DEVELOPMENT AND EVALUATION OF PROTEIN ENRICHED RTE EXTRUDED FOOD PRODUCTS

By

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(2017-18-001)

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THESIS

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KERALA, INDIA
2019

DECLARATION

I, hereby declare that this thesis entitled **"Development and evaluation of protein enriched RTE extruded food products"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Tavanur **ATHIRA K**

Date**:** **(2017-18-001)**

CERTIFICATE

Certified that this thesis entitled **"Development and evaluation of protein enriched RTE extruded food products"** is a bonafide record of research work done independently by **Ms. Athira K** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Dedicated to
My beloved family

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SYMBOLS AND ABBREVATIONS

% : Per cent

/ : Per

± : Plus or minus sign

≤ : Less than or equal to

≥ : Greater than or equal to

°C : Degree centigrade

ANOVA : Analysis of variance

AOAC : Association of Official Analytical Chemists

a* : Greenness or redness

B : Bengal gram flour

b* : Blueness or yellowness

cfu : Colony forming unit

cm : Centimetre

cm^3/g : Cubic centimeter per gram

et al. : And others

etc. : Etcetera

Fig.	:	Figure
G	:	Ground nut flour
g	:	Gram
g/cm^3	:	Gram per centimeter cube
g/g	:	Gram per gram
g/ml	:	Gram per milliliter
h	:	Hour
H_2SO_4	:	Sulphuric acid
HCL	:	Hydrochloric acid
HDPE	:	High density polyethylene
ISS	:	Indian standard sieve
i.e.	:	That is
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
kcal	:	Kilo Calories
kg	:	Kilogram
kg/h	:	Kilogram per hour
kJ	:	Kilo Joule

kJ/100 g	:	Kilo Joule per 100 gram
LA	:	Laminated aluminum
LDPE	:	Low density polyethylene
L*	:	Lightness or darkness
Ltd.	:	Limited
MAP	:	Modified atmospheric packaging
MC	:	Moisture content
mg	:	Milligram
mg/100 g	:	Milligram per 100 gram
min	:	Minute
ml	:	Milliliter
mm	:	Millimeter
mm/s	:	Millimeter per second
N		Newton
N_2	:	Nitrogen
No.	:	Number
PP	:	Polypropylene
pps	:	Parts per second
R	:	Rice four

RARS	Regional Agricultural Research Station
Rg	Ragi flour
rpm	Revolution per minute
Rs	Rupees
RSM	Response surface methodology
RTC	Ready to cook
RTE	Ready-to-eat
S	Soybean flour
s	Second
Sl.	Serial
TPC	Total plate count
V	Volts
viz	Namely
WAI	Water absorption index
WSI	Water solubility index
w.b.	Wet basis
Yr	Year

CHAPTER I

INTRODUCTION

Nutrition is a significant aspect that determines the association of public with the environment and is critical for health, efficiency and resistance to harmful surrounding effects. At present, majority of the world population suffers from quantitative and qualitative insufficiency of energy and dietary nutrients. It weakens the physiological maintenance and growth of body which promote malnutrition. Protein energy malnutrition is a serious threat which accounts for half of the deaths of children under 5 years of age especially in developing countries (Pathak and Kochhar, 2018).

Diets of poor income groups are lacking lot of nutrients such as protein, iron, calcium, vitamin A and B. Dietary deficiencies of these nutrients are more among children, pregnant and lactating women whose requirements of nutrients are higher than others. Deficiency of these nutrients in their diet is leading to diseases like protein energy malnutrition. According to Global Nutrition Report (2017), India has a large number of populations suffering from different type of malnutrition. The energy requirement recommended by Indian council of medical research for boy, girl (upto 12 yr), adult men and adult women is 2190 kcal/day, 2010 kcal/day, 2730 kcal/day and 2230 kcal/day but these requirements not satisfied due to malnutrition especially in children. Fortification or combination of two or more food ingredients can make a solution for this nutritional deficiency to a certain extent. Cereal based food products are rich in carbohydrates and energy but they are deficient in terms of protein. Food products with improved nutritional profile can be produced by blending legumes (protein rich food) and cereals (carbohydrates rich food) (Balasubramanian *et al.,* 2012).

