		Colour		Aroma		Taste		Texture		Overall acceptability	
		RJB	RJP	RJB	RJP	RJB	RJP	RJB	RJP	RJB	RJP
Control		9.2^{b}	8.6^{b}	9.0^{b}	9.0^{b}	9.4^{b}	8.5^{b}	9.8^{b}	8.4^{a}	9.1^{b}	8.7^{b}
SP1	SB1	7.0^{a}	7.1^{a}	7.2^{a}	6.9^{a}	6.8^{a}	6.8^{a}	6.5^{a}	6.7^{a}	7.1^{a}	6.9^{a}
SP2	SB2	6.8^{a}	6.0^{a}	6.8^{a}	6.0^{a}	6.3^{a}	6.0^{a}	6.4^{a}	6.0^{a}	6.4^{a}	6.0^{a}
SP3	SB3	7.4^{a}	7.1^{a}	6.5^{a}	6.8^{a}	7.0^{a}	6.2^{a}	7.5^{a}	6.6^{a}	7.2^{a}	6.8^{a}
SP4	SB4	5.8^{a}	7.3^{a}	6.0^{a}	6.0^{a}	5.8^{c}	5.3^{c}	5.2^{c}	6.4^{a}	6.1^{a}	5.6^{c}
SP5	SB5	7.5^{a}	5.8^{c}	7.6^{a}	7.5^{a}	7.3^{a}	6.8^{a}	7.3^{a}	7.1^{a}	7.3^{a}	7.0^{a}
SP6	SB6	5.6^{c}	6.0^{a}	5.8^{c}	5.9^{c}	5.6^{c}	5.4^{c}	5.4^{c}	6.1^{a}	5.9^{c}	5.7^{c}
SP7	SB7	7.0^{a}	6.8^{a}	6.8^{a}	6.5^{a}	6.7^{a}	6.5^{a}	6.8^{a}	6.8^{a}	6.8^{a}	6.8^{a}
SP8	SB8	5.6^{c}	6.3^{a}	6.5^{a}	6.8^{a}	6.4^{b}	6.4^{a}	6.2^{b}	7.1^{a}	6.4^{a}	6.6^{b}
SP9	SB9	6.0^{a}	6.2^{a}	6.2^{a}	6.7^{a}	6.4^{a}	6.3^{a}	6.2^{a}	7.2^{a}	6.2^{a}	6.8^{a}

Table F3 Sensory score for retort pouch sterilised ripe jackfruit sample

Treatment	Colour		Aroma		Taste		Texture		Overall acceptability	
	RJB	RJP	RJB	RJP	RJB	RJP	RJB	RJP	RJP	RJB
Control	8.0[a]	8.0[a]	7.5[a]	7.0[a]	8.3[a]	8.4[a]	7.5[a]	7.2[a]	7.0[a]	8.5[b]
R1	7.2[a]	7.1[a]	7.0[a]	6.5[a]	7.0[a]	7.1[a]	6.3[a]	6.5[a]	6.4[a]	6.8[a]
R2	7.3[a]	7.1[a]	6.9[a]	6.6[a]	7.5[a]	6.4[a]	6.5[a]	7.0[a]	6.8[a]	6.8[a]
R3	7.0[a]	7.1[a]	7.1[a]	6.2[a]	8.0[a]	6.5[a]	7.1[a]	6.2[a]	6.9[a]	6.4[a]
R4	6.5[a]	6.3[a]	7.0[a]	6.1[a]	7.1[a]	6.6[a]	8.0[b]	7.0[a]	6.3[a]	7.3[a]
R5	7.1[a]	6.9[a]	7.0[a]	6.3[a]	6.9[a]	6.1[a]	6.3[a]	6.0[a]	6.4[a]	7.0[a]
R6	6.5[a]	6.4[a]	7.2[a]	6.8[a]	8.0[a]	6.2[a]	6.4[a]	7.0[a]	6.9[a]	7.1[a]
R7	7.3[a]	6.5[a]	6.9[a]	6.6[a]	7.6[a]	6.9[a]	7.0[a]	7.0[a]	6.4[a]	6.8[a]
R8	6.9[a]	6.6[a]	7.1[a]	6.7[a]	7.5[a]	6.9[a]	6.9	6.8[a]	6.7[a]	6.5[a]
R9	7.0[a]	6.7[a]	6.9[a]	6.9[a]	6.9[a]	6.4[a]	7.1[a]	6.5[a]	6.9[a]	6.4[a]

