EVALUATION OF OHMIC HEATING SYSTEM FOR PRESERVATION OF PASSION FRUIT PULP

By

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TAVANUR - 679573, MALAPPURAM

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THESIS

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

KERALA, INDIA

2022

DECLARATION

We hereby declare that this project report entitled "**EVALUATION OF OHMIC HEATING SYTSEM FOR PRESERVATION OF PASSION FRUIT PULP**" is a bonafide record of project work done by us during the course of project and that report 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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CERTIFICATE

Certified that this project report entitled "**EVALUATION OF OHMIC HEATING SYTSEM FOR PRESERVATION OF PASSION FRUIT PULP**" is a record of project work done jointly by Ms. Fathima Thanseeka K, Ms. Hanna K, Mr. Aswin Dileepkumar, Mr. Mohammed Thasreef P K and Mr. Sudhakar Gupta under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associate ship, fellowship to them.

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LIST OF SYMBOLS AND ABBREVIATIONS

% : Percent
& : And
/ : Per
< : Less than
> : Greater than
Σ : Conductivity
µg : Micro gram
AC : Alternating current
ANOVA : Analysis of Variance
BHA : Butylated hydroxy anisole
Ca : Calcium
Cfu : Colony forming units
Cl : Chlorine
Cm : Centimetre
DNA : Deoxyribonucleic acid
E : Electric field strength
et al. : and others
Etc : Et cetera
FDA : Food and Drug Administration
Fe : Iron
G : Gram
H : Heat
Hz : Hertz
I : Current
IU : International unit
K : Potassium

K.C.A.E.T	Kelappaji College of Agricultural Engineering and Technology
Kcal	Kilo calories
M	Meter
Mg	Milligram
Mg	magnesium
ml	Millilitre
MT	Million tones
Na	Sodium
º	Degree
ºC	Degree Celsius
P	Phosphorus
P&FE	Processing and food engineering
PET	Polyethylene terephthalate
pH	Hydrogen ion concentration
R	Resistance
RSM	Response surface methodology
S	Sulphur
S	Siemens
TNAU	Tamil Nadu Agricultural University
TSS	Total soluble solids
USDA	United States Department of Agriculture
V	Voltage
viz.	Namely

INTRODUCTION

CHAPTER I

INTRODUCTION

Passion fruit (*Passiflora edulis*) is a nutritious tropical fruit belongs to the family Passifloraceae. The purple passion fruit is local from southern Brazil through Paraguay to northern Argentina. In India, for a long time, has appreciated a moderate collect of purple passion fruit in the Nilgiris in the south and in various parts of northern India. The Passion fruit has good amount of antioxidants, flavanoids, anti- inflammatory, anti- bacterial, anti- fungal and anti- ageing properties. This fruit has huge economical importance as all the parts of this fruit (seed, peel, flower, pulp) are rich in medicinal and therapeutic properties.

The seasonality of production and losses resulting from climate conditions, harvesting, transportation and perishability (since the fruits lose quality quickly after harvest when stored under ambient conditions) (Cerqueira *et al*., 2011) stimulate industrial production of pulp near to growing areas, since the pulp can be maintained in good quality during shipment to markets much more easily than the fresh fruit.

The crucial point for success in producing high-quality pulp starts with the adoption of good practices in choosing the raw material and harvesting of the fruits (Nunes *et al*., 2015). Therefore, the fruits must be selected and the pulp prepared by technological processes that assure good quality of the physical and physico-chemical, nutritional and microbiological characteristics, from processing until sale to end consumers.

Processed passion fruit products fall into two main categories: those preserved by heat processing techniques and those that are frozen and held in frozen storage until consumed. Pulp heat treatments are associated with quality depletion because of vitamin destruction and flavour component damage. Carotenoids, for instance, are sensitive to light, temperature and chemical exposure (metals, oxygen) during processing. As heat can alter the nutritional and organoleptic properties, improvements in process technologies are sought to minimize pulp heat exposure. This issue meets consumer demand for improved flavour and less-processed products.But in the case of freezing passion fruit pulp, the high cost required for its transportation is one of the main problem.

Over the years, new thermal and non-thermal technologies have emerged to reduce or eliminate the exposure of food to heat (Mercali *et al.,* 2013). Innovative technologies *viz.,* high pressure processing, pulsed electric fields and ohmic heating have widely been in research as alternatives to traditional thermal processing (Sarkis *et al.,* 2013). Ohmic heating is an alternative heating system for pumpable foods which is based on the passage of electrical current through a food product which serves as an electrical resistance (Icier, 2003). Ohmic heating relies on direct resistive heating of foods which occurs when an alternating current is passed through the food in which the food is made a part of an electrical circuit. Heat generation takes place volumetrically within the food because of its inherent electrical resistance. In a conventional heating system, the thermal conductivity of a particle controls its heating rate, whereas in an ohmic heating process, the electrical conductivity is the controlling factor (Halden *et al.,* 1990). The method holds good because most pumpable foodstuffs contain dissolved ionic salts, acids and water in excess of 30 per cent which render the material electrically conductive. It has also shown promising results in reduction of microorganisms and increasing product shelf life without the use of preservatives (Rastogi *et al.,* 2007).

Conventional process for solid-liquid mixtures is dependent upon the heating of liquid phase which then transfers the heat to the solid phase. Whereas in ohmic heating particulates are heated simultaneously at the similar rate (Khalaf and Sastry, 1996; Tucker, 2004). The heating of the food material is more uniform and rapid resulting in higher yield and higher retention of nutritional value of food and particulate integrity (Castro *et al.,* 2004). Heat is generated inside the product rather than being conducted or radiated from outside. This makes ohmic heaters an excellent choice for products where traditional heat exchangers can lead to problems such as fouling, overheating leading to product quality reduction and where products are difficult to heat because of larger solid content. The ohmic heating is energy efficient technique as most of the electrical energy is converted into the heat energy (Sastry 2005; Ghnimi *et al.*, 2008).

The principal mechanisms to inactivate microbes using ohmic heat are due to thermal effects. Recent researches argue that ohmic heating may leads to mild non-thermal cellular damage due to the presence of the electric field (Pereira *et al.*, 2010). The most widely accepted mechanism is that of severe electroporation (Park *et al*., 2003). Electroporation is the formation of holes in a cell membrane due to individual ion pressure, which cause changes in the permeability of the cell membrane, due to the varying electric field. The attraction of opposite charges induced on the inner and outer surfaces of the cell membrane, compression pressure occurs, resulting in a decrease in membrane thickness takes place. If critical electrical field strength is exceeded, the membrane gets permeabilized by pore formation and it could be reversible or irreversible, depending on the electrical field strength, treatment time, cell size, membrane surface charge, cytoplasm, and suspending liquid medium.

Ohmic heating of food products serves as a potential alternative to the conventional heating processes because particles heat faster than liquid. The particular interest in this technology stems from the ongoing food industries' concern for aseptic processing of liquid particulate foods. Presently, food industries have focused on ohmic heating of the pumpable food. This is due to the fact that the food products processed by giving ohmic treatment are found to be of superior quality as compared to the one treated conventionally. Thus, the present investigation is planned with the following objectives: -

Objectives

- To standardise the process parameters of ohmic heating process of passion fruit pulp
- To evaluate the quality characteristics of the ohmic heated passion fruit pulp

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

This chapter briefly discusses the passion fruit pulp and its composition, importance of passion fruit and its utilization in the industry. The variables which decide the quality parameters and the functional properties relevant to the ohmic heating of passion fruit pulp also been reviewed and discussed.

2.1. PASSION FRUIT

Passion fruit (*Passiflora edulis)* belongs to the genus *Passiflora* of the estimated 465 species, *Passiflora* is the most important genus of the family Passifloraceae (Vanderplank.,1996). Within the species, there are two distinct forms: the purple, *P. edulis f. edulis* Sim and the yellow, *P. edulis f. flavicarpa* Degener (Petry RD *et al.*,2001). The yellow form of passion fruit is a mutation of the purple variety of natural hybrid between *P.edulis f. edulis* and another related species.

P. edulis f flavicarpa is a vigorous-growing, woody, perennial vine which under most conditions is more robust than the purple variety. The leaves are three-lobed, with finely-toothed edges and a cordate or heart-shaped base. The fruit is round or oval in shape and varies from 1.5 to 2.5 inches in diameter, and from 2.5 to 4 inches in length. The fruit has a tough rind, canary yellow in color, with a smooth, glossy surface and an inner white layer similar to the albedo of citrus fruits. Within this hard, brittle rind are numerous small blackish seeds, each enclosed in a sac containing a yellowish, aromatic juice with a pleasant but rather acid flavor.

It is a native of Brazil. In India it is found to be growing wild in many parts of Western Ghat such as Nilgiris, Waynad, Kodaikanal, Shevroys, Coorg and Malabar as well as Himachal Pradesh and North Eastern States like Manipur, Nagaland and Mizoram. The fruit is valued for its pronounced flavour and aroma which helps not only in producing a high-quality squash but also in flavouring several other products. The juice of passion fruit with an excellent flavour is quite delicious, nutritious and liked for its blending quality. To enhance the flavour of the final produce, passion fruit juice is often mixed with juices of pineapple, mango, ginger etc. The juice is extensively used in confectionery and preparation of cakes, pies and ice cream. It is a rich source of Vitamin A and contains fair amounts of Sodium, Magnesium, Sulphur and Chlorides. Commercial Processing of yellow passion fruit yields 36 % juice, 51 % rinds and 11 % seeds (TNAU,2012).

2.1.1. International Scenario

Passion fruit vines are found wild and cultivated to some extent in many parts of the world including the highlands of Java, Sumatra, Malaya, Western Samoa, Norfolk Islands, Cook Islands, Solomon Islands, Guam, the Philippines, the Ivory Coast, Zimbabwe and Taiwan. Brazil has long had a well-established passion fruit industry with large-scale juice extraction plants. Passion fruit is grown in North Eastern Region of India. Other countries include Australia, New Zealand, Kenya, Uganda, Rwanda etc.

2.1.2 Indian scenario

Table 2.1 Indian production of passion fruit (2011-2021)

Year	Production (‘000 MT)
2011-2012	97.4
2012-2013	100.5
2013-2014	123.6
2014-2015	129.3
2015-2016	78.0
2016-2017	72.0
2017-2018	82.0
2018-2019	81.0
2019-2020	56.0
2020-2021	70.0

Source : Ministry of Agriculture and Farmers Welfare, Govt. of India.

2.1.3. Varieties

There are two recognized forms of edible passion fruit; purple (*Passiflora.edulis* Sims) and yellow (*Passiflora f. flavicarpa* Deg.). The purple passion fruit is originally native of Tropical America, whereas yellow passion fruit is being considered as a mutation of the purple variety or as a natural hybrid between purple and another related species of passion fruit (Alkamin *et al.*,1959). *Passiflora quadrangularis* L., the giant granadilla, is also cultivated to a limited extent for local consumption. It grows best in a hot, moist climate and produces a round or oblong, pale yellow to yellowish-green fruit when ripe, which may reach up to 8 inches in size. *Passiflora foetida* L., a wild species, bears very small fruits and has unique characters of being highly precocious and very short fruit maturity period (Hatchinson,1967). Purple and yellow are commonly cultivated in northeast region of India, while Kavery (hybrid between purple and yellow) is common in south India (Kishore *et al.*, 2006)

2.1.3.1 Purple Passion Fruit

Vines are productive at higher elevations. Fruits are 4-5 cm in diameter, deep purple when ripe each weighing 35-45 g. The juice content varies from 31-35 per cent. The variety is known for its quality in terms of flavour and nutrient content. Seeds are black in color. The variety is susceptible to leaf spot, collar rot, attack by thrips and nematodes (TNAU,2012).

2.1.3.2 Yellow Passion Fruit

This variety is suitable for lower elevations and is less productive at higher elevations due to its sensitiveness to low temperature. The fruit is bigger in size than purple variety, each weighing about 60 g, round in shape with yellow mottled spots, turns golden yellow when ripe. Juice is more acidic, its recovery being comparatively less than the purple. Seeds are brown, tolerant to leaf spot and wilt, escapes the damage by thrips and tolerant to nematodes (TNAU,2012).

2.1.3.3 Kaveri Hybrid Passion Fruit

It is a hybrid between purple and yellow passion fruit developed at Central Horticulture Experimental Station, Indian Institute of Horticulture Research, Chettalli, Karnataka. It is a high yielding variety and each fruit weighs 85-110 g. The fruits are purple in color, fruit quality comparable to that of purple variety. The variety is reported to have field tolerance to brown leaf spot, collar rot, wilt and nematodes(TNAU,2012).

2.1.3.4 Giant Granadilla

The giant Granadilla has large leaves, and bears very striking flower. The greenish-yellow fruits of P. quadrangularis resemble melons and are the largest in the genus. Fruits are 15-20 cm long and about 600 g weight. The fruits are oblong, with a delicate aroma and a thin, smooth skin. Fruit contents thick pulp with large seeds.

2.1.4 Importance of passion fruit

According to, Joy (2010), the fruit has high nutritive and medicinal value. Passion fruit is a high acid food (pH~ 3.2) due to the predominance of two acids, citric and malic acid. The fruit provides a good source of nutrients such as Vitamin A, B_2 and C and non-nutritive phytochemicals, carotenoids and polyphenols. It is also rich in minerals like K, P, Ca, Fe, Na, Mg, S, Cl and protein (Table 2.2.). Passion fruit is also known as a nutritionally dense fruit, based on the level of nutrients present. The high amount of vitamin A, C and B_2 in passion fruit is the primary driver of such nutritional scores. Nutritional composition of passion fruit per 100 g is enumerated in Table 2.2. Passion fruit can be grown to eat or for its juice, which is often added to other fruit juices to enhance aroma. The fruit is eaten alone or in fruit salads, sherbets, ice cream, jams, cool drinks and as concentrates. The yellow variety is used for juice processing, while the purple variety is sold in fresh fruit markets. It has been reviewed by Zas *et al.* (2016) that *Passiflora edulis* plant contains anti-inflammatory, anticonvulsant, antimicrobial, anticancer, anti-diabetic, antihypertensive, anti-sedative, antioxidant properties and various remedial measures for treating conditions like osteoarthritis, asthma and act as colon cleanser. The different parts of the plants have also been used for treatment of ulcers haemorrhoids, as sedatives, remedy for insomnia, digestive stimulant and remedy for gastri carcinoma.

Table 2.2 Approximate nutrient composition of passion fruit cultivars

Compostion	Nutrient value	percentage
Energy	97 kcal	5%
Carbohydrate	23.38 g	18%
Protein	2.20 g	4%
Total Fat	0.70 g	3%
Cholesterol	0 mg	0%
Dietary fiber	10.40 mg	27%
Folates	14 µg	3%
Niacin	1.500 mg	9%
Pyridoxine	0.100 mg	8%
Riboflavin	0.130 mg	10%
Thiamine	0.00 mg	0%
Vitamin A	1274 IU	43%
Vitamin C	30 mg	50%
Vitamin E	0.02 µg	<1%
Vitamin K	0.7 mg	0.5%
Sodium	0 mg	0%
Potassium	348 mg	7%
Calcium	12 mg	1.2%
Copper	0.086 mg	9.5%
Iron	1.60 mg	20%
Magnesium	29 mg	7%
Phosphorous	68 mg	10%
selenium	0.6 µg	1%
Zinc	0.10 µg	1%
Carotene-β	743 µg	-

Cryptoxanthin-β	41 µg	-
lycopene	0 µg	-

Passion fruit (*Passiflora edulis*), fresh, nutritive value per 100 g.