Most of the weaning foods are mainly prepared by using locally available cereals (rice, wheat, maize etc.) that are processed into porridges (Ljungqvist *et al.,* 1981). But these cereal based foods have reduced nutritional quality and they do not accomplish the protein and other nutrients requirements and finally leads to protein energy malnutrition. The best strategy to correct the nutrition deficiencies is food based approach where supplementary foods are developed by blending nutrient rich familiar foods which is referred as food fortification (Egounlety, 2002). Enhancement of nutritional value of conventional weaning mixes is attained by the addition of commonly accessible protein-rich resources like pulses and proteinized seeds with cereals (Ojofeitimi *et al.,* 1984).

Snack industry is a rapid developing food sector and is a significant donor in worldwide convenience food market. In India, ready to eat snacks and convenience snacks are more popular among the consumers. Properly developed snack foods can create a vital improvement in societies where social modifications are changing the usual way of food formulation. Maintaining and accelerating nutritional characteristics of food throughout processing is usually a key section of research. The traditional cooking methods utilize high temperature leading to loss of nutritional qualities of food materials (Singh *et al.,* 2007). Most of the commercially available snacks are produced by deep frying method. However, it uses very high temperature under atmospheric pressure, causing increased oil uptake in the final product. High oil uptake in fried snacks is related with number of health problems such as obesity, cardiovascular diseases, cancer, hypertension and other health problems and is incompatible with recent consumer trends.

Extrusion cooking is a well known method for developing ready to eat (RTE) snack foods from cereals and plant protein food stuff, perceives evoked substantial curiosity and attraction over the last 30 years. Extrusion cooking has a remarkable place in food processing industry and it has been adapted over 50 years. In extrusion processing, pre-conditioned raw materials are allowed to pass under a set of processing situations through a narrow shaped hole (die) at a controlled rate to attain different products (Ajitha and Jha, 2017a). Extrusion is one of the commonly adopted processing techniques by food industries which employs unit operations like mixing, forming, texturing and cooking to develop a novel food product (Singh *et al.,* 2007). Single screw/twin screw extruder is used for the manufacture of extruded snacks. It has been used amply in the food industry to process a variety of raw materials into RTE/ready to cook foods, including breakfast cereals, snacks, pastas, meat products etc. In older days the application of extruder is limited to the development of macaroni and ready to eat cereal pellets, but nowadays this "HTST (high temperature short time)" process is considered to be a dominant food processing techniques which convert basic raw components into reshaped, transitional and finished substances (Alam *et al.,* 2016).

In extrusion cooking, the food material undergo structural, chemical and nutritional changes like starch gelatinization and degradation, protein denaturalization, lipid oxidation, degradation of vitamins, anti nutritious and photochemical, formation of flavours, increase of mineral bio availability and dietary fibre solubility due to thermal and shear energy application. Extrusion is a multi step process which includes mixing, grinding, shearing, starch cooking, protein denaturation, texture alteration, enzyme inactivation, thermal cooking, shaping products, expansion and puffing. During extrusion operation the ingredients are mixed mechanically and due to elevated temperature and pressure food material is cooked and is exposed to shear which produced in the screw barrel assembly. The cooked products of desired shape is obtained when it pass through the die (Arhaliass *et al.,* 2003).

Extrusion cooking is suitable for the manufacture of a wide variety of food products such as cereal based foods, protein supplements and sausage products, pasta, breakfast cereals, bread crumbs, biscuits, crackers, croutons, baby foods, snacks foods, confectionary items, chewing gum, texturized vegetable protein, modified starch, pet foods, dried soups and beverage mixes (Chang and Ng, 2009). It had several advantages like high capacity, continuous operation, automated control, high productivity, versatility, adaptability, energy efficiency and low cost. Furthermore, it is also capable for the formulation and production of new food products with high nutrient quality, particular product shape and features and no effluent generation (Faraj *et al.,* 2004). Extrusion process also facilitate modification of structural components, increasing solubility, swelling power, water hydration viscosity and water holding capacity (Rouilly *et al.,* 2006). RTE products have very less water content and water activity making the products shelf secure. Shelf secure, nutrient rich products considered to be idyllic to eradicate malnutrition in the developing world. These healthy snacks will provide sufficient macro and micronutrients remarkably to the nutritionally susceptible segment of population. In this context, extrusion is one of the commonly adopted processing techniques by food industries. By extrusion cooking, a nutritionally balanced RTE food product can be developed by fortifying both cereals and legumes which ensures adequate food security to all age groups.