Table F4 Sensory score for PL processed ripe jackfruit samples

Treatment	colour	Aroma	Taste	Texture	Overall acceptability
control	8.7	8.8	8.6	8.8	8.7
PL1	7	6.8	6.6	8.4	6.3
PL2	7	5.6	5.5	8.4	5.6
PL3	7.1	6.8	6.9	8.6	7.41
PL4	7	4.1	4	8	4
PL5	7.3	6.8	6.5	8.7	7.3
PL6	6.8	5.4	4.9	8.1	5.1
PL7	7.2	6.5	6.8	8.4	7.1
PL8	6.8	4.4	4.5	8	4.4
PL9	7.2	7.1	6.6	8.3	7.12
PL10	6.2	4.8	4.3	8.5	4.2
PL11	6.4	5.9	5.1	8.4	5.4
PL12	6.5	4.6	4.8	8.3	4.5
PL13	6.6	4.1	4.1	8	4
PL14	6.8	4.4	4.5	8.3	4.6
PL15	6.8	4.3	4.3	8.54	4.8

Plate F1 Sensory analysis of PL processed RJP

APPENDIX G

Cost economics of developed retort pouch pasteurised ripe jackfruit products

G1. Cost of retort pouch pasteurised RJB

1. Cost of operation of

plant/hr Cost of machineries

i) Steam air retort machine (reformer & seamer) : ` 10,00,000

ii) Exhaust box : ` 1,00,000

iii) Filling and sealing machines : ` 4,50,000

Initial cost (C) : ` 15,50,000

Assumptions

Useful life L : 15 years

Annual working hours, T : 2000 hours

Salvage value, S : 10% of initial cost

Interest on initial cost, r : 12% annually

Repairs and maintenance : 5% of initial cost

Insurance and taxes : 2% of initial cost

Electricity charge : ` 8/unit

Labour wages (8 working hours/day) : `

500/day Cost of retort pouch : `Rs.

25/-

Time for peeling, cutting and bulb separation of a

Ripe jack fruit (t_1) : 15

min Time for filling and sealing the pouches (t_2): 3

min

a. Fixed cost

i) Depreciation : $\frac{C - S}{L}$

: Rs. 93,167/year

ii) Interest on average investment : $\frac{C + S}{2} \times r$

: Rs. 1,02,300/year

iii) Insurance and taxes : `0.02×C

: Rs.31,000/year

Total fixed cost : i+ii+iii

: Rs.2,26,467/year

b. Variable cost

i) Repair and Maintenance : 0.05×C= Rs.77,500/year

ii) Electricity cost

Total power consumption : 10 HP = 7.5 kW

Cost of energy consumption/ year :7.5kW×2000hours×Rs.8/unit

: Rs.1,20,000/year:

iii) Annual labour cost : Rs.1,25,000/year

Total variable cost : i+ii+iii= Rs.3,22,500/year

Total cost : Fixed cost + Variable cost

: Rs.5,48,967/year

Cost of operation of plant/hr (C_{oper}) : $\frac{\text{Total cost}}{\text{T}}$

: Rs.274.48/hr

Number of batches required for retorting 100 pouches (n) : 2

Time required for retorting under pasteurization temperature (t_p) : 5 min

Total cost of retorting operation (C_r) : $\frac{C_{oper} \times \text{n} \times t_p}{60}$

: $\frac{274.48 \times 2 \times 5}{60}$

≈ Rs.45.75/-

2. Labor cost for jackfruit

Cost of 100 pouches (C_p)	:	Rs.2500/-
Quantity of ripe jack fruit bulbs	:	25 kg
Number of ripe jackfruits required (N_j)	:	10
Weight of 10 jackfruit (10 kg each)		:100 kg
Cost of jackfruit, C_{TJ} (` 25/ kg)	:	` 2500/-
Sugar required for 100 pouches	:	5.25 Kg
Cost of sugar/Kg		: Rs.40/-
Cost of sugar for 100 pouches(Cs)		: Rs.210/-
Time required for peeling, cutting and Bulb separation	:	$\frac{t_1 \times N_j}{60}$
	:	5hrs
Total number of pouches (N_c)	:	100
Time required for filling and sealing the pouches		: $\frac{t_2 \times N_c}{60}$
	:	5 hrs
Total working hours	:	5 hrs
Labour cost wages (C_L)	:	$\frac{C \times 200}{8}$
	:	` 325/-
Total expenditure for retorting 100 pouches of ripe jackfruit bulb	:	$C_L + C_r + C_{TJ} + C_p + Cs$
		:5280.75
Total expenditure for retorting single jackfruit pouch of 250 g	**:**	**` Rs.52.81/-**
		: Rs.211/-

For 1 Kg cost

The market value for jackfruit bulb based on the information, the current market price for jackfruit bulb is ₹700 for 1 kg.