Source: USDA National Nutrient database.

2.2. EFFECT OF THERMAL PROCESSING ON NUTRITIONAL QUALITY OF FRUIT PRODUCTS

Shrikhande *et al.* (1976) conducted studies on thermal processing for bulk packaging of mango pulp and found that carotenoid and ascorbic acid content of fresh pulp reduced from 7.9 and 39.24 mg/100g to 4.6 and 15.38 mg/100g after six months of storage after heat sterilization in cans.

Ranote and Bains (1982) investigated on preservation of kinnow fruit juice and found that juice heated to 98^{o}C for 1 minute underwent ascorbic acid loss from 18.7 to 10.7 mg/100g after storage for 3 months. Beerh and Rane (1983) studied the canning of mandarin orange segments. It was found that 23.46 % of ascorbic acid was lost during canning and 35 – 40 % on storage for 10 months after a heat treatment of 88^{o}C for 13 minutes and sealed cans at 82.5^{o}C for 10-12 minutes.

Sudhakar and Maini (1994) studied stability of carotenoids during storage of heat processed mango pulp at room temperature. Among the various treatments tried ascorbic acid (200 mg/100g) and 0.01% BHA (Butylated Hydroxy Anisole) was found to be best as there was no loss of carotenoids up to four months storage. Anil (1998) found that β-carotene, lycopene and ascorbic acid contents decreased with increase in temperature during ohmic heating. The initial beta carotene content of papaya, carrot and tomato were 628, 6497 and 330 µg/100g respectively which lowered to 298, 4798, 112 µg respectively, after ohmic heating to 100^{o}C. The lycopene content of papaya carrot and tomato during ohmic heating reduced from initial values of 363, 1018 and 649 µg/100g to 110, 324 and 195 µg/100g respectively and the ascorbic acid content lowered during ohmic heating for papaya, carrot and tomato from 55.9, 30.34 and 23.02 to 6.75, 6.9 and 2.1 mg/100g respectively.

Ghorai and Khurdiya (1998) conducted studies on storage of heat processed kinnow mandarin juice (90°C for 10 minutes) and reported that TSS, ascorbic acid, carotenoids, free amino acids, soluble proteins and acidity decreased with increase in storage period. Browning in juice and purees during manufacture and storage are of vital interest for the food industry (Garza *et al.*, 1999). Changes in food color can be associated with its previous heat treatment. Various reactions such as pigment destruction and non-enzymatic browning reactions can occur during heating of fruits and vegetables and therefore affect their color. Color can be used as a quality indicator to evaluate the extent of deterioration due to thermal processing (Avila and Silva, 1999).

Ascorbic acid is one of the most important natural antioxidants supplied by fruits and vegetables; it is the main biologically active form of vitamin C. This vitamin, present in high levels in the acerola pulp, is used as a quality index because it is very sensitive to degradation during processing and storage. Vitamin C is most sensitive to destruction when the product is subjected to adverse handling and storage conditions. Losses are increased by extended storage, high temperatures, low relative humidity, physical damage, and chilling injury (Lee and Kader, 2000).

Kinetic parameters for the degradation of anthocyanins in blackberry juice were estimated, and studies concluded that the rate of anthocyanin degradation is time and temperature dependent and that these compounds are especially sensitive to temperatures above 70° C (Sadilova *et al.*, 2006; Wang & Xu, 2007; Jimenez *et al.*, 2010).

Julia *et al.* (2013) evaluated the anthocyanin degradation in blueberry pulp after thermal treatment using ohmic and conventional heating. Results showed that when lower voltage levels were used, the percentage of degradation was lower or similar to those obtained during conventional heating. However, for high electric fields, the pulp processed using ohmic heating exhibited higher anthocyanin degradation.

2.3 OHMIC HEATING AND ITS PRINCIPLE

Ohmic heating takes its name from Ohm's law (Icier and Ilicali, 2005), which is known as the relation between current (I), voltage (V), and resistance (R) (Equation 2.1). The food material switched between electrodes has a role of resistance in the circuit (Icier, 2012).

$$I = \frac{V}{R} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

Ohmic heating is referred to as Joule heating, electrical resistance heating or electro conductive heating. Ohmic heating is an advanced thermal process where food acts as an electrical resistor. The experimental design usually consists of electrodes that contact the food, whereby electricity (usually alternating current) is passed through the food substance using a variety of voltage and current combinations. The substance is heated by the dissipation of electrical energy. The heat produced in the resistor (food material) is directly proportional to the square of the electric field strength (E) and the resistance for a given current and also directly proportional to the time for which the current flows through the resistor (Equation 2.2).

$$H = I^2 RT \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

Where,

H – heat generated, joules
I – current, amperes
R – resistance, ohms
T – time, seconds

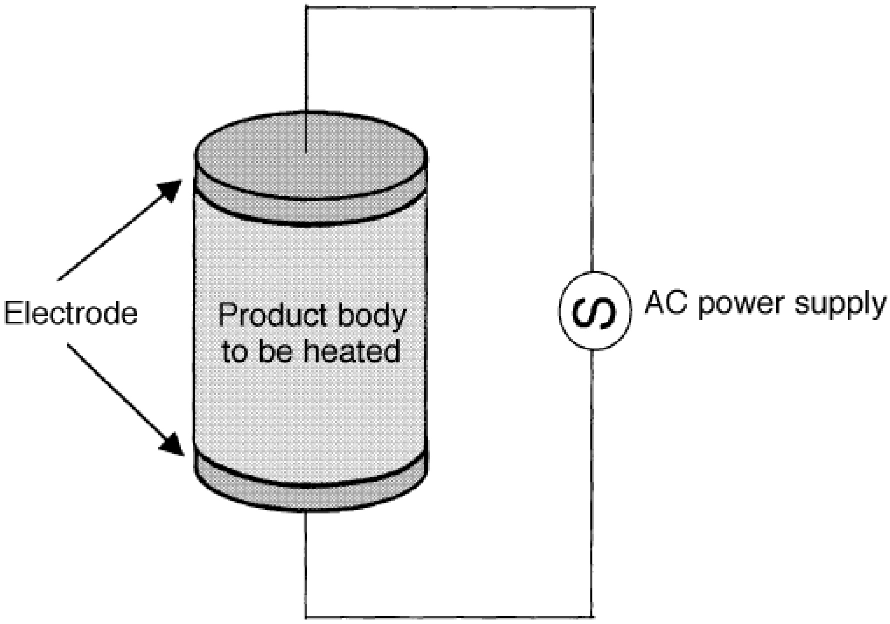


Fig.2.1 Schematic diagram showing the principle of ohmic heating

The ohmic heating consists of the application of AC voltage to electrodes in contact with the product (Mercali *et al.*, 2014). Darvishi *et al.* (2011) described that the passage of electrical current through a food product that serves as an electrical resistance result in heating of the product due to the conversion of the electric energy into heat (Zareifard *et al.*, 2003).

OH can be seen as an internal thermal energy generation technology and not only as a thermal energy transfer (Knirsch *et al.*, 2010). Most foods contain water, ionic species such as salts and acids, hence, electric current can be made to pass through the food and generate heat inside it (Palaniappan and Sastry, 1991). Heat is generated instantly, and its amount is directly related to the voltage gradient, and the electrical conductivity (Sastry and Li, 1996).

Ohmic heating rates depend on the type and composition of the food material, relating with its electrical conductivity and the voltage gradient applied (Icier, 2012). Butz and Tauscher (2002) explained that the ohmic heating is a thermal method which reduces the damage due to heat and also minimise energy input. If an electric current is passing through a conductive medium, in this case the food, medium warms up as a result of the movement of ions. Direct conversion of electric current to heat takes place when the joule heating utilises the electrical resistance within the conductive liquid or the solid material.

The conductivity (σ) is measured by the quantity of electricity transferred across a unit area, per unit potential gradient and per unit time (Goullieux and Pain, 2005). Based on the electrical conductivity of the foods are classified into three categories:

i) $\sigma > 0.05$ S/m: good conductivity (condiments, eggs, yoghurts, milk desserts, fruit juices, wine, gelatine, hydrocolloids, etc).

ii) 0.005 to 0.05 S/m: low conductivity requiring high electrical field strength (margarine, marmalade, powders, etc).

iii) $\sigma < 0.005$ S/m: poor conductivity requiring very high electrical field strength and often difficult to process by ohmic heating (frozen foods, foam, fat, syrup, liquor, etc).

Food, which contains water and ionic salts in abundance, is the most suitable for ohmic heating (Palaniappan and Sastry, 1991). Knirsch *et al*. (2010) stated that there are also critical values ($0.01 < \sigma > 10$ S/m) where ohmic heating is not applicable.

Kim & Kong (2015) stated that in contrast to conventional heating, the factors such as heating rate, electrical conductivity and electrode corrosion are need to be considered in optimizing the ohmic heating process of pasteurization of juice.

Ohmic heating is differentiated from other electrical heating methods by the presence of electrodes in direct contact with the food (as opposed to microwave and inductive heating, where electrodes are absent) or by the frequencies and waveforms used (FDA, 2000).

2.4 ADVANTAGES OF OHMIC HEATING

Ohmic heating is rapid and uniform method of heating which leads to the minimal losses of the structural, nutritional and sensorial properties of the food unlike microwave heating, which has a finite penetration depth into solid materials.

It is particularly found interesting for the products of high viscosity or insoluble suspended solids, because liquid and solid phases can have the same heating rates, avoiding the overheating of the liquid phase and the solids surfaces.

Ohmic heating is technically simple, high energy efficient and low investment cost. The OH technology provides new, high-added-value, shelf-stable products with a quality unachievable by the traditional processing technologies. The process can be utilized for the pasteurization of whole liquid egg (Parrott, 1992)

It may also have continuous production without heat-transfer surfaces and it is an ideal process for shear-sensitive products because of low flow velocity. Optimization of capital investment and product safety are the result of high solids loading. There is a reduced fouling in case of ohmic heating when compared to conventional heating. Electro conductive heating is much better, simpler process control with reduced maintenance costs and environmentally friendly system.

2.5 CONVENTIONAL THERMAL PROCESSING VS OHMIC HEATING

During conventional thermal processing, due to slow conduction and convection heat transfer which result in considerable product quality deterioration takes place either in cans or aseptic processing systems for particulate foods, On the other hand, ohmic heating volumetrically heats the entire mass of the food material and thus the resulting product is of far greater quality than its canned counterpart. It is possible to process large particulate foods (up to 1 inch) that would be difficult to process using conventional heat exchangers. Additionally, ohmic heater cleaning requirements are comparatively less than those of traditional heat exchangers due to reduced product fouling on the food contact surface.

The fouling in ohmic heating units is much less than in the conventional heat transfer equipment. So, it has the advantages of reduced labor and cleaning costs (Icier and Tavman, 2006). In a conventional heating system, the thermal conductivity of a particle controls its heating rate, whereas in an ohmic process, the electrical conductivity is the controlling factor. The latter is a function of the structure of the food, which is often changed by cooking (Halden *et al.*, 1990). In addition, HTST (High Temperature Short Time) or UHT (Ultra High Temperature) processes cannot be used for particulate foods (solid-liquid mixtures), as it is not possible to heat the particle to the required temperature in the short time. Ohmic heating offers the use of HTST techniques on particulate foods. Particles can be made to heat at the same rate, or faster than, the carrier liquid (Halden *et al.*, 1990).

2.6 INFLUENCE OF ELECTRODE, FREQUENCY AND WAVE SHAPE DURING OHMIC HEATING

2.6.1 Electrodes

Electrodes in ohmic heating can be regarded as a junction between a solid-state conductor (current feeder) and a liquid state conductor (heating medium). Electrodes play a important role by conveying the current uniformly into the heating medium. Various electrode material has been used as electrodes in ohmic heating application namely aluminium, carbon (graphite), dimensionally stable node (DSA Type), glassy carbon, platinum, platinised titanium, rhodium plated stainless steel, stainless steel, titanium (Samaranayake and Sastry, 2005).

Important factors to be considered while applying ohmic heat on food sample such as quality of the treated sample and the electrodes which are used should be free of corrosion (Kim and Kong, 2015).

Saulis *et al.* (2007) stated that the problem related with food safety, corrosion can also cause serious damages to the electrodes, whose surface roughness can increase as a consequence of the metal release or deposition. This in turn causes local electric distortion and arching drastically limiting the lifetime of the electrodes and hence reducing the feasibility of OH technology as an alternative for thermal processing of food products.

2.6.2 Frequency and wave shape

The frequency and waveform of applied voltage affects the electrical conductivity and the process of heating foods (Lima *et al.*, 1999). Lima and Sastry (1999) stated that the frequency and wave shape of alternating current has been found to alter heat and mass transfer properties significantly. Imai *et al.* (1998)

discussed the effect of temperature and frequency under a constant voltage gradient 10 V/cm on the electrical conductivity values of egg albumin solution. The report says that the heating rate of the solution was almost constant and increased slightly as the frequency increased. The mean time taken to reach 40°C was 33 s for 4 Hz, while for 60 Hz it was 109 secs. Due to increased electrical conductivity at 4 Hz, pretreatments at this frequency require considerably less time than pretreatments at 60 Hz (Lima and Sastry, 1999). The ohmic heating of turnip as a function of frequency and wave shape of alternating current was investigated by Lima *et al.* (1999). The lower the frequency, the faster the sample reached elevated temperatures. The electrical conductivity observed for sine and saw-tooth waves at low frequency (4 Hz) values are higher than those observed by using square waves (Lima *et al.*, 2001).

2.6.3. Influence on Electrical conductivity and Heating rate

The electrical conductivity (σ) of the samples was calculated from voltage and current data using the following equation:

$$\sigma = \frac{L\,I}{A\,V} \times 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.3$$

Where L is the gap between the electrodes (cm); A is the cross-section surface area of the electrodes (cm^2); I is the electrical current (A) and V is the voltage gradient applied.

Tulsiyan *et al.* (2008) used the same formula equation 2.3 to determine the electrical conductivity of a multi-component food (chicken chowmein). A wide variation in the electrical conductivity of individual components was observed and also variation was noted in the electrical conductivity between samples of the same constituent. It was concluded that if ohmic heating process was to be successful, the formulation of the food needed to be modified so that the components approached a nearly in conductive state.

Electrical conductivity of the food is the major factor which controls the rate of ohmic heating and it can be affected by many factors such as electrical field strength, particle size of solids, and fat content of food. Electrical conductivity of food increases with increases with temperature (Castro *et al.*, 2003; Sarang *et al.*, 2008).

The success of ohmic heating depends on the rate of heat generation in the system, the electrical conductivity of the food, and the method by which the food flows through the system (Leizerson and Shimoni, 2005).

Kautkar *et al.* (2015) concluded that the electrical conductivity of the ginger paste is strongly dependent on the temperature and ionic concentration. Hence the electrical conductivity linearly increased with the temperature.