In this background, the present investigation entitled “Development and evaluation of protein enriched RTE extruded food products” was undertaken with the following objectives.

1. To standardise the composition of RTE food from ragi flour, rice flour, soybean flour, bengal gram flour and groundnut flour

2. To optimise the extrusion process parameters *viz.,* moisture content of feed, screw speed and barrel temperature for the production of RTE extruded food

3. Shelf life studies and quality analysis of the developed extruded food

CHAPTER II

REVIEW OF LITERATURE

This section reviews the research work done by several researchers on application of hot extrusion processing to develop extruded products. Literature related to physical, functional and textural properties of extruded RTE products and its shelf life studies are also reviewed.

2.1. MALNUTRITION

Malnutrition is defined as a pathological condition occurring due to relative or complete deficit of a particular or many nutrients. It is a state of physiological inequality that generated due to poor eating of food in terms of quantity and quality (Soeters *et al.,* 2017). Protein energy malnutrition is a serious health burden especially in developing countries. According to WHO, about 60% of all death happening children of less than 5 years can be attributed to malnutrition (Chauhan *et al.,* 2015). Even though the world has progressed technologically and economically, still in 2010, globally there were 155 million children (age <5 years) stunted, 52 million wasted, and 41 million overweight (Victora *et al.,* 2010).

2.2. FOOD FORTIFICATION

In developing countries weaning foods are mainly prepared by using locally available cereals that are processed into porridges (Ljungqvist *et al.,* 1981). But these cereal rich gruels have less nutritional quality and finally lead to the occurrence of PEM (protein energy malnutrition), which is a main reason for elevated infant mortality rate in developing countries (Eka, 1978). Enhancement of traditional weaning foods can be attained by the blending of commonly obtainable protein-rich materials like grain legumes and proteinized seeds with cereals (Ojofeitimi *et al.,* 1984).

2.3. CONVENTIONAL SNACKS

Most of the Indian conventional snack foods are developed using cereals, legumes and spices. The developing processes of these snacks consist of cleaning, pretreatment, soaking, roasting, frying etc.

Murukk is a well known snack in India with various names such as *chakli* in Marathi and Kannada and *chakri* in Gujarat and *murkoo* in Tamil. This snack is prepared from a mix of *Urad* (Black gram), rice flour, salt, and flavourings elements like chilli or cumin. The paste prepared with rice powder is squeezed out in particular shapes and then fried in oil. Crispy *murukku* having shape of little coils are mainly popular especially in southern region of India. The pulse - rice flour mixture is made into a batter, mechanically extruded, formed into a spiral or coil, and fried to a crisp. *Murukku* can be rolled into a flat ribbon shape (ribbon Murukku) or shaped by hand (kai Murukku). *Murukku* is usually enjoyed for its crunchy texture and better taste (Ravi *et al.,* 2011).

Papad is a popular snack food of India. It is indigenous traditional snack food item which is wafer like product prepared from variety of ingredients. These are made from blends of pulse flour, cereal flour and edible starches with other ingredients (Veena *et al.,* 2012). Starchy flours are blended with water to form a slurry and then allowed to ferment, after that cooked and spread as thin sheets. The cooked slurry may also be extruded to a noodle-like structure, dried, and stored. Papads may be roasted or fried prior to consumption (Srinivasan, 2010).

Wadis is another type of snack food which is popular in India. They are mainly made from pulses and cereals. Pulses are soaked and coarsely ground after draining excess water; mixed with shredded vegetables and allowed to ferment overnight. After that cooked and mixed with salt and spices; deposited as small masses or balls and dried. The dried product is fried before consumption (Srinivasan, 2010).

Fermented batter foods from cereals and legumes are the most popular and nutritious Indian traditional breakfast foods in the southern region of India. These include *dosa* (a pancake made from a fermented batter of rice and black gram (3:1), *idli* (steamed rice cakes made from a fermented batter of rice and black gram (2:1), and *vada* (a deep-fried doughnut made from a batter of lentils, usually black gram) (Sarkar *et al.,* 2015).