BCR = Market Price per kg /Cost per kg

=700/211=3.31

G2. Detailed Steps for Retorting pouch pasteurisation of RJP

1. Cost of Operation of the Plant (per hour)

- Machinery Involved:
  - Steam air retort machine (reformer & seamer): ₹10,00,000
  - Exhaust box: ₹50,000
  - Filling and sealing machines: ₹5,00,000
  - Pulper: ₹3,00,000 (as mentioned)
  - Initial cost (C): ₹18,50,000 (₹15,00,000 + ₹3,00,000)

2. Assumptions

- Useful life of machinery (L): 15 years
- Annual working hours (T): 2000 hours
- Salvage value (S): 10% of initial cost
- Interest on initial cost (r): 12% annually
- Repairs and maintenance: 5% of initial cost
- Insurance and taxes: 2% of initial cost
- Electricity charge: ₹8/unit
- Labor wages: ₹500/day (8 working hours)

3. Fixed Cost Calculations

i. Depreciation:
(C - S) / L = (18,50,000 - 1,85,000) / 15 = ₹1,11,000/year

ii. Interest on Average Investment:
((C + S) / 2) × r = ((18,50,000 + 1,85,000) / 2) × 0.12 = ₹1,21,410/year

iii. Insurance and Taxes:
0.02 × C = 0.02 × 18,50,000 = ₹37,000/year

Total Fixed Cost:
₹1,11,000 + ₹1,21,410 + ₹37,000 = ₹2,69,410/year

4. Variable Cost Calculations

i. Repairs and Maintenance:
0.05 × C = 0.05 × 18,50,000 = ₹92,500/year

ii. Electricity Cost:
Total power consumption: 10 HP = 7.5 kW
Annual energy consumption:
7.5 kW × 2000 hours × ₹8/unit = ₹1,20,000/year

iii. Annual Labor Cost:
₹1,25,000/year

Total Variable Cost:
₹92,500 + ₹1,20,000 + ₹1,25,000 = ₹3,37,500/year

5. Total Cost of Operation

Total Cost:
Fixed Cost + Variable Cost = ₹2,69,410 + ₹3,37,500 = ₹6,06,910/year

Cost of Operation per Hour:
₹6,06,910 / 2000 = ₹303.45/hour

6. Number of Batches and Retorting Time

Number of Batches (n) required for 100 pouches: 2
Time required for retorting:
- Pasteurization time (tp): 12 minutes

Total cost of retorting operation (C_{RT}):
Coper × n × (tp / 60) = ₹121.38/100 pouches

7. Labor Cost for Processing Jackfruit

Cost of 100 pouches (CC): ₹2500
Quantity of ripe jackfruit Pulp for 100 packets : 25 kg
Number of ripe jackfruits required (Nj): 12

Cost of jackfruit (CTJ): ₹25/kg
Total cost for 12 jackfruits: ₹3000

Time for Peeling, Cutting, and Bulb Separation and pulping:
Time per jackfruit (t1): 15 minutes
Total time: (t1 × Nj) / 60 = 5 hours

Labor Cost:
Labor wages: ₹500/day
Total labor cost for 5 hours: ₹325

8. Filling and Sealing

Time per pouch (t2): 3 minutes
Total time for 100 pouches: (t2 × Nc) / 60 = 5 hours

9. Total Expenditure for 100 Pouches

Labor cost (CL): ₹325
Cost of pouches (CC): ₹2500
Cost of jackfruit (CTJ): ₹3000
Cost of retorting (CRT): ₹121.38

Total expenditure:
CL + CC + CTJ + CRT + Cs = 325+2500+3000+121.38=₹5946.38/100 pouches

10. Cost per Pouch

Cost per 250g pouch: ₹60
Cost per kg: ₹240
the market value for jackfruit pulp. Based on the information, the **current market price** for **jackfruit pulp** is ₹400 for 1.5 kg.

1. Revenue for Jackfruit Pulp:

From the market price:

Market Price per kg for pulp=₹400/1.5

=₹267/kg

4. Benefit-Cost Ratio (BCR) Calculation:

For Jackfruit Pulp:

BCR (Pulp)=Market value/Cost per kg

=₹267/₹240

=1.11

Considering the above calculation retort pouch sterilized products were carried out and given below

D3. Total cost of production of retort pouch sterilized RJB

Sterilisation time: 7 min.

Total cost = 5299.12

Cost for producing single pouch (250 g) = Rs.53/-

Cost for producing 1 kg = Rs.211/-

BCR = 700/211 =3.31

D4. Total cost of production of retort pouch sterilized RJP

Sterilisation time: 5 min.