The electrical conductivity of the heating medium is the major parameter controlling the heating rate in an ohmic heating process. It is defined as the ability to conduct electric current and depends on both the ionic strength and temperature (Patora *et al*., 2014).

Palaniappan and Sastry (1991) have quoted electrical conductivity is influenced by the nature of ions (chemical composition) and ionic movement in the liquid. LWE contains higher amount of ionic species, such as salts and acids, which acts as an electrolyte results in high electrical conductivity of 0.73 ± 0.01 S/m for untreated samples. Electrical conductivity of LWE is much greater than fruits juices namely apple, orange, and pineapple juices (0.1-0.63 S/m) reported by Amiali *et al.* (2006), which is due to the increase in temperature and decreased with solid content.

Icier and Ilicali (2005) reported that the electrical conductivity increased linearly with increasing temperatures for fruit juices such as orange at voltage gradients ranging from 20 to 60 V/cm. Palanippan and Sastry (1991) reported that the electrical conductivity of the orange, carrot and tomato juices increased with temperature and decreased with solids content. Icier *et.al.* (2008) similarly found that the electrical conductivity increased as the temperature increased ranging from 0.4 to 0.75 S/m for fresh grape juice. The ohmic heating of fruit juice was studied at different voltage gradients (7.5 to 26.25 V/cm) by Kong *et al.* (2008). Results indicated that the voltage gradient significantly influenced the ohmic heating rates. Also, they found that the electrical conductivity changed significantly with temperature.

Kim and Kong (2015) stated that due to higher electrical conductivity, temperature increased rapidly with increasing pH. Icier and Bozkurt (2009) applied a medium voltage gradient of 25 V/cm to whole liquid egg and found a linear relationship between the electrical conductivity and temperature.

Knirsch *et al.* (2010) stated that there are also critical values ($0.01 < \sigma > 10$ S/m) where ohmic heating is not applicable. This is because very large voltages would be needed to generate the amount of heat required for raising the temperature. It is because the amount of generated heat during ohmic heating is directly related to the electrical conductivity of food (Icier and Ilicali, 2005). Thus, the foods which have lower electrical conductivities will be heated slower than those of higher electrical conductivities if the same electrical field strength is applied. In other words, to obtain the same heating rate more intense electrical field strength is needed for the lower conductive food (Tumpanuvatr and Jittanit, 2012).

Ohmic heating times are dependent on the voltage gradient used. As the voltage gradient increases, the heat generation per unit time increases, and hence the heating time necessary to reach the prescribed temperature decreases (Icie rand Ilicali, 2005).

The heating process causes membrane destruction and consequently the free water content increases (Castro *et al*., 2004) and results in increasing fluid motion through the capillaries, which is directly proportional to electrical conductivity (Halden *et al*., 1990). The sharp decrease of the ohmic heating time with increasing voltage gradient was obvious in milk and reconstituted whey solutions having various concentrations (Icier, 2004). Icier and Tavman (2006) noticed that as the voltage gradient increased from 10 V/cm to 60 V/cm, the ohmic heating times required to heat up the ice-cream mixes to 80ºC from 4ºC decreased approximately 50 and 31 times for maras-type and standard type ice-cream mixes, respectively.

Unfortunately, the high electrical conductivity and thermal sensitivity of LWE limit the application of PEF at elevated temperature due to the occurrence of arcing (Monfort, 2012).

2.7 INFLUENCE OF OHMIC HEATING ON MICROBIAL INACTIVATION

The principal mechanisms to inactivate microbes using ohmic heat are due to thermal effects. Recent researches argue that ohmic heating may leads to mild non-thermal cellular damage due to the presence of the electric field (Pereira *et al.,* 2010; Sun *et al*., 2008). The most widely accepted mechanism is that of severe electroporation (Park *et al*., 2003). Electroporation is the formation of holes in a cell membrane due to individual ion pressure, which cause changes in the permeability of the cell membrane, due to the varying electric field (Weaver and Chizmadzhev, 1996). The attraction of opposite charges induced on the inner and outer surfaces of the cell membrane, compression pressure occurs, resulting in a decrease in membrane thickness takes place. If critical electrical field strength is exceeded, the membrane gets permeabilized by pore formation and it could be reversible or irreversible, depending on the electrical field strength, treatment time, cell size, membrane surface charge, cytoplasm, and suspending liquid medium (Lojewska *et al*., 1989). Conventionally heated samples reached plate counts of 10,000 cfu/ml compared to the ohmically heated samples with plate counts of 10 cfu/ml after 12 weeks (Reznick, 1996). The principal reason for the additional effect of ohmic treatment might be its low frequency (usually 50 - 60 Hz), which allows cell walls to build up charges and form pores (USA-FDA, 2000). As a main consequence of this effect, the D value observed for the microbial inactivation under ohmic heating gets reduced compared to traditional heating methods. Pereira *et al*. (2010) studied inactivation kinetics of *E. coli* in goat's milk, and *Bacillus licheniformis* ascospores in cloudberry jam during ohmic heating found that the thermal death times under ohmic heating were shortened. Similar reduction has also been observed for *Bacillus subtilis* (Cho *et al*., 1999), *Streptococcus thermophilus* (Sun *et al.,* 2008). This result was explained by the injury effects of the ohmic heating to the cells due to possible electroporation.

2.8 OHMIC HEATING TREATMENT ON LIQUID FOODS

Leizerson *et al.* (2005) worked on the stability and sensory shelf life of orange juice pasteurized by continuous ohmic heating. The objective of this research was to examine the effects of ohmic heating on the stability of orange juice with comparison to conventional pasteurization. During storage at 40°C, degradation curves of ascorbic acid followed a linear decrease pattern in both ohmic-heated and conventionally pasteurized orange juices. For five representative flavour compounds (decanal, octane, limonene, pentene, and Miocene), higher concentrations were measured during storage in the ohmic-heated orange juice than in conventionally pasteurized juice. Although residual pectin esterase activity remained negligible in both types of juices, particle size was lower in the ohmic-heated orange juice. The sensory shelf life was determined by using the Weibull-Hazard method. Although both thermal treatments prevented the growth of microorganisms for 105 days, the sensory shelf life of ohmic-treated orange juice was >100 days and was almost 2 times longer than that of conventionally pasteurized juice.

Vikram *et al.* (2005) worked on the thermal degradation kinetics of nutrients in orange juice heated by electromagnetic and conventional methods. Newer processing technologies like infrared, microwave processing is being harnessed to optimize the processes to ensure minimum loss of the vital nutrients in processed foods. Vitamin C is an important nutrient known for its potential antioxidant, anti-cancerous and other health promoting properties. Orange juice is a very popular and rich source of vitamin C. The present research focuses on the status of the vitamin C during thermal treatment of orange juice heated by different methods. The study includes a comparative study of kinetics of vitamin degradation and changes in visual color as an index of carotenoids. The degradation kinetics of vitamin C and color in terms of reaction rate constant, destruction kinetics, enthalpy and entropy for different methods of heating are discussed. The destruction of vitamin C was influenced by the method of heating and the temperature of processing. The degradation was highest during microwave heating due to uncontrolled temperature generated during processing. Out of the four methods studied, ohmic heating gave the best result facilitating better vitamin retention at all temperatures.

Icier *et al.* (2008), studied on fresh grape juice was ohmically heated at different voltage gradients (20, 30 and 40 V/cm) from 20°C to temperatures 60, 70, 80 or 90°C and the change in the activity of polyphenol oxidase enzyme (PPO) was measured. The critical deactivation temperatures were found to be 60°C or lower for 40 V/cm, and 70°C for 20 and 30 V/cm. various kinetic models for the deactivation of PPO by ohmic heating at 30 V/cm were fitted to the experimental data. The simplest kinetic model involving one step first-order deactivation was better than more complex models. The activation energy of the PPO deactivation for the temperature range of 70-90°C was found to be 83.5 kJ/mol.

Baysal and Icier (2010) compared *Alicyclobacillus acidoterrestris* inactivation in orange juices and found significant differences between the two heating methods. Lower D values were obtained with ohmic processing at 30 V/cm (58.48, 12.24 and 5.97 min for 70, 80 and 90°C, respectively) when compared to Conventional heating (83.33, 15.11 and 7.84 min for 70, 80 and 90°C, respectively).

Somavat *et al.* (2013) explained the ambiguous results concerning the frequency effects obtained by different authors by stating that some microbial intracellular compounds can be impacted differently due to changes in the electric field oscillation. The extent of this effect is dependent on the species morphology.

Lee *et al.* (2015) during OH: 2.5, 3.5 and 4.5. The scenario with a more acidic pH (2.5) had a greater inactivation rate compared with the others; scenarios in which the pH values were 3.5 and 4.5 showed similar values (ANOVA was not performed). The additional effect observed in the lowest pH may not have been related to the electric field, but rather to the hostility of such environments to bacterial species

Kang *et al.* (2017) demonstrated that none of the analysed species could resist more than 30 s of OH with an electric field of 60 V/cm; when a 30 V/cm field was applied, a high number of viable cells was observed even after 60 s of processing. On the other hand, the same authors stated that the conversion of electricity into thermal energy within the food product was higher when an electric field of 30 V/cm was used in comparison with 60 V/cm. This can be a positive economic factor concerning the utilization of low electric fields.

To clarify the mechanism of non-thermal spore inactivation, Schottroff *et al.* (2019) studied the inactivation of Bacillus subtilis endospores, focusing on determining which components of the spore cell were more affected by the electric field. The authors prepared three mutant species lacking different components known to contribute to spore heat resistance: (i) small-acid soluble proteins that protect the DNA; (ii) the coat covering the spore; (iii) the spore germination enzyme. Mutant inactivation was compared with the results obtained for the wild-type microorganism (with all the constituents intact) submitted to Conventional heating and ohmic heating. The results showed that the electric field affects the cell coat and enzyme less than the cell core. This influence is probably due to the increased release of proteins (mainly if they are not firmly bound to DNA). Additionally, the authors demonstrated that the DPA release from the core is similar in both conventional heating and ohmic heating.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the different materials and methods adopted for the study of ohmic processing of passion fruit pulp and the procedure followed for evaluation of this technique leading to the standardisation of the operating parameters towards the preservation of passion fruit pulp. The procedures adopted for the evaluation of physicochemical, microbial and sensory qualities of passion fruit pulp are also explained in detail.

3.1 PREPARATION OF PASSION FRUIT PULP

Fresh passion fruit pulp was purchased from Mariya farm, Manthavady. The passion fruit pulp was stored in well sterilised air tight bottles in deep freezer at below -18°C until treatment. Prior to the treatment, the passion fruit pulp was taken out of the freezer.

3.2 OHMIC HEATING SYSTEM

The experiments were conducted in the ohmic heating system developed in Food Engineering Laboratory of K.C.A.E.T, Tavanur as shown in Plate 3.1. The Ohmic heating system consist of ohmic heating chamber along with two electrodes, power supply system, variable transformer, ammeter and voltmeter. A Teflon coated thermocouple inserted into the chamber is used to measure the temperature. The ohmic heating chamber was developed using a Teflon cylinder with inner and outer diameter of 70 mm and 80 mm respectively. It has a length of 150 mm and both sides of the cylinder were fixed with stainless steel (SS 304) electrodes with same inner diameter of chamber. It is covered with Teflon and caps. The system can process 300 ml of passion fruit pulp per batch.

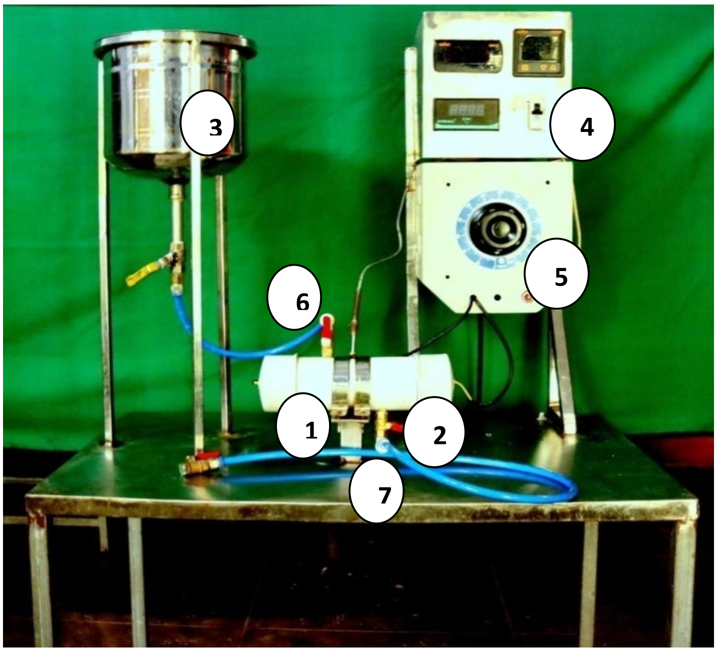


Plate 3.1 Ohmic heating system

1. Ohmic heating chamber (Teflon)
2. Electrode (SS 304, 2 mm thickness)
3. Feeding system
4. Control panel
5. Variable transformer
6. Valve V1
7. Valve V2

3.3 OHMIC HEATING OF PASSION FRUIT PULP

The fresh passion fruit pulp was fed to the ohmic heating chamber from the feeding tank through the connected pipes and valves. After completely filling the chamber and properly closing valve V_1 (the valve between feeding system and ohmic heating chamber) and valve V_2 the valve between ohmic heating chamber and discharge tube), the electric supply was put on and the predetermined voltage was set using a variable transformer. The system was switched on and the pulp samples were ohmic heated by applying three different levels of voltages, temperatures and holding times by adjusting the voltage supply using the variable transformer. The treated samples were collected in sterile amber colored PET bottles and stored in refrigerated condition at 4±2°C.

3.4 EXPERIMENTAL DESIGN

3.4.1 Independent variables

- Voltage

  V_1 : 150 V

  V_2 : 185 V

  V_3 : 220 V

- Process temperature

  T_1:55°C

  T_2: 60°C

  T_3: 65°C

- Holding time

  t_1 : 1 minute

  t_2 : 2 minutes

  t_3 : 3 minutes

3.4.2 Dependent variables

The physicochemical properties *viz.* TSS, titrable acidity, ascorbic acid content, and color of treated fruit juices are analysed to optimise the process parameters of ohmic heating process.

1. Ascorbic acid
2. Titrable acidity
3. Total soluble solids
4. color

Microbial load

The bacterial population count was calculated for optimized sample.

3.5 DESIGN OF EXPERIMENTS USING RESPONSE SURFACE METHODOLOGY

Response surface methodology (RSM) would be used to determine the optimal processing condition. The Box-Behnken design with the three experimental factors such as A, B and C requires twelve data points in the middle of each two-factor combination and five replications at the centre of the cube, totaling seventeen data points in contrast to 3^3 runs required for a full factorial design. About 17 treatment combination would be suggested by the software. All experiments would be performed in triplicates.

3.5.1 Experimental design of ohmic heating treatment

In the study of ohmic heating treatment of passion fruit pulp, the process parameters such as voltage, treatment temperature, and time are to be optimised. Each process parameters need to be specified with the ranges of the parameter when a Box-Benhken design is applied to the response surface method. The minimum and maximum values of voltage were selected as 150 and 220 V, treatment temperature as 50 and 60°C and treatment time as 1 and 3 minutes specifically given as in Table 3.1 based on the preliminary studies conducted and a thorough review of literature.