2.4. COOKING METHODS FOR SNACK PRODUCTION

Different types of heat utilizing process are employed for the commercial production of snack foods. Among these, baking is the major one. Damage of one or more nutrients often taking place during the baking process. Baking is negatively affect the nutrient components which is more intense in the crust portions since the interior (crumb) of most baked foods rarely approaches the oven temperature (Bembem *et al.,* 2018).

Frying is very common process for snack production. The high temperature and short transit time of the frying process cause less loss of heat labile vitamins than other types of cooking. Even though when oil is heated to a high temperature for a long period of time, toxic aldehydes are formed, which will cause an increased risk of cancer and other diseases. Drying and dehydration also utilized for snack production (Bembem *et al.,* 2018).

2.5. READY TO EAT (RTE) FOODS

“Ready-to-eat (RTE)” foods are more accepted among the consumers, mainly because of their ease of consumption and simplicity in preparation and storage and also consumer satisfaction like convenience, value, appealing appearance and better texture (Harper, 1981).

The Food Standards Agency (FSA, UK) states that any food products for eating without additional heating or processing can be regarded as RTE foods. This statement includes both open and pre-wrapped food items and it may be consumed hot or cold (Food Standards Agency, 2011). Large number of foods like biscuits, pies, crisps, breads, sandwiches and rolls, dairy food products (milk, cheese, spreads), prepared salads and vegetables, and fruit can also be included in RTE food group. The list of RTE foods can be exceptionally large and with new food items are coming in to the food marketplace nearly each day and the list is getting bigger and bigger (Fast, 1999).

The cereal RTE section is considered as the most significant sectors of the RTE food product market. This is traditionally controlled by extruded snack items, breakfast cereals, extruded cereal shapes, biscuits and bars (Bernnan *et al.,* 2013).

2.6. RAW MATERIALS FOR RTE PRODUCTS

2.6. 1. Rice

Rice (*Oryza sativa*) is the most important cereal crop which serves as a staple food for majority of the world population. Rice is known as the grain of life and is synonymous with food for Asians and provides 80% of their energy requirements (Chaudhari *et al.,* 2018). Hundred gram of rice contain 1,527 kJ (365 kcal) energy, 77.40 g carbohydrates, 0.12 g sugar, 1.30 g dietary fibre, 0.66 g fat, 8.50 g protein, 11.61 g water, 10 mg calcium, 2.80 mg iron, 9 mg carotene. Rice also contains vitamins as riboflavin 0.0149 mg, niacin 1.62 mg, thiamine 0.27 mg. Health benefits of rice comprise of its capability of supplying fast and instant energy, balance blood sugar level and it is great supplier of vitamin B1 to the human body. Further benefits consists of its capacity to enhance skin health, intensify the metabolism, decrease high blood pressure, build up immune system and give protection against cancers and heart diseases (Chandrashekaran *et al.,* 2008).

2.6.2. Finger Millet

Finger millet (*Eleusine coracana*) also called ragi which has sixth position in India in terms of production after wheat, rice, maize, sorghum and bajra. It is abundant in carbohydrate, protein, calcium, dietary fibre, iron, minerals and less fat.

It is a fundamental food for those peoples suffering from metabolic disorders like diabetes and obesity. Ragi is well known for its least allergic and most digestible properties. Nutritionally, its importance is well recognized due to its high content of dietary fibre (18%), calcium (0.38%) and phenolic compound (0.03 to 3%). 100 g of ragi contains 7.7 g protein, 2.7 g ash, 1.5 g fat, 72.6 g total carbohydrate, 3.6 g crude fibre (Devi *et al.,* 2014). Finger millet has many health benefits such as it is nutritious and simple to digest, encourage healthy eating, promote natural weight loss, helps to keep optimum sugar level in the blood and acts as a good infant food due to its unique nutrient characteristics. It is also recognized for its health beneficial effects, such as anti-diabetic, anti-tumorigenic, atherosclerogenic effects, antioxidant and antimicrobial properties (Mathanghi and Sudha, 2012).