Total cost = 5875.57/100 pouch

Cost for producing single pouch (250 g) = Rs.58.75/-

Cost for producing 1 kg = Rs.235/-

BCR = 267/235 =1.13

G3. Cost economics for processing RJB using High Pressure Processing

Optimized HPP Condition: 600 MPa for 20 minutes
Pouch Size: 250g

Step 1: Raw Material Cost (RJB)

Cost of whole ripe jackfruit	=	₹50 per kg
Yield of deseeded RJB	=	20%
RJB required annually	=	500 kg
Whole fruit required	=	500 kg / 0.20 = 2500 kg
Total raw material cost	=	2500 kg × ₹50 = ₹1,25,000
Cost per pouch (250g)	=	₹1,25,000 / 2000 = ₹62.50

Step 2: Packaging Cost

Packaging cost per pouch	=	₹25
packaging cost	=	2000 × ₹25 = ₹50,000

Step 3: Fixed Costs (Per Year)

Initial Equipment Cost (3L Capacity)	=	HPP (₹1,75,00,000) + Vacuum packer (₹2,00,000)	=	1,77,00,000
Salvage Value (10%)	=	10% of Initial Cost	=	17,70,000
Depreciation	=	(1,77,00,000 - 17,70,000)/15	=	10,61,500
Interest on Avg Investment	=	[(1,77,00,000 + 17,70,000)/2] × 0.12	=	11,67,120
Insurance and Taxes (2%)	=	2% × 1,77,00,000	=	3,54,000
Repairs & Maintenance (5%)	=	5% × 1,77,00,000		8,85,000
Total Fixed Costs (Yearly)			=	₹34,67,620

Step 4: Variable Costs (Per Year)

Electricity	=	6 kW × ₹5.5/unit × 2000 hours	=	₹66,000/yr
Labor	=	₹500/day (8 working hours)	=	₹50,000/yr
Total Variable			=	₹1,16,000/yr

Step 5: Total Annual Cost

Fixed Costs	=	₹34,67,620
Variable Costs	=	₹1,16,000
Raw Material Cost	=	₹1,25,000
Packaging Cost	=	₹50,000
Total Cost	=	₹37,58,620

Step 6: Cost per 250g Pouch

Component	**Cost per pouch (₹)**
Processing Cost	37,58,620 / 2000 = 1,879.31
Raw Material (RJB)	62.50
Packaging	25.00
Total cost per Pouch	₹1,879.31

G4. Cost Economics for Processing RJP using High Pressure Processing (HPP)
Optimized HPP Condition: 600 MPa for 15 minutes

Pouch Size: 250g

Step 1: Raw Material Cost (RJP)
Cost of whole ripe jackfruit = ₹50 per kg

Yield of pulp = 15%

RJP required annually = 500 kg

Whole fruit required = 500 kg / 0.15 = 3333.33 kg

Total raw material cost = 3333.33 kg × ₹50 = ₹1,66,667

Cost per pouch (250g) = ₹1,66,667 / 2000 = ₹83.33

Step 2: Packaging Cost
Packaging cost per pouch = ₹25

packaging cost = 2000 × ₹25 = ₹50,000

Step 3: Fixed Costs (Per Year)
Initial Equipment Cost = HPP (₹1,75,00,000) + Vacuum packer (₹2,00,000) = ₹1,77,00,000

Salvage Value (10%) = 10% of Initial Cost = ₹17,70,000

Depreciation = (₹1,77,00,000 - ₹17,70,000) / 15 = ₹10,61,500

Interest on Avg Investment = [(₹1,77,00,000 + ₹17,70,000)/2] × 0.12 = ₹11,67,120

Insurance and Taxes (2%) = 2% × ₹1,77,00,000 = ₹3,54,000

Repairs & Maintenance (5%) = 5% × ₹1,77,00,000 = ₹8,85,000

Total Fixed Costs (Yearly) = ₹34,67,620

Step 4: Variable Costs (Per Year)
Electricity = 6 kW × ₹5.5/unit × 1500 hours = ₹49,500/year

Labor = ₹500/day (8 working hours) = ₹50,000/year

Total Variable = ₹99,500/year

Step 5: Total Annual Cost

Component	Cost (₹)
Fixed Costs	34,67,620
Variable Costs	99,500
Raw Material Cost	1,66,667
Packaging Cost	50,000
Total Cost	₹37,83,787

Step 6: Cost per 250g Pouch

Component	Cost per pouch (₹)
Processing Cost	1,891.89
Raw Material (RJP)	83.33
Packaging	25.00
Total cost/pouch	₹2,000.22