Table 3.1 independent variables and its coded and actual values

Independent variables	units	Code levels		
		-1	0	1
Voltage (A)	V	150	185	220
Holding time (B)	°C	55	60	65
Process temperature (°C)	min	1	2	3

Table 3.2 Coded and Decoded Levels of Factors used in RSM for Ohmic Heating of Fruit Juices

Coded factors				Decoded factors		
Treatment run	A	B	C	Voltage (V)	Temperature (°C)	Holding Time (min)
1	0	0	0	185	60	2
2	0	+1	-1	185	65	1
3	0	0	0	185	60	2
4	0	0	0	185	60	2
5	-1	0	-1	150	60	1
6	-1	-1	0	150	55	2
7	+1	0	+1	220	60	3
8	-1	0	+1	150	60	3
9	0	+1	+1	185	65	3
10	0	-1	+1	185	55	3
11	-1	+1	0	150	65	2
12	0	-1	-1	185	55	1
13	+1	+1	0	220	65	2
14	+1	0	-1	220	60	1
15	+1	-1	0	220	55	2
16	0	0	0	185	60	2
17	0	0	0	185	60	2

3.6 QUALITY EVALUATION OF PASSION FRUIT PULP

Physicochemical properties such as color, total soluble solids (TSS), pH, titrable acidity, ascorbic acid content and total color difference of the passion fruit pulp were analysed.

3.6.1 TSS

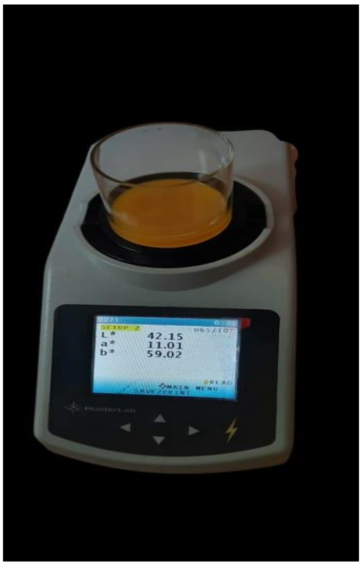
The TSS of passion fruit pulp was determined using a hand refractometer (Plate 3.2). When light passes from one medium to another, the speed at which the light travels will change depending on the parameters of the materials. The ratio or change in the speed of light is called refractive index and instruments that measure this parameter are called refractometers. The refractive index of a liquid is related to its concentration and so a refractometer can display the concentration in suitable units, such as °Brix (% sugar). First of all, calibration was done of refractometer with the help of distilled water, a drop of it was placed on the prism of refractometer and its reading was observed. Reading should be 0 for distilled water and after this a drop of passion fruit pulp was placed on the measuring port of the refractometer to read the value of total soluble solids (TSS) in ºBrix and the reading was recorded. Observations were repeated three times to get a concordant reading.

3.6.2 Color

The color of the passion fruit pulp was found using a Hunter lab color flex meter (Hunter Association laboratory, Inc., Reston, Virgina, USA; model: Hunter Lab's Color Flex EZ) (plate 3.3)

The Hunter lab's color flex spectro calorimeter consists of measurement (sample) port, opaque cover and display unit. This color flex meter operates on the theory of focusing the light and measuring energy reflected from the sample across the entire visible spectrum. For matching a sequence of color across the visible spectrum, primary lights are required and describes the color by mathematical model called as Hunter model. It reads the color of sample in respect of L*, a* and b* values where, luminance (L) forms the vertical axis, which denotes whiteness to darkness. Chromatic portion of the solids is designated by: redness a (+), greenness a (-), yellowness b (+), and blueness b (-). A transparent glass cup filled with sample was placed over the port of the instrument and an opaque cover which act as a light trap to exclude the interference of external light was placed over the cup. Before actual measurements color was calibrated by fixing the definite colors like white and black tiles. After calibration, the sample was placed over the port and values of 'L*', 'a*' and 'b*' were recorded and repeated three times.

Plate 3.2 Refractometer



```
SETUP 2        D65/10°
L*      42.15
a*      11.01
b*      59.02
```

Plate 3.3 Hunterlab colorflex meter

3.6.3 Titrable Acidity

Total acidity of passion fruit pulp was determined and expressed in malic acid equivalent percentage (AOAC,2000). Five millilitres of passion fruit pulp samples were collected in 250 ml conical flask containing 100 ml of distilled water. Few drops of phenolphthalein were added to the solution as an indicator and shaken well. The burette was filled with 0.1 N NaOH. The solution was titrated against the solution in burette until the sample solution showed a faintest discernible pink color which persisted for 30 seconds. Acidity was estimated using the following equation:

Acidity (% malic acid)

$$= \frac{\boldsymbol{volume\ of\ titrant(ml) \times Normality\ of\ titrant \times 0.067}}{\boldsymbol{Sample\ weight(g)}} \times \mathbf{100}$$

Were, 0.067 – milli equivalent of malic acid

3.6.4 Ascorbic acid

Ascorbic acid content in passion fruit pulp were estimated using the 2,6-dichlorophenol indophenols titrimetric method as described by Sadasivam and Manickam (1992). Dye solution was prepared by dissolving 52 mg of 2,6 dichloro phenol indophenol, and 42 mg of sodium bicarbonate in 200 ml distilled water. Standard solution was prepared by adding 100 mg of ascorbic acid to 100 ml of 4% oxalic acid. To prepare working standard solution, 10 ml of standard solution was pipetted out and was diluted to 100 ml using 4% oxalic acid. The 5 ml passion fruit pulp samples were made up to 50 ml using 4 percent oxalic acid. To find dye factor, 10 ml of working standard solution was pipetted out into a 50 ml conical flask and 10 ml of 4% oxalic acid was added and titrated against the dye. The end point was the appearance of pink color which persisted for a few minutes. The titration was repeated to get concordant values. The amount of dye consumed was equal to the amount of ascorbic acid present in the working standard solution (V_1). Ten millilitre of sample extract was pipetted out to which 10 ml of 4% oxalic acid was added. It was then titrated against the dye. The titration was replicated for each sample until the concordant values were obtained (V_2).

$$\text{Dye factor} = \frac{0.5}{Titrable\ value(V1)}$$

$$\text{Ascorbic acid}\ \frac{mg}{100g} = \frac{0.5\ mg}{v1\ ml} \times \frac{v2}{5\ ml} \times \frac{100\ ml}{Wt.of\ the\ sample} \times 100$$

V_1- Amount of dye consumed by ascorbic acid present in the working standard solution, ml

V_2- Amount of dye consumed by the liquid sample, ml.

3.7 MICROBIOLOGICAL ANALYSIS

The microbiological quality characteristics of the passion fruit pulp samples were determined both for fresh and optimised samples. The growth of bacteria was found through standard plate count method.

3.7.1 Total Bacterial Count in Passion Fruit Pulp

The bacterial population in passion fruit pulp were analysed by different microbiological methodologies, that includes enumeration of the microorganism in selective media for different dilutions of sample, incubation of plates and counting the number of colonies present. The media generally used for enumeration bacteria is nutrient agar medium. The passion fruit pulp of 1 ml was pipetted using a sterile pipette into a test tube containing 9 ml of sterile water which gave a 1:10 (10^{-1}) dilution. The test tubes were shaken well for 10-15 minutes for uniform distribution of microbial cell in the water blank. Then 10^{-2} dilution was prepared by pipetting out 1 ml of (10^{-1}) dilution to 9 ml of sterile water in test tube with a sterile one ml pipette. The process was repeated up to 10^{-6} dilutions with a serial transfer of the dilutants. One millilitre of aliquots from 10^{-4} and 10^{-5} dilutions were transferred to the sterile petri dishes for the enumeration of bacteria.

For ohmic heated samples, dilutions of 10^{-1} and 10^{-3} were selected for enumeration of bacterial colonies. The ohmic treatment is a mild thermal treatment, the chance of survival of microorganisms is limited and therefore higher dilutions can be omitted. The experiments were carried out in triplicate and the mean value is reported.

Approximately,15-20 ml of molten and cooled (45°C) agar medium was added to each petridish containing the sample dilutions and the plates were rotated in clockwise and anticlockwise direction for thorough mixing of the dilutants and the medium. The plates were then incubated at 35°C (room temperature) for 24-48 hours for bacteria. After the incubation period, the colonies were counted and the number of organisms (total bacteria) per gram of sample was calculated by using the equation

Number of colony forming units (cfu) per gram of the sample

$$= \frac{mean\ number\ of\ cfu \times Dilution\ factor}{Quantity\ of\ sample\ on\ weight\ basis}$$

3.8 SENSORY ANALYSIS

Sensory analysis is a scientific study used to measure, analyse and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch, and hearing. In general, sensory quality of liquids foods is the consumer’s reaction to the physical nature and chemical constituents of the food in its prepared and formulated form. Organoleptic evaluation of the optimized sample was carried out by a panel of fifteen untrained judges for color, flavour, taste, and overall acceptability using 9-point hedonic scale.

3.9 STATISTICAL ANALYSIS

The statistical analysis for optimising the process variables of ohmic heating system was performed through Response Surface Methodology (RSM) using Design Expert (version 12.0; Stat Ease Inc.,Minneapolis,MN,USA) software.

RESULTS AND DISCUSSIONS

CHAPTER IV

RESULTS AND DISCUSSIONS

This chapter details the results of the experiments conducted towards optimization of the process parameters of ohmic heating treatment of passion fruit pulp. The results of the experiments conducted towards characterisation of the optimally treated passion fruit pulp are also elaborated. The results of the microbial inactivation studies to determine the effectiveness of ohmic heating treatment is also discussed.

4.1 CHARACTERESTICS OF THE PASSION FRUIT PULP

In order to assess the effectiveness of the ohmic heating, the changes in quality attributes of the fresh passion fruit needs to be assessed. The characterisation of passion fruit pulp in the form of biochemical and microbiological properties were determined. The properties of the fresh passion fruit pulp are presented in Table 4.1

Table 4.1 Properties of the Fresh Passion Fruit Pulp

Properties	**Passion fruit pulp**
Physico-chemical properties	
TSS (°Brix)	15±1.0
Titrable acidity (mg/100 ml)	1.12±0.1
Ascorbic acid (mg/100 ml)	23.68±2.4
Color values	
L*	48.73±0.01
a*	16.94±0.04
b*	65.61±0.13
Initial microbial population	
Total bacterial count (cfu/ml)	14×10^4

The physicochemical properties of passion fruit has been investigated by researchers from various geographical locations on the most important commercial Passiflora fruits; P. edulis f. flavicarpa (Sandi *et al.*, 2004) and P. edulis (Frank *et al.*, 2006).

The passion fruit pulp registered an ascorbic acid content of 23.68 mg/100 ml and the TSS content of the fresh passion fruit pulp was found to be 15±1.00°Brix.

The titrable acidity values of fresh passion fruit pulp was found to be 1.12 mg/100 ml. It might be due to the presence of organic acids in the passion fruit pulp. Organic acids play important roles in Passion fruit juices because of their influence on the organoleptic properties (flavor, color and aroma) as well as the stability and microbiological control of the products (Hasib *et al.*, 2002). Three organic acids identified and quantified in Passion fruit juice was citric, malic and acetic acids (Joy, 2010).

Citric and malic acid content in the Passiflora fruit could be responsible for the usual sourness of the fruits. It is an important component of cell metabolism in fruits and is the primary acid found in some fruits which plays a major role in metabolism in the human body. Citric and malic acid is also an indicator of the freshness of fruits and is used as a common parameter to evaluate the quality of agricultural products and food control points in the food process (Hasib *et al.*, 2002).

Color of the passion fruit pulp is a key factor that influences consumer sensory acceptance (Quitão-Teixeira *et al.*, 2007). For liquid foods, color is typically measured by the color parameters such as ‘L*’ indicating lightness, ‘a*’ indicating chromaticity on green (-) to red (+) axis and ‘b*’ indicating chromomaticity on blue (-) to yellow (+) axis (Chutintrasria and Noomhorm,2007). The L*, a* and b* values of passion fruit pulp were 48.73±0.01, 16.94±0.04 and 65.61±0.13 respectively.

The initial microbial population of liquid foods depends on many factors such as cleanliness of fruit, storage period, processing conditions and application of GAP, GMP etc. (Laorko *et al.*,2013). The total initial bacterial count of fresh passion fruit pulp was 14×10^4 cfu/ml.

4.2 OPTIMISATION OF PROCESS PARAMETERS

The ohmic heating treatment of passion fruit pulp was evaluated for its preservation of the natural quality attributes. As the passion fruit sample behaves differently to the process parameters of ohmic heating, the parameters were optimised for the treatment. The quality parameters were then observed and analysed to conclude the treatment condition.

4.2.1 Optimisation of Ohmic Heating Process Parameters for Passion fruit Pulp

The passion fruit pulp was subjected to ohmic heating at voltage 150, 185 and 220 V process temperatures of 55, 60 and 65°C and treatment time 1, 2, and 3 min in the ohmic heating chamber. A come-up time was required in all ohmic heating treatment to attain specified temperature for each voltage. The higher come up time during ohmic heating results in a negative influence on quality parameters. The physicochemical quality characteristics of passion fruit pulp was analysed. Fresh passion fruit pulp was taken as control for comparison. The results obtained are presented in Table 4.2.

The variation in physicochemical properties such as pH, TSS, ascorbic acid, titrable acidity and color during ohmic heating with different combination of process parameters for passion fruit pulp are discussed in detail in the following sections.