2.6.3. Bengal Gram

Bengal gram also called as garbanzo bean or chickpea is one of the important pulse which plays a vital role in the diets of vegetarians around the world. India is the largest chickpea producing country which provides approximately 66% of global production. The chemical composition of chickpea flour consist of 24.4-25.4% of protein, 47.4-55.8% of carbohydrates, 3.7-5.1% fat, 3.9-11.2% fibre and 3.2-2.8% ash (Rachwat *et al.,* 2013). Chickpea has predominant amount of most of the essential amino acids except sulfur containing types and it also a good source of vitamins such as riboflavin, niacin, thiamin and vitamin A precursor, β- carotene. The minerals such as calcium, magnesium, phosphorous and potassium also present in chickpea. Chickpea has several potential health benefits and in combination with other pulses and cereals, it could have beneficial effect on some of the important human diseases like cardiovascular diseases, type 2 diabetes, digestive diseases and some cancer (Jukantil *et al.,* 2012).

2.6.4. Groundnut

Groundnut (*Arachis hypogaea* L.) or peanut is one of the important oil seed crop which is a great source of protein. Peanut have very good nutritional profile and are rich in vitamins, minerals and bioactive materials (Win *et al.,* 2011). The partial extraction of oil from peanut leads to the production of peanut flour which is well accepted with chefs due to its high protein content makes it suitable as a flavour enhancer. Defatted peanut cake flour extensively used in the preparation of variety of food products and when it fortified with cereal flour to yield products with exceptional flavour, texture and colour. Due to its unique nutritional properties it has been used in the diets of cardio vascular disease, celiac disease and in the diets of malnourished. The peanut flour contains 45-60% protein, 22-30% carbohydrates, 3.8-7.5% crude fibre and 4-6% minerals (Desai *et al.,* 1999).

2.6.5. Soybean

Soybean (*Glycine max*) is a significant and economical food crop which is a good source of basic nutrients including protein, fat, dietary fibre, vitamins, minerals, soy saponins and isoflavones (Kang *et al.,* 2017). The fat present in soybean is removed and the remaining products is known as deffated soy flour, that can be used to develop high protein, low fat diet food and due to its unique nutritional profile it serve as promising protein source for the future (Singh *et al.,* 2008). The chemical composition of deffated soy flour consists of about 50.5% protein, 1.5% fat, 5.8% ash and 34.2 % carbohydrates (Mustakas, 1971). Soybean have several health benefits and it provides protection against heart disease, cancer, cardiovascular disease, diabetes, asthma, cancer, osteoporosis and bowel and kidney diseases (Bolla, 2015).

2.7. EXTRUSION COOKING

Extrusion is a commonly adopted processing techniques by food industries as efficient manufacturing processes. It contains screws having higher tolerance revolving inside a barrel. Raw ingredients with appropriate water content are transferred into the extruder, where cooking of the food material occurred due to viscous shear and heat generated and then the food materials are moved towards the die section. This process causes rise in temperature and pressure. Food materials expand largely because of flashing of moisture vapour as the dough exits the die (Smith, 1971).

Harper (1981) emphasized the significance of extrusion cooking over convectional cooking methods due to its versatility, efficiency and economy of space and labour. Transport of material through extruders depends mainly on friction at the barrel surface. Harper and Jansen (1985) concluded that material flows forward (drag flow) owing to the action of screw and to a lesser extent, backwards along the barrel (pressure flow and leakage flow). The role of the screw is to convey, compress, melt and plasticize the material and to force it under pressure through small die holes at the end of the barrel. The screw has a number of sections, including a feed section/ solid conveying to compress particles in to a homogenous mass, a kneading/melting section to compress, mix and shear the plasticized food and in high shear screws, a metering/cooking section (Leszek and Zuilichem, 2011). Pressure flow is occurred due to the build-up of high pressure behind the die and by material movement between the screw and barrel. Slipping can be minimised by special groves on the inside of the barrel.

Extrusion cooking is superior over other food processing technique due to its unique characteristics such as uninterrupted process having greater productivity and also considerable nutrient retension, owing to the large temperature and lesser time needed and it offers advantage of preparation of RTE foods of desired size, shape, texture and sensory characteristics at low processing cost (Guy, 2001). In developing economies, to eradicate poverty and achieve food and nutrition security, more effort is needed in harnessing extrusion technology for producing safe food utilizing locally grown legumes and cereal grains (Filli *et al.,* 2014).

Extrusion is mainly classified into two groups depending on temperature (hot and cold extrusion). If the food material is heated below 100°C, then the process is termed as cold extrusion. Typical food products include pasta, pet food etc. If the food is heated above 100°C, the process is termed as hot extrusion (or extrusion cooking). Typical products include a wide variety of ready to eat (RTE) puffed cereals and expanded snack foods (Bordoloi and Ganguly, 2014).