G5. Cost Economics for Processing Ripe Jackfruit Pulp (RJP) using Pulsed Light

Pulsed Light System Process Time: 200 seconds

Pouch Size: 500 ml PET Bottle

Step 1: Raw Material Cost (RJP)

Cost of whole ripe jackfruit	=	₹50 per kg
Pulp yield from whole fruit	=	9–14%
RJP required annually	=	1000 kg
Whole fruit required	=	1000 kg / 0.09 to 0.14
	=	≈ 11111 to 7143 kg
Average whole fruit required	=	8696 kg
Total raw material cost	=	8696 kg × ₹50 = ₹4,34,800
Cost per bottle (500 ml)	=	₹217.40

Step 2: Packaging Cost

Packaging cost per bottle	=	₹5
packaging cost	=	2000 × ₹5 = ₹10,000

Step 3: Fixed Costs (Per Year)

Initial Equipment Cost	=	PL (₹50,00,000) + Bottling (₹4,00,000)	=	₹54,00,000
Salvage Value (10%)	=	10% of Initial Cost	=	5,40,000
Depreciation	=	(54,00,000 - 5,40,000)/15	=	₹3,24,000
Interest on Avg Investment	=	[(54,00,000 + 5,40,000)/2] × 0.12	=	₹3,40,800
Insurance and Taxes (2%)	=	2% × 54,00,000	=	₹1,08,000
Repairs & Maintenance (5%)	=	5% × 54,00,000	=	₹2,70,000
Total Fixed Costs (Yearly)			=	₹10,42,800

Step 4: Variable Costs (Per Year)

Electricity	=	₹5.5/unit × 500 units = ₹2,750
Labor	=	₹50,000
Total Variable	=	₹52,750

Step 5: Total Annual Cost

Fixed Costs	=	₹1,058,400
Variable Costs	=	₹52,750
Raw Material Cost	=	₹434,782
Packaging Cost	=	₹10,000
Total Cost	=	₹1,555,932

Step 6: Cost per 500 ml Bottle

Component	Cost per bottle (₹)
Processing Cost	1555932.61 / 2000 = ₹777.97
Raw Material (RJP)	₹217.40
Packaging	₹5.00
Total per Bottle	₹777.97

STANDARDISATION AND EVALUATION OF THERMAL AND NON-THERMAL PROCESSING OF RIPE JACKFRUIT

by

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ABSTRACT OF THE THESIS

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DOCTOR OF PHILOSOPHY IN AGRICULTURAL ENGINEERING

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ABSTRACT

This study aims to standardize protocols for varikka variety ripe jackfruit (bulb and pulp), using retort pouches, HPP, and PL, focusing on enhancing safety, quality, and shelf life. Retort pouch processing involved pasteurisation at 75-95°C for 5-15 minutes and sterilisation at 105-121°C for 5-15 minutes. High-pressure processing applied pressure ranging from 300 to 600 MPa for 5-20 minutes, maintaining the fresh-like qualities of the fruit while enhancing bioactive compound retention. PL used a voltage range of 1-2.5 kV with 50-200 pulses and a lamp to sample distance of 4-10 cm, effectively decontaminating the pulp and maintaining biochemical integrity.

The results showed that retort pouch processing extended the shelf life of processed jackfruit to over 150 days, reducing microbial growth but causing thermal softening and pigment loss at higher temperatures. Pasteurisation at 99°C/15 minutes led to a 33.72% reduction in ascorbic acid (AA) and minor losses in total phenolic (TPC) and flavonoid content (TFC), while lower temperatures (71°C/15 minutes) better-preserved antioxidant activity and firmness. The highest bacterial reduction occurred at 99°C/15 minutes, with optimal conditions for RJB at 80°C/5 min (desirability 0.917) and for RJP at 80°C/12 min (desirability 0.812). Sterilisation resulted in higher AA losses (up to 42%) in sterilised RJB, with optimal conditions 106°C/7min, and for sterilised RJP at 106°C/5 min, yielding desirability of 0.956. HPP, particularly at 600 MPa, significantly improved shelf life (40 days) and bioactive compound release, extending freshness by threefold to that of fresh samples. Optimized pulsed light processing at 1.50 kV, 200 pulses, and a distance of 4.00 cm effectively preserved biochemical compounds and ensured microbial safety, allowing PL-treated samples to maintain quality for over 30 days. The study suggests that retort pouches, HPP, and PL, enhanced the safety, quality, and shelf life of RJB and RJP. Non-thermal techniques have been shown to better preserve product quality compared to retort processing. Retort pouch processing remains the best option for safety and shelf life, making it more commercially viable.