Table 4.2 Effect of ohmic heating process parameters on the physicochemical of passion fruit pulp

Run	Voltage (V)	Process temperature (°C)	Holding time (min)	TSS (°Brix)	Titrable acidity (mg/100 ml)	Ascorbic acid (mg/100 ml)
1	185	60	2	16.6	1.558	19.13
2	185	65	1	15.5	1.56	20.982
3	185	60	2	16.15	1.62	19.834
4	185	60	2	16.2	1.5	19.736
5	150	60	1	15.4	1.6492	21.458
6	150	55	2	15.23	1.5946	22.368
7	220	60	3	18.4	1.6219	18.12
8	150	60	3	17.3	1.5797	18.856
9	185	65	3	18.2	1.6815	18.034
10	185	55	3	15.4	1.6961	20.531
11	150	65	2	17.5	1.5127	18.966
12	185	55	1	15.3	1.4254	21.052
13	220	65	2	17.7	1.5802	18.23
14	220	60	1	15.9	1.6559	19.423
15	220	55	2	15.5	1.5209	20.076
16	185	60	2	16.8	1.53	19.951
17	185	60	2	17.1	1.48	19.265

Table 4.3 Effect of ohmic heating process parameters on the color of passion fruit pulp

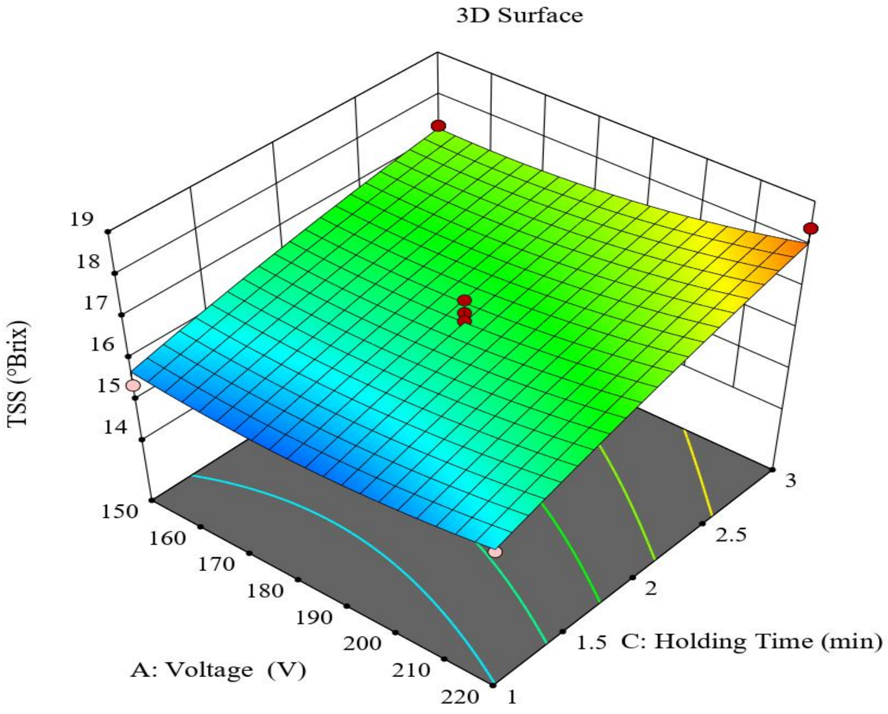
Run	Voltage (V)	Process temperature (°C)	Holding time (min)	Color		
				L*	a*	b*
1	185	60	2	43.26	13.75	61.65
2	185	65	1	42.3	13.12	61.78
3	185	60	2	43.35	13.78	61.54
4	185	60	2	45.34	13.92	61.19
5	150	60	1	47.38	12.63	63.87
6	150	55	2	41.27	12.59	65.12
7	220	60	3	46.28	16.87	57.83
8	150	60	3	41.61	14.81	60.11
9	185	65	3	44.71	15.82	56.57
10	185	55	3	44.58	13.69	59.97
11	150	65	2	42.06	12.97	63.94
12	185	55	1	44.13	12.86	63.49
13	220	65	2	41.54	16.37	58.09
14	220	60	1	44.91	15.59	61.83
15	220	55	2	43.21	14.12	59.27
16	185	60	2	44.53	13.96	60.11
17	185	60	2	46.28	14.02	60.62

4.2.1.1 Effect of ohmic heating process parameters on TSS of passion fruit pulp

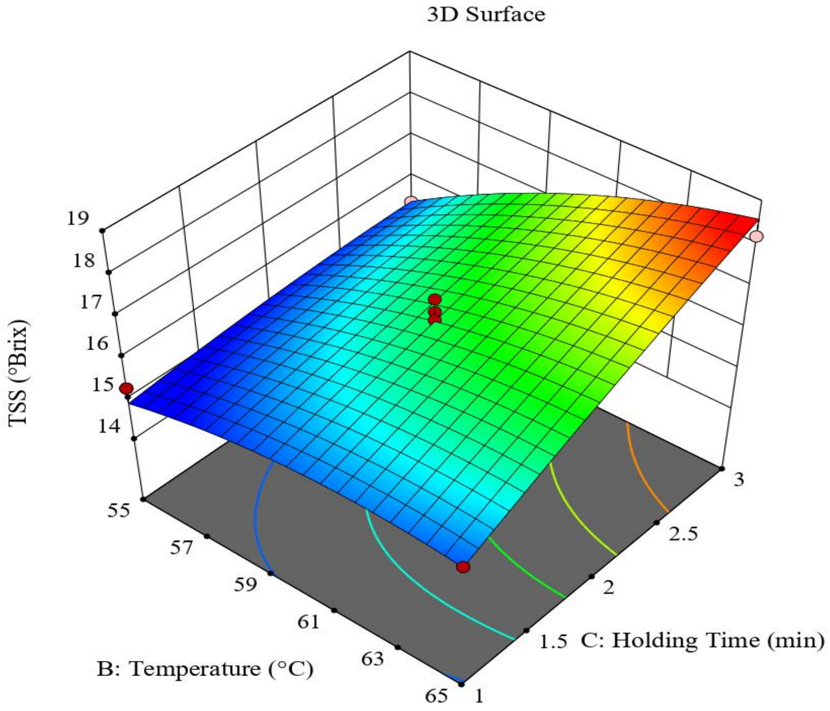
The variation in TSS content of passion fruit pulp with different combinations of ohmic heating operating variables are summarised in Table 4.2 and it is plotted in Fig.4.1.

The TSS value of passion fruit pulp was found to be in between 15.23 to 18.4° Brix. The lowest variation in TSS values of ohmic processed pulp with that of fresh pulp was observed in samples treated with voltage of 150 V, holding time of 2 min and process temperature of 55°C.

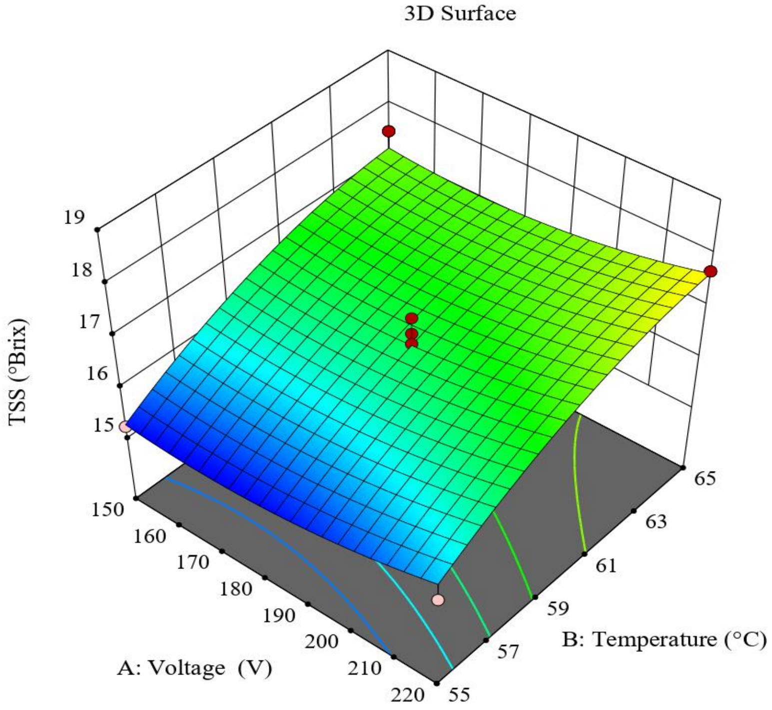
From the figures it may be observed that TSS content increased with increase in voltages, holding time and process temperature for passion fruit pulp. This might be due to boiling of pulp with increase in heating which will in turn increases the solute concentration. The conversion of organic acids to sugar could also be a reason for the modification of TSS content (Echeverria and Valich,1989).



(a)



(b)



(c)

Fig.4.1Effect of ohmic heating parameters on TSS of passion fruit pulp

The equation 4.1 shows the quadratic equations for the effect of process parameter on TSS value of passion fruit pulp.

$$TSS = 16.57 + 0.2588\,A + 0.9338\,B - 0.9\,C - 0.0175\,AB + 0.15\,AC + 0.65\,BC + 0.2812\,A^2 - 0.3688\,B^2 - 0.1012\,C^2$$

$$R^2 = 0.9227 \qquad 4.1$$

Where, A = Voltage, V

B = Holding time, min

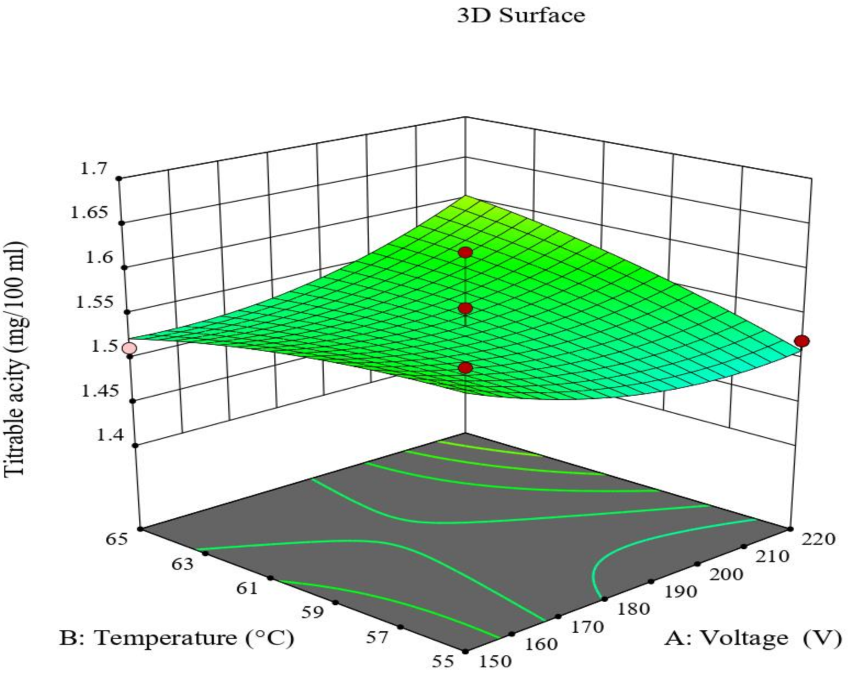
C = Treatment temperature, °C

The ANOVA tables (A.1) showed that the regression model was significant as p-value was low ($P<0.05$) and the lack of fit was not significant indicating the adequacy of the model. The adequate precision value was found to be 10.7012,which is more than 4 and the R^2 value is greater than 0.9 and adjusted R^2 value is near to 0.9.So the model could be termed as adequately fit.The coefficient of variance was found to be less than 10% indicating that the model can be considered as reproducible

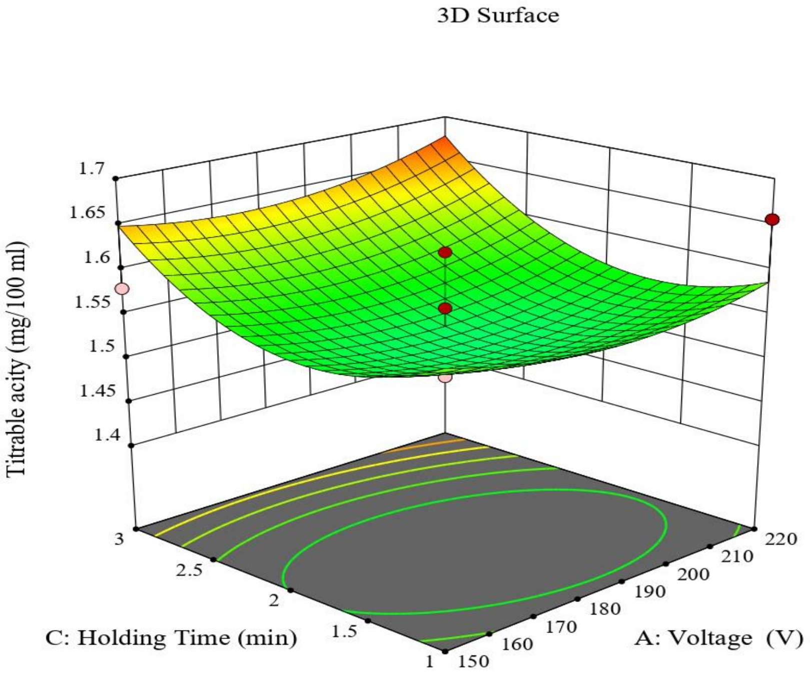
4.2.1.2 Effect of ohmic heating process parameters on titrable acidity of passion fruit pulp

The effect of ohmic heating treatment on titrable acidity of passion fruit pulp are presented in Table 4.2 and the 3D response surface plots are depicted inFig.4.2

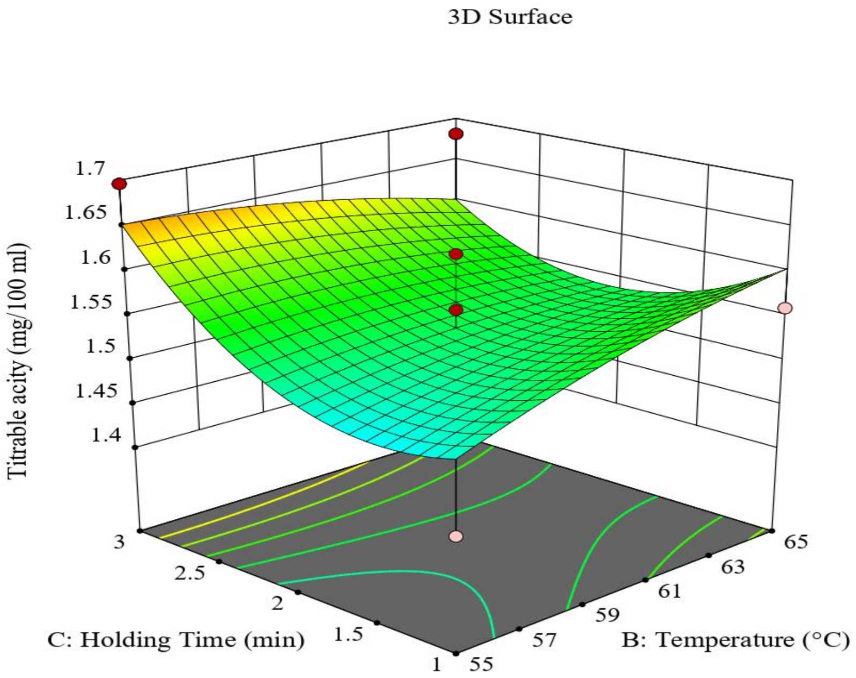
The results shows that titrable acidity of passion fruit pulp varied between 1.42 and 1.69 mg/100 ml. It may be concluded from the results that the titrable acidity did not show any significant changes after ohmic heating treatment since any typical trends were not observed in the titrable acidity values of passion fruit pulp.