Using cold extrusion generally ready to cook (RTC) food products such as pasta, noodles etc are developed. Pasta, with its origin in Italy has gained large fame as a convenient and nutritionally palatable, low glycemic food. Consumers are more and more concerned in foods containing healthy ingredients (Marchylo *et al.,* 2001).

2.8. BENEFITS OF EXTRUSION COOKING

Extrusion is a versatile cooking process with a wide scope in product texture, ingredient utilization, product forms and densities. It may be controlled over a wide range of processing conditions; the product reaches sterilization in most of the cases due to high temperature and pressure involved (Williams, 1977). There has been substantial attention in High-Temperature Short-Time (HTST) extrusion technology in food processing because of the flexibility and ease of obtaining products which require minimum drying.

Bhattacharya and Hanna (1985) reported that extrusion cooking improved both protein digestibility and water holding capacity. As well as the usual benefits of heat processing, extrusion cooking offers the probability of modifying the functional properties of food ingredients and/or of texturizing them (Cheftal, 1986). Extrusion technology has many unique advantages like versatality, low cost, better product quality and no process effluents (Camine *et al*., 1990).

Extrusion cooking is a multivariable unit operation which includes number of processes such as blending, shearing, cooking, expanding and drying. It is very energy efficient, fast and incessant method. The benefits of this process also include gelatinization of starch constituents, alteration of lipids, denaturation of proteins, inactivation of microbes, enzymes and also several anti nutritional factors (Banerjee *et al.*, 1998). Konstance *et al.* (1988) concluded that, the merits of an extruded food item would be the removal of extended cooking by the customer and lesser loss of nutrients.

2.9. EXTRUSION PROCESSING PARAMETERS

The process variables that are straightly control quality aspects of the product are termed as independent variables. Alterations made into these independent variables will influence the functional properties of extrudates and process data i.e., dependent variables (Banerjee *et al.*, 1998).

Empirical studies have showed that moisture content and extrusion temperature are the most significant variables affecting expansion in any particular system (Lawton *et al.*, 1972). Water clearly plays a vital role in the expansion process and strongly affects degree of gelatinization along with other components (Mercier and Feillet, 1975). For a given design and feed material, the product characteristics are largely determined by mass moisture, shear (screw speed), temperature, moisture profiles and residence time distribution (Linko *et al.*, 1984).

In starchy extrudates, like expanded snacks and RTE cereals, density and mechanical properties of dry materials are the main considerations in packaging and shipping; while density, rate and extent of hydration and solubility are important to mouth feel (Phillips *et al.*, 1984).

The sensory attributes of extruded products, which are very important when considering consumer acceptability and they are depends mostly on the physical characteristics. These characteristics are depends upon the extruder operating conditions and the major raw material utilized in the formulations (Sanderude, 1969) and moisture content (Faller *et al.*, 1999) of the formulation.

2.10. PHYSICAL PROPERTIES OF EXTRUDATES

2.10.1. Moisture Content

Residual moisture of extrudates is important when considering drying and storage. Low moisture extrusion requires less drying of the product, which results in saving of energy and better shelf life. The extruded product moisture was flashed off upon emergence from the die (Miller, 1985). So that the final moisture content of the extruded product will always be lesser than that of feed material.

Ansah *et al.* (1982) explained the impact of extrusion parameters on final product moisture and extrusion crystallinity of corn extrudates and reported that both feed moisture and temperature had a significant effect on final extrudate moisture content. The effect of screw speed was significant only if the effect of both temperature and moisture content was removed.

The residual moisture of extrudates is affected by the extrusion process conditions. Moisture content of feed material has most significant effect on extrudate moisture. As moisture of feed increased, extrudate with higher moisture was obtained (Badrie and Mellows, 1991b)

Lo *et al*. (1998) reported that molten corn meal at a higher temperature has higher potential energy to flash off super heated water as it leaves the die. Therefore a high temperature process produced extrudates with low moisture content and higher screw speed also produced extrudates with lower moisture content.

Rice- fish based extrudates were developed by Rajesh *et al*. (2014) and explained the impact of process parameters viz temperature, feed moisture content and fish content in feed on final moisture content of the extrudates. The study indicated that final moisture content of the product varied from 6.60 to 8.75% and concluded that final moisture content was raised with increment in feed moisture and fish content but decreased with increment in temperature.