3D Surface
Titrable acity (mg/100 ml)
1.7
1.65
1.6
1.55
1.5
1.45
1.4
B: Temperature (°C)
65
63
61
59
57
55
A: Voltage (V)
150
160
170
180
190
200
210
220

(a)


3D Surface
Titrable acity (mg/100 ml)
1.7
1.65
1.6
1.55
1.5
1.45
1.4
C: Holding Time (min)
3
2.5
2
1.5
1
A: Voltage (V)
150
160
170
180
190
200
210
220

(b)



(c)

Fig.4.2 Effect of ohmic heating on titrable acidity of passion fruit pulp

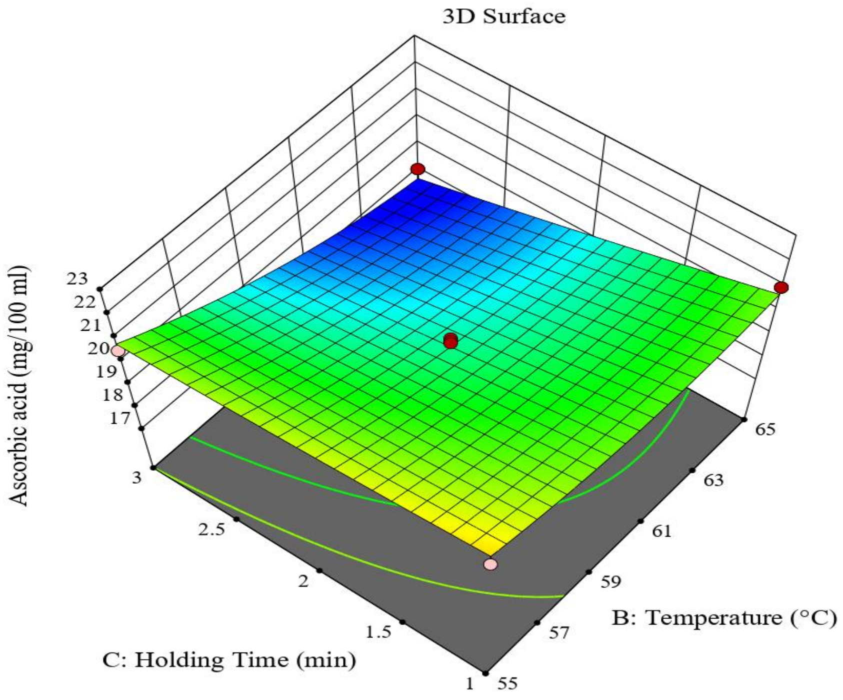
It could be seen from the ANOVA tables Appendix A.2, that the low R^2 values shows the low correlation. It can be concluded that the ohmic heating treatment have no significant effect on the titrable acidity value of passion fruit pulp.

4.2.1.3 Effect of ohmic heating process parameter on ascorbic acid of passion fruit pulp

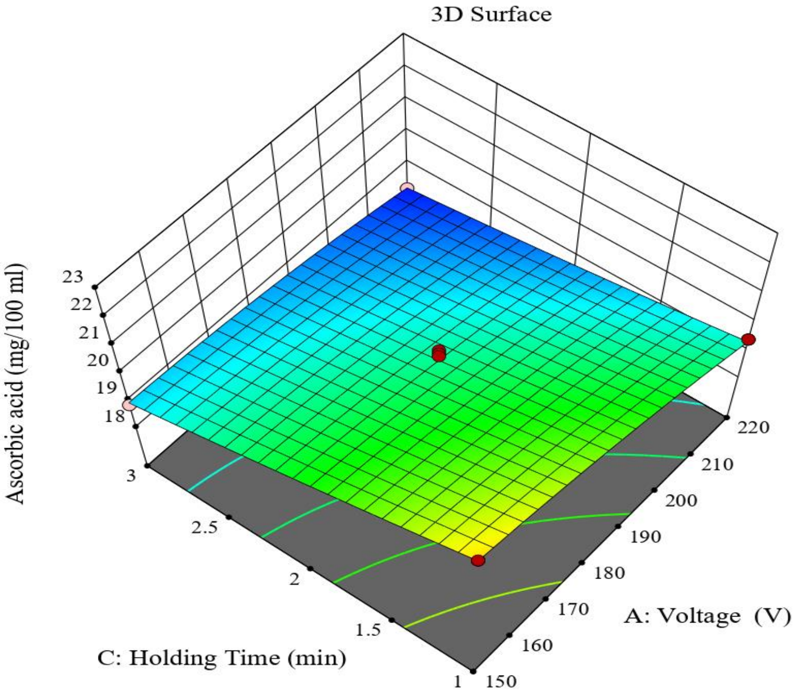
The ascorbic acid content of passion fruit pulp subjected to different ohmic heating treatment is shown in Table 4.2 and the 3D surface plot is presented in Fig.4.3.

Ascorbic acid content of the pulp was found to be decreasing for different process parameters of ohmic heating. The ascorbic acid content varied between 18.12 and 22.368 mg/100 ml. The maximum reduction of ascorbic acid was noted at a voltage of 220 V, process temperature of 60°C and holding time of 3 min for the passion fruit pulp. The minimum reduction in ascorbic acid content was shown at a voltage of 150 V Process temperature of 55°C and holding time of 2 min.

From Fig.4.3 it may be noted that significant reduction in ascorbic acid content of passion fruit pulp occured with increase in temperature,voltage and holding time. This could be due to the heat sensitive nature of ascorbic acid compounds. The degradation of ascorbic acid might be attributed to several chemical reactions such as oxidative and corrosive reactions during ohmic heating. In this study the overall reduction in ascorbic acid content of the passion fruit pulp were minimum, compared to that of other thermal processing technologies, due to the mild conditions such as lower temperature and voltage employed.



(a)



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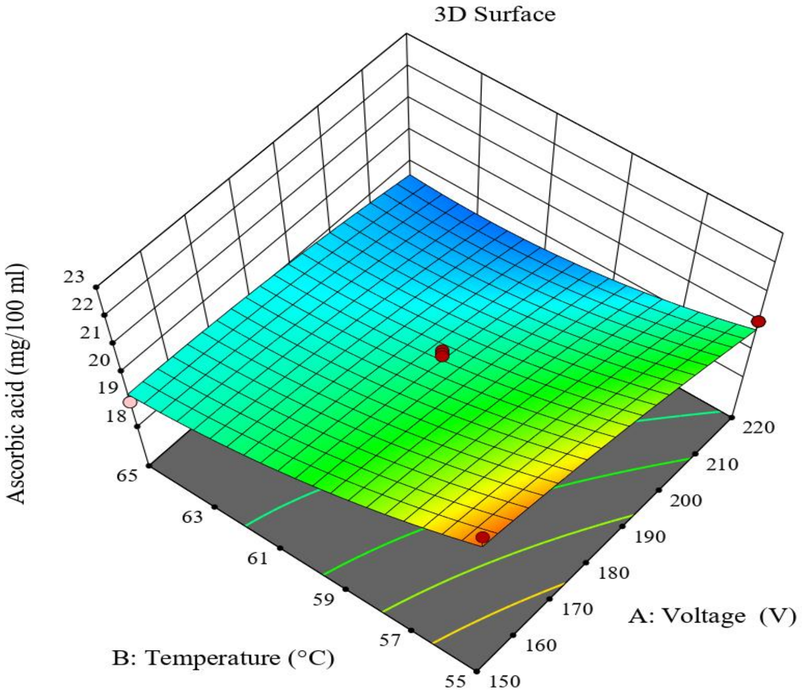


(c)

Fig.4.3 Effect of ohmic heating parameters on ascorbic acid of pulp

Ascorbic acid content (mg/100ml) = $19.58-0.7249A-0.9769B-0.9217C+0.3890AB+0.3248AC-0.6067BC-0.1793A^2+0.5061B^2+0.0604C^2$

$R^2=0.9387$ 4.2

Where,

A= Voltage,V

B= Holding time, min

C= Treatment temperature, °C

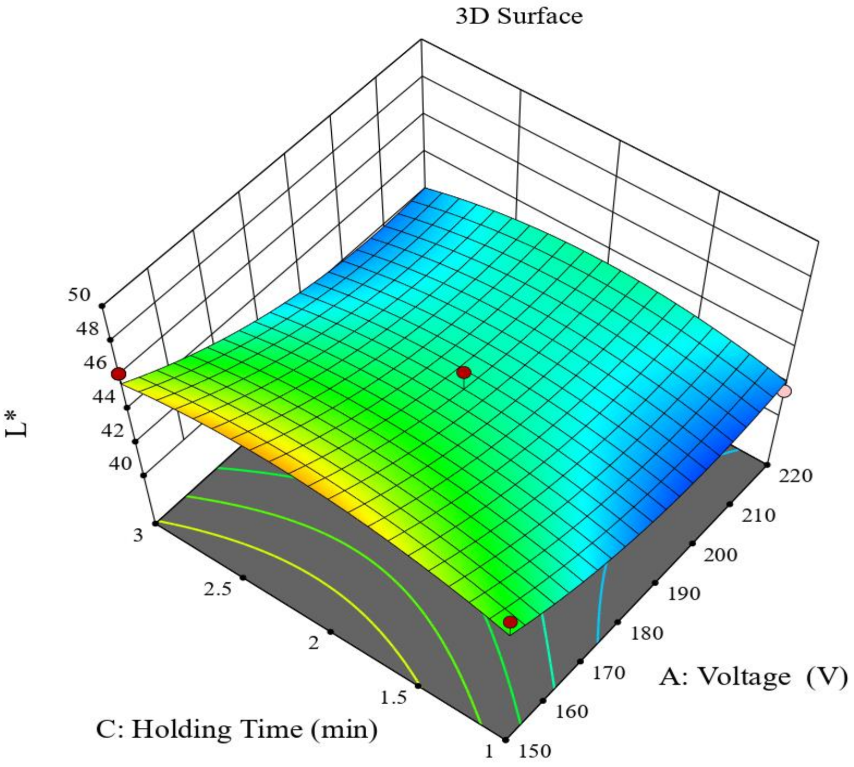
The ANOVA tables (A.3) showed that the regression model was significant as p-value was low ($P<0.05$) and the lack of fit was not significant indicating the adequacy of the model. The adequate precision value was found to be 12.4429,which is more than 4 .The R^2 value is greater than 0.9 and adjusted R^2 value is near to 0.9.So the model could be termed as adequately fit.The coefficient of variance was found to be less than 10% indicating that the model can be considered as reproducible

4.2.1.3 Effect of ohmic heating process parameters on L value of passion fruit pulp*

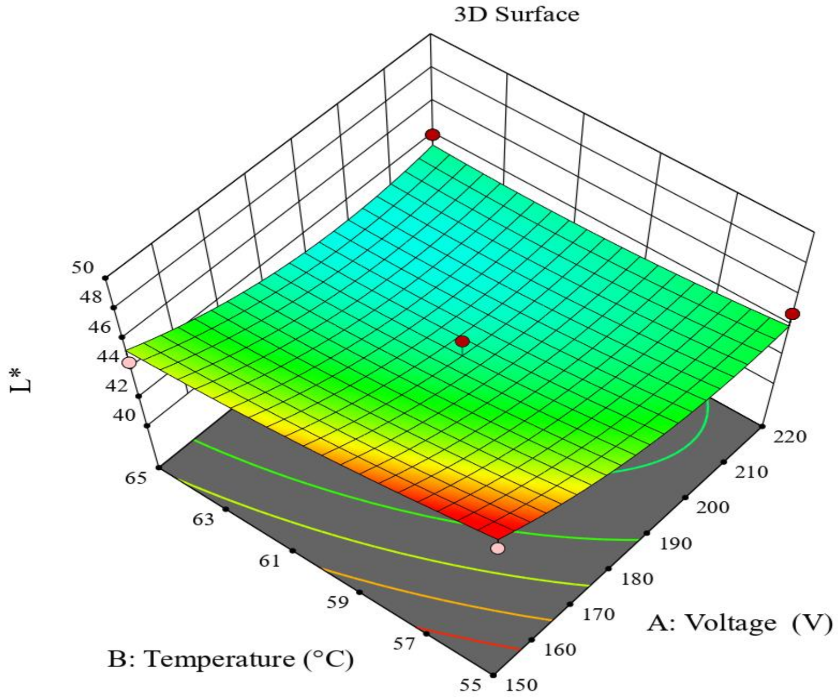
Color is an important quality parameter affecting the sensory perception and consumers' acceptance of food (Villani *et al.*, 2015). The effect of ohmic heating process parameters on L*values of passion fruit pulp was evaluated and presented in the Appendix A.4. Color perception is the result of three parameters (L*, a*, and b*).

From Fig.4.4 and Table 4.3 ,it can be infered that L* values shows a slight decrease with increase in voltage, temperature and holding time. The reduction in L* values indicate reduction of lightness. A decline in lightness has been associated with browning in fruit (Labuza *et al.*, 1992).

It may be observed from the results that the L* value of passion fruit pulp ranged between 41.27 to 47.38. The lowest variation in L* values of ohmic processed pulp with that of fresh pulp was observed in samples treated with voltage of 220 V, holding time of 3 min and process temperature of 60°C while the highest variation was found in samples treated with voltage of 150V,holding time of 2 min and process temperature of 55°C.This change in L* values might be due to degradation of color compounds in passion fruit pulp during ohmic heating.



(a)



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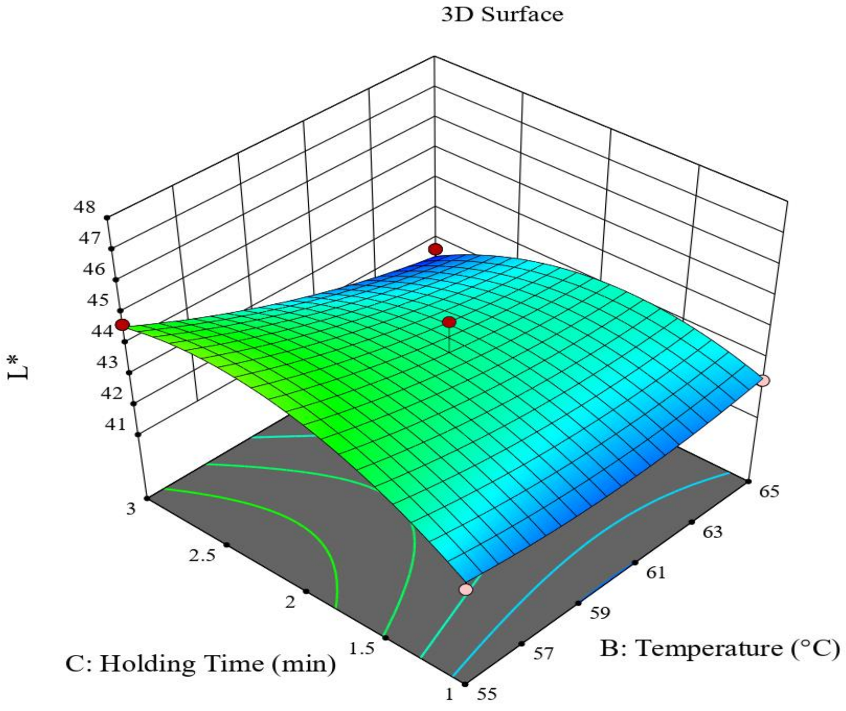


(c)

Fig.4.4 Effect of ohmic heating parameters on L* value of pulp

$$L^* = 43.53 - 1.47\,A - 0.8050\,B + 0.3288\,C + 0.5050\,AB - 0.3025\,AC - 0.8350\,BC - 1.33\,A^2 + 0.3932\,B^2 - 1.25\,C^2$$

$R^2=0.8757$ 4.3

Where,

A= Voltage,V

B= Holding time, min

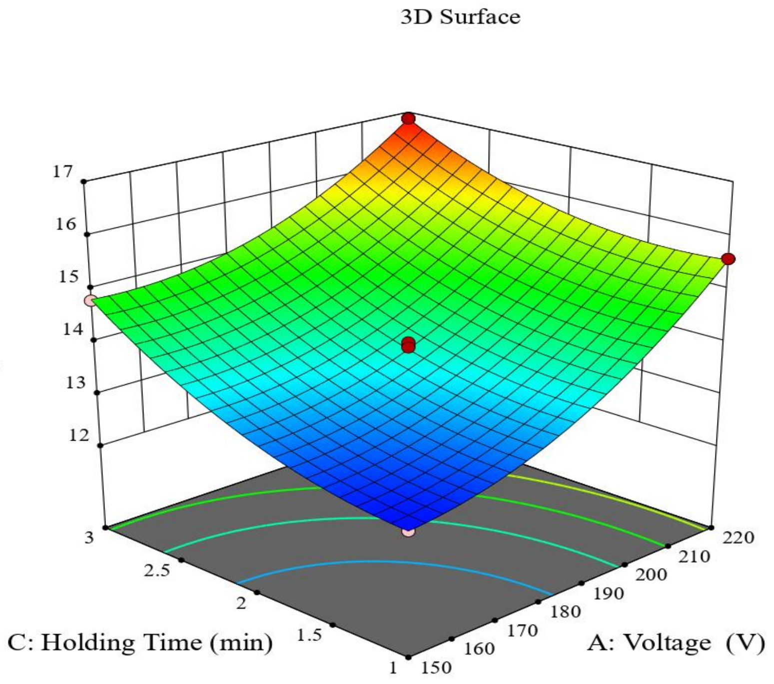
C= Treatment temperature, °C

The ANOVA tables (A.4) showed that the regression model was significant as p-value was low ($P<0.05$) and the lack of fit was not significant indicating the adequacy of the model. The adequate precision value was found to be 9.4857,which is more than 4 .The R^2 value and adjusted R^2 value is near to 0.9.So the model could be termed as adequately fit.The coefficient of variance was found to be less than 10% indicating that the model can be considered as reproducible

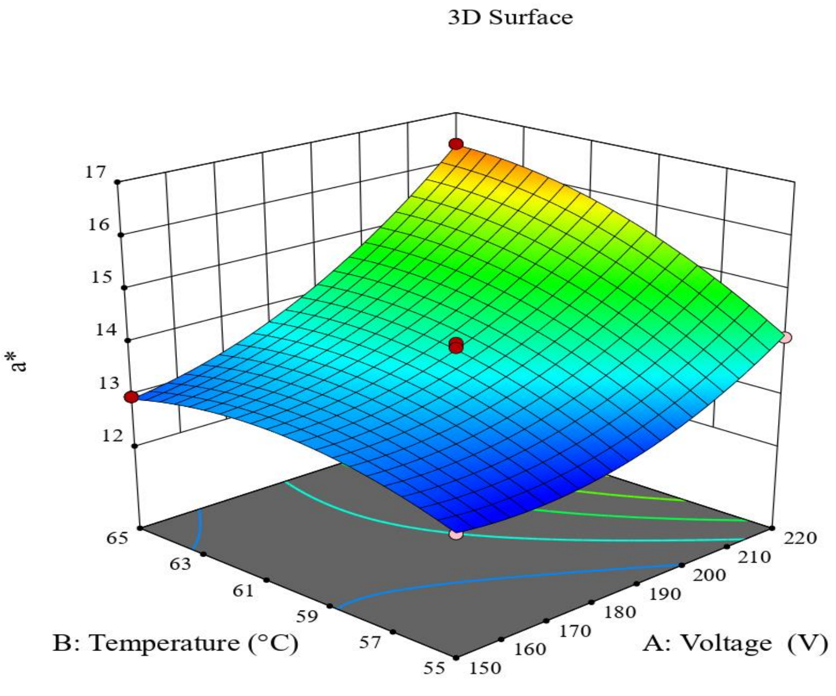
4.2.1.4 Effect of ohmic heating process parameters on a value of passion fruit pulp*

The effect of ohmic heating treatment on a* values of passion fruit pulp are depicted in Table 4.3 and the analysis of variance (ANOVA) is presented in Appendix A.5

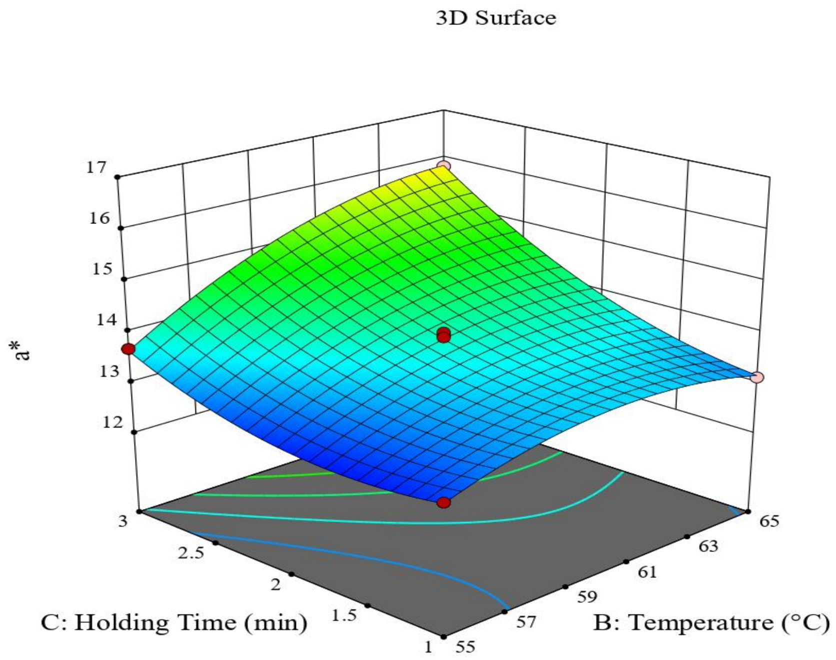
From Fig.4.5 it can be concluded that a* values show a slight increase with increase in voltage, temperature and holding time. The a* values of passion fruit pulp ranged between 12.59 to 16.87. The rise in a* values stand for increase in redness of passion fruit pulp after ohmic heating treatment. The highest variation in a* values of ohmic processed pulp with that of fresh pulp was observed in samples treated with voltage of 220 V, holding time of 3 min and process temperature of 60°C while the lowest variation was found in samples treated with voltage of 150V,holding time of 2 min and process temperature of 55°C.This might be due to degradation of color compounds in passion fruit pulp during ohmic heating.


3D Surface
17
16
15
14
13
12
a*
3
2.5
2
1.5
1
C: Holding Time (min)
150
160
170
180
190
200
210
220
A: Voltage (V)

(a)


3D Surface
17
16
15
14
13
12
a*
65
63
61
59
57
55
B: Temperature (°C)
150
160
170
180
190
200
210
220
A: Voltage (V)

(b)



(c)

Fig.4.5 Effect of ohmic heating process parameters on a* value of pulp

a* = 13.89 + 1.24 A + 0.6275 B + 0.8738 C + 0.4675 AB - 0.2250 AC + 0.4675 BC + 0.6145 A^2 - 0.4880 B^2 + 0.4745 C^2

R^2=0.9977 4.4

Where,

A= Voltage,V

B= Holding time, min

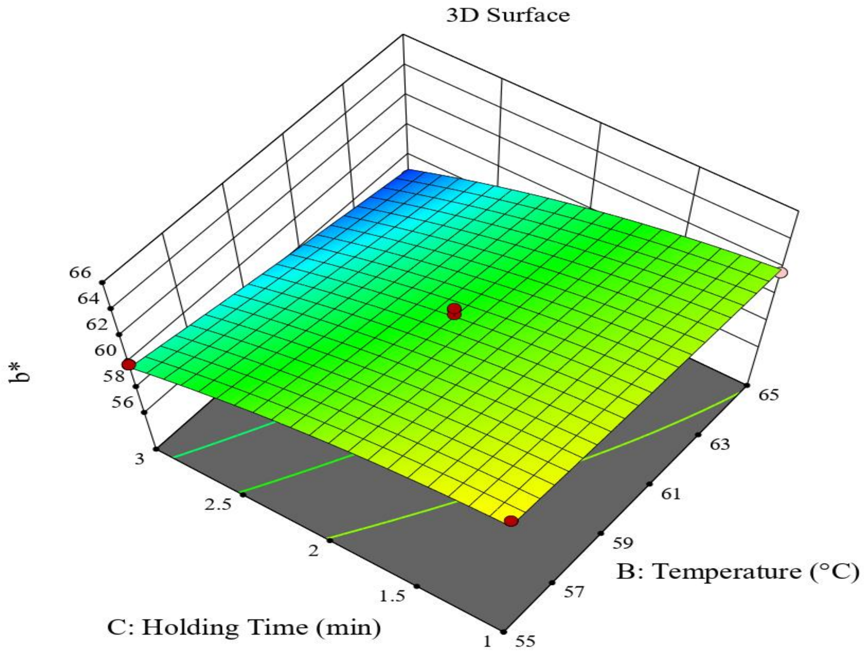
C= Treatment temperature, °C

The ANOVA tables (A.5) showed that the regression model was significant as p-value was low ($P<0.05$) and the lack of fit was not significant indicating the adequacy of the model. The adequate precision value was found to be 58.4637,which is more than 4 .The R^2 value and adjusted R^2 value are found to be greater than 0.9.So the model could be termed as adequately fit.The coefficient of variance was found to be less than 10% indicating that the model can be considered as reproducible

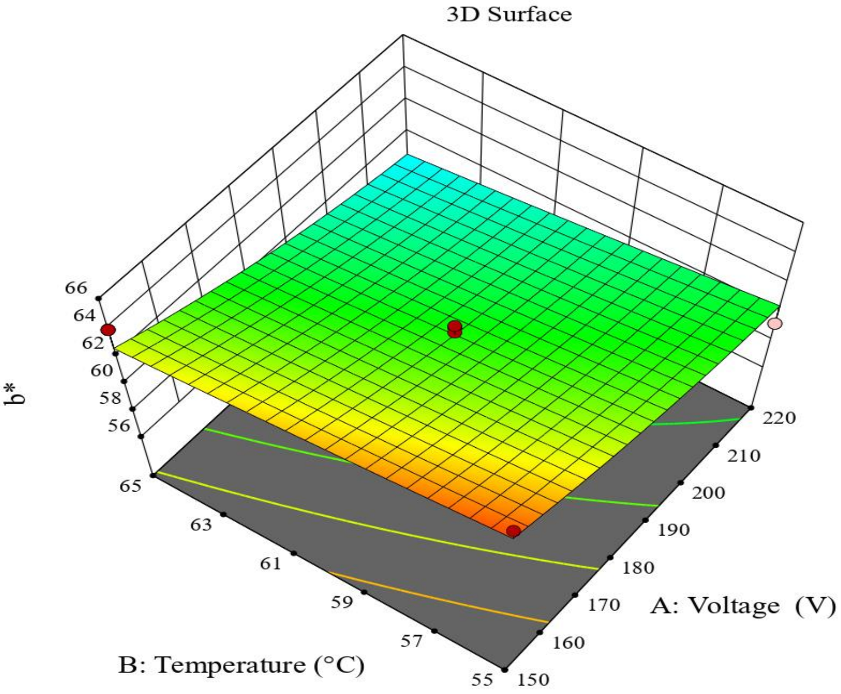
4.2.1.5 Effect of ohmic heating process parameters on b value of passion fruit pulp*

The effect of ohmic heating treatment on b* values of passion fruit pulp are depicted in Table 4.3 and the analysis of variance (ANOVA) is presented in Appendix A.6

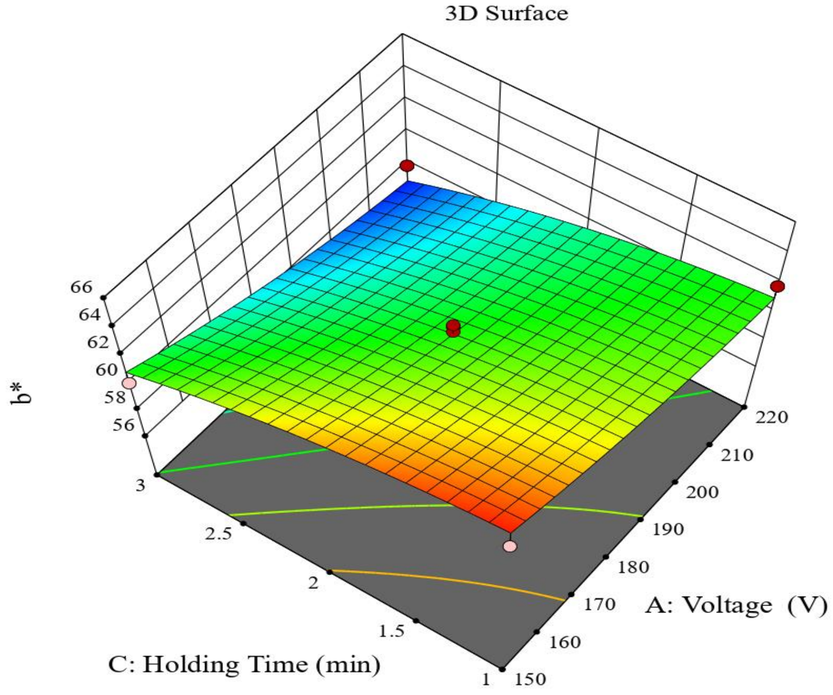
From Fig.4.6 it can be concluded that b* values shows a slight decrease with increase in voltage, temperature and holding time. The decrease in b* values represent the reduction in yellowness. The b* value of passion fruit pulp ranged between 57.83 to 65.12. The lowest variation in b* values of ohmic processed pulp with that of fresh pulp was observed in samples treated with voltage of 220 V, holding time of 3 min and process temperature of 60°C while the highest variation was found in samples treated with voltage of 150V,holding time of 2 min and process temperature of 55°C.This change in b* values might be due to degradation of color compounds in passion fruit pulp during ohmic heating.



(a)



(b)



(c)

Fig 4.6 Effect of ohmic heating parameters on b* values of pulp

$$b^* = 61.02 - 2\,A - 0.9337\,B - 2.06\,C - 0.06\,AC - 0.4225\,BC + 0.5203\,A^2 + 0.0628\,B^2 - 0.6322\,C^2$$

$$R^2=0.8899 \qquad 4.5$$

Where,

A= Voltage,V

B= Holding time, min

C= Treatment temperature, °C

The ANOVA tables (A.6) showed that the regression model was significant as p-value was low ($P<0.05$) and the lack of fit was not significant indicating the adequacy of the model. The adequate precision value was found to be 9.070,which is more than 4 .The R^2 value and adjusted R^2 values are near to 0.9.So the model could be termed as adequately fit.The coefficient of variance was found to be less than 10% indicating that the model can be considered as reproducible

4.3 EFFECT OF OHMIC HEATING ON MICROBIAL COUNT

The microbial count was found to be decreased by 2 log reduction in ohmic heated sample. This indicates the efficiency of ohmic heating treatment on microbial inactivation. It might be due to heat generation and electroporation effect during ohmic heating.

4.5 SENSORY EVALUATION

The result of sensory evaluation is shown in the Fig 4.7. The taste, flavour, color and overall acceptability of ohmic heated passion fruit pulp was found to be similar to fresh passion fruit pulp.

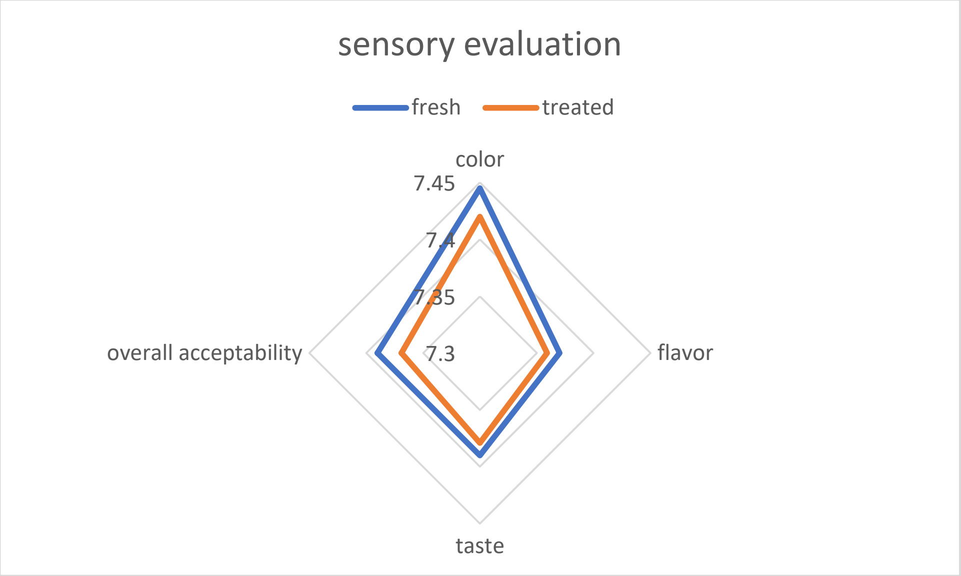


Fig. 4.7 sensory evaluation of passion fruit pulp

4.6 OPTIMISATION OF OHMIC HEATING PROCESS PARAMETERS

Optimisation of three process variables such as voltage (150,185 and 220 V), holding time (1,2 and 3 min) and process temperature (55.60 and 65°C) was performed using the Box-Behnken design in Design Expert Software 12.0. For optimisation of the operating parameters during ohmic heating, the responses were minimised, maximised or kept in a target value to get the desired outcome. Higher desirability values were selected as optimum process conditions of ohmic heating treatment. The highest desirability was obtained at a voltage of 185.34 V, holding time of 2.32 min and treatment temperature of 60.26°C for passion fruit pulp.

Plate 4.1 Sensory evaluation of treated and fresh sample

Plate 4.2 Treated passion fruit pulp in amber-colored bottles

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

Passion fruit (*Passiflora edulis)* is a nutritious tropical fruit which belongs to the genus *Passiflora*.It has a huge economical importance as all part of the fruit are rich in medicinal and therapeutic properties.Due to the seasonality of production and the harvesting and transportation losses and its highly perishable nature,it became necessary to process it with lesser nutritional losses.In this regard,passion fuit pulp was found to be a better option.

Passion fruit pulp can be maintained for a longer period of time by freezing.Frezzing has been widely used but the main problem is that its high cost. Other than freezing thermal methods can also be employed.The major shortcomings of conventional heating methods are non-uniform heating,loss of nutrients and more time requirement.

Innovative technologies *viz.,* high pressure processing,radio frequency processing,ultrasound processing, pulsed electric fields and ohmic heating have widely been in research as alternatives to traditional thermal processing .Ohmic heating is an alternative heating system for pumpable foods which is based on the passage of electrical current through a food product which serves as an electrical resistance . Ohmic heating relies on direct resistive heating of foods which occurs when an alternating current is passed through the food in which the food is made a part of an electrical circuit. Heat generation takes place volumetrically within the food because of its inherent electrical resistance which gives an advantage of uniform and rapid heating. Heat is generated inside the product rather than being conducted or radiated from outside. This makes ohmic heaters an excellent choice for products where traditional heat exchangers can lead to problems such as fouling, overheating leading to product quality reduction and where products are difficult to heat because of larger solid content.

For the study to be conducted fresh passion fruit pulp was purchased and was stored in well sterilised air tight bottles in deep freezer.For ohmic heating,an ohmic heating system consisting of ohmic heating chamber along with two electrodes, power supply system, variable transformer, ammeter and voltmeter is used. A Teflon coated thermocouple is inserted into the chamber to measure the temperature. The fresh passion fruit pulp was fed to the ohmic heating and pulp sample was treated by applying three different levels of voltages, temperatures and holding times by adjusting the voltage supply using the variable transformer. The treated samples were collected in sterile amber colored PET bottles and stored in refrigerated condition at 4±2°C.

After treatment the physicochemical properties *viz.* TSS, titrable acidity, ascorbic acid content, and color of treated fruit juices were analysed to optimise the process parameters of ohmic heating process.The bacterial population for the optimised sample was also found.

The results were presented and discussed using tables and graphs. Graphs were plotted for different voltage,temperature and holding time combnations. From theresults it was found that ascorbic acid was slightly decreasing.It might be due to the heat sensitive nature of ascorbic acid compounds. In this study the overall reduction in ascorbic acid content of the passion fruit pulp were minimum, compared to that of other thermal processing technologies, due to the mild conditions such as lower temperature and voltage employed.

Color parameters such as L* and b* values were found to be slightly decreasing while a* values was found to be slightly increasing.This might be due to the degradation of color compounds in passion fruit pulp during ohmic heating.

The TSS of the passion fruit pulp was found to be increased with increase in voltages, holding time and process temperature for passion fruit pulp. This might be due to boiling of pulp with increase in heating which will in turn increases the solute concentration. The conversion of organic acids to sugar could also be a reason for the modification of TSS contentThe titrable acidity of passion fruit pulp was found to be not much affected by ohmic heating treatment.

The microbial count was found to be decreased by 2 log reduction in ohmic heated sample. It might be due to heat generation and electroporation effect during ohmic heating.

The sensory evaluation results showed that the taste, flavour, color and overall acceptability of ohmic heated passion fruit pulp was found to be similar to fresh passion fruit pulp.

The statistical analysis for optimising the process variables of ohmic heating system was performed through Response Surface Methodology (RSM) using Design Expert and from the results,a voltage of 185.34 V, process temperature of 60.26°C and holding time of 2.32 min was found to be the optimal condition for ohmic heating treatment of passion fruit pulp.

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APPENDICES

APPENDIX A

Appendix A.1. Analysis of variance (ANOVA) for TSS

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	16.68	9	1.85	9.28	0.0039	significant
A-Voltage	0.5356	1	0.5356	2.68	0.1455	
B-Temperature	6.98	1	6.98	34.93	0.0006	
C-Holding Time	6.48	1	6.48	32.45	0.0007	
AB	0.0012	1	0.0012	0.0061	0.9398	
AC	0.0900	1	0.0900	0.4507	0.5235	
BC	1.69	1	1.69	8.46	0.0227	
A^2	0.3331	1	0.3331	1.67	0.2375	
B^2	0.5725	1	0.5725	2.87	0.1342	
C^2	0.0432	1	0.0432	0.2162	0.6561	
Residual	1.40	7	0.1997			
Lack of Fit	0.7497	3	0.2499	1.54	0.3340	not significant
Pure Error	0.6480	4	0.1620			
Cor Total	18.08	16				

Std. Dev.	0.4469	**R^2**	0.9227
Mean	16.48	**Adjusted R^2**	0.8233
C.V. %	2.71	**Predicted R^2**	0.2805
		Adeq Precision	10.7012

Appendix A.2. Analysis of variance (ANOVA) for titrable acidity

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0435	9	0.0048	0.7407	0.6701	not significant
A-Voltage	0.0002	1	0.0002	0.0350	0.8570	
B-Temperature	0.0012	1	0.0012	0.1819	0.6825	
C-Holding Time	0.0104	1	0.0104	1.60	0.2466	
AB	0.0050	1	0.0050	0.7646	0.4109	
AC	0.0003	1	0.0003	0.0483	0.8323	
BC	0.0056	1	0.0056	0.8537	0.3862	
A^2	0.0027	1	0.0027	0.4106	0.5421	
B^2	0.0005	1	0.0005	0.0741	0.7933	
C^2	0.0172	1	0.0172	2.63	0.1486	
Residual	0.0456	7	0.0065			
Lack of Fit	0.0336	3	0.0112	3.74	0.1176	not significant
Pure Error	0.0120	4	0.0030			
Cor Total	0.0891	16				

Std. Dev.	0.0807	**R^2**	0.4878
Mean	1.57	**Adjusted R^2**	-0.1707
C.V. %	5.13	**Predicted R^2**	-5.2513
		Adeq Precision	2.7742

Appendix A.3. Analysis of variance (ANOVA) for ascorbic acid

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	22.34	9	2.48	11.91	0.0018	significant
A-Voltage	4.20	1	4.20	20.17	0.0028	
B-Temperature	7.63	1	7.63	36.64	0.0005	
C-Holding Time	6.80	1	6.80	32.62	0.0007	
AB	0.6053	1	0.6053	2.90	0.1321	
AC	0.4219	1	0.4219	2.02	0.1978	
BC	1.47	1	1.47	7.07	0.0325	
A^2	0.1354	1	0.1354	0.6500	0.4466	
B^2	1.08	1	1.08	5.18	0.0570	
C^2	0.0154	1	0.0154	0.0737	0.7938	
Residual	1.46	7	0.2084			
Lack of Fit	0.9305	3	0.3102	2.35	0.2138	not significant
Pure Error	0.5282	4	0.1320			
Cor Total	23.80	16				

Std. Dev.	0.4565	**R^2**	0.9387
Mean	19.77	**Adjusted R^2**	0.8599
C.V. %	2.31	**Predicted R^2**	0.3397
		Adeq Precision	12.4429

Appendix A.4. Analysis of variance (ANOVA) for L*

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	41.42	9	4.60	5.48	0.0177	significant
A-Voltage	17.20	1	17.20	20.48	0.0027	
B-Temperature	5.18	1	5.18	6.17	0.0419	
C-Holding Time	0.8646	1	0.8646	1.03	0.3441	
AB	1.02	1	1.02	1.21	0.3069	
AC	0.3660	1	0.3660	0.4358	0.5303	
BC	2.79	1	2.79	3.32	0.1112	
A^2	7.46	1	7.46	8.88	0.0205	
B^2	0.6511	1	0.6511	0.7752	0.4078	
C^2	6.57	1	6.57	7.82	0.0266	
Residual	5.88	7	0.8399			
Lack of Fit	4.61	3	1.54	4.84	0.0809	not significant
Pure Error	1.27	4	0.3175			
Cor Total	47.30	16				

Std. Dev.	0.9165	**R^2**	0.8757
Mean	43.75	**Adjusted R^2**	0.7159
C.V. %	2.09	**Predicted R^2**	-0.6011
		Adeq Precision	9.4857

Appendix A.5. Analysis of variance (ANOVA) for a* value

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	27.03	9	3.00	332.97	< 0.0001	significant
A-Voltage	12.38	1	12.38	1371.88	< 0.0001	
B-Temperature	3.15	1	3.15	349.20	< 0.0001	
C-Holding Time	6.11	1	6.11	677.05	< 0.0001	
AB	0.8742	1	0.8742	96.91	< 0.0001	
AC	0.2025	1	0.2025	22.45	0.0021	
BC	0.8742	1	0.8742	96.91	< 0.0001	
A^2	1.59	1	1.59	176.25	< 0.0001	
B^2	1.00	1	1.00	111.16	< 0.0001	
C^2	0.9480	1	0.9480	105.09	< 0.0001	
Residual	0.0631	7	0.0090			
Lack of Fit	0.0088	3	0.0029	0.2166	0.8803	not significant
Pure Error	0.0543	4	0.0136			
Cor Total	27.10	16				

Std. Dev.	0.0950	**R^2**	0.9977
Mean	14.17	**Adjusted R^2**	0.9947
C.V. %	0.6703	**Predicted R^2**	0.9917
		Adeq Precision	58.4637

Appendix A.6. Analysis of variance (ANOVA) for b* value

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	76.47	9	8.50	6.22	0.0124	significant
A-Voltage	32.08	1	32.08	23.50	0.0019	
B-Temperature	6.98	1	6.98	5.11	0.0583	
C-Holding Time	33.99	1	33.99	24.90	0.0016	
AB	1.421E-14	1	1.421E-14	1.041E-14	1.0000	
AC	0.0144	1	0.0144	0.0105	0.9211	
BC	0.7140	1	0.7140	0.5231	0.4930	
A^2	1.14	1	1.14	0.8349	0.3913	
B^2	0.0166	1	0.0166	0.0121	0.9153	
C^2	1.68	1	1.68	1.23	0.3035	
Residual	9.56	7	1.37			
Lack of Fit	7.87	3	2.62	6.23	0.0547	not significant
Pure Error	1.68	4	0.4211			
Cor Total	86.03	16				

Std. Dev.	1.17	**R^2**	0.8889
Mean	61.00	**Adjusted R^2**	0.7461
C.V. %	1.92	**Predicted R^2**	-0.4945
		Adeq Precision	9.0700

APPENDIX B

Score card for sensory evaluation

SENSORY SCORE CARD

Department of Processing and Food Engineering

K.C.A.E.T,Tavanur

Name of judge : **Date:**

You are requested to assess the product in terms of general acceptability on a 9 point hedonic scale.

Characteristics	**Sample 1**	**Sample 2**
Color & appearance		
Flavor		
Taste		
Overall acceptability		

Score System:

Dislike extremely	: 1	Like slightly	: 6
Dislike very much	: 2	Like moderately	: 7
Dislike moderately	: 3	Like very much	: 8
Dislike slightly	: 4	Like extremely	: 9
Neither like nor dislike	: 5		

Comments if any :

Signature :

EVALUATION OF OHMIC HEATING SYSTEM FOR PRESERVATION OF PASSION FRUIT PULP

By

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ABSTRACT OF PROJECT REPORT

Submitted in partial fulfilment of the requirement for the degree of

Bachelor of Technology

In

FOOD ENGINEERING AND TECHNOLOGY

(**Department of Processing and Food Engineering**)

Faculty of Agricultural Engineering & Technology

DEPARTMENT OF PROCESSING AND FOOD ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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2022

ABSTRACT

Passion fruit,a flowering tropical vine that grows in warm climate has recently gained a lot of attention because of its rich source of powerful antioxidants and healthful nutrition profile.Due to its perishable nature, the need for its processing is also increasing.For this purpose several non-thermal and thermal techniques are gaining attention all over the world.One among them is Ohmic heating.Ohmic heating with its many advantages, is a volumetric heating mechanism,where food is heated by its electrical resistance.Inoder to preserve passion fruit pulp with higher retention of its nutritional value,ohmic heating was applied using an ohmic heating system consisting of ohmic heating chmber,electrodes,variable transformer and control panel.The effect of ohmic heating parameters – voltage , temperature and holding time on different physicochemical properties of passion fruit pulp was also studied and the optimal condition for ohmic heating treatment of passion fruit pulp with minimal losses was found. Also the microbial population of the optimized sample was determined. From the results obtained it was concluded that the increase in ohmic heating parameters has caused an decrease in ascorbic acid,L* and b* values of passion fruit pulp while TSS and a* values of the pulp was found to be increasing.The ttrable acidity of the pulp was not much affected by ohmic heating. By analyzing the results a voltage of 185.34 V, process temperature of 60.26°C and holding time of 2.32 min was found to be the optimal condition for ohmic heating treatment of passion fruit pulp The microbial population was found to be significantly low in treated sample.So by using the optimal conditions,ohmic heating can be successfully used for preservation of passion fruit pulp with minimum losses.