2.10.2. Water Activity

Water activity is an essential element, as it influences the activity of enzymes, vitamins, shelf life and color of food items over time. Water activity is a measure of the accessible free water presented in the material. It is one of the main factor in controlling spoilage, since it indicates the lowest limit of accessible water for microbial growth. (Lowe and Kershaw, 1995).

Fallahi *et al.* (2013) reported that water activity of extrudates from distillers dried grains increased with increasing water content. Water activity also increases with screw speed up to a limit and then decreased.

Foley and Rosentrater (2013) reported that water activity of the extrudates decreases with increasing extrusion temperature for corn based extrudates.

2.10.3. Expansion Ratio

The primary physical characteristic of an extruded food product is its puffing characteristics. Conway and Anderson (1973) reported that the final product density, tenderness and fragility are highly depending up on the extent of expansion. The expansion ratio is defined as the "ratio of diameter of the extruded product to diameter of the die" (Gujska and Khan, 1990; Artz *et al*., 1990; Onwaluta *et al*., 1998).

Gujral *et al.* (2001) evaluated the effect of extrusion parameters such as temperature (100-150°C), screw speed (100-150 rpm) and feed moisture (16-24%) on flint and sweet corn grits based extrudates and reported that expansion of extrudates decreased with the increase in feed moisture and extrusion temperature and also an increase in screw speed resulted in an increasing expansion. Extrudates from sweet corn had greater expansion than extrudates from flint corn.

Charunuch *et al.* (2003) investigated the potential of two varieties of Thai brown rice as main raw supplies for the development of extruded snack. Three varying screw speed (250, 300 and 350 rpm) and feed moisture (13, 15 and 17%)

were used for extrusion. The results pointed out that major factor (screw speed or feed moisture) had predominant impact on physical characteristics of extrudates by indicating that lowering feed moisture from 17 to 13% or increasing screw speed from 250 to 350 rpm developed more expandable extrudates with larger expansion ratio, WSI and lesser bulk density and also broad peak in textural measurement. Extruded snack prepared at 13% feed moisture and 350rpm screw speed showed required nutritional quality and acceptability.

Mezreb *et al*. (2003) evaluated the effect of screw speed on the physical properties of wheat and corn based exrudates. The extrusion process was carried in a co rotating twin screw with three different screw speeds (200, 300 and 500rpm). The result indicated that for wheat extrudates, the sectional expansion index initially increased from 9.15 to 10.54 as the screw speed increased from 200 to 300 rpm, and then decreased to near the initial expansion for a speed of 500 rpm and for corn extrudates, longitudinal expansion increases with increment in screw speed.

Seth *et al.* (2015) studied the effect of yam flour (10-40%), feed moisture content (12-24%) and extruded barrel temperature (100-140°C) on expansion characteristics of extrudates produced from blends of yam, rice and corn. The result indicated that radial expansion ratio differed significantly with change in all independent variables. Highest expansion (3.97) was obtained at lowest moisture content (12%) and highest barrel temperature (140°C). The result also showed that with increased yam flour level decreased expansion ratio significantly.

Sharma *et al.* (2016) described the impact of process parameters viz, feed moisture (14–18% w.b), die head temperature (90–110°C), and screw speed (330–350 rpm) on the response expansion ratio and concluded that both temperature and screw speed had a positive relation with expansion ratio where as moisture content had a negative relationship with expansion ratio. The experiment was designed using central composite rotatable design and expansion ratio of different samples ranges from 2.64 to 3.18.

Nino *et al.* (2018) explained the impact of extrusion process parameters on expansion ratio of taro flour extrudates fortified with mango pulp and reported that higher temperature and lower moisture content will produce extrudate with higher expansion ratio. The expansion index of the extrudates ranged from 0.92 to 1.65. An increment in expansion ratio also reported for mango pulp proportion of 2-8 g/100g.

2.11. ENGINEERING PROPERTIES OF EXTRUDATES

2.11.1. Density and Porosity

The lesser densities are most acceptable feature of well puffed extruded products like dry texturized plant protein (TPP), utilized as meat extender and expanded cereals, utilized as snacks (Harper, 1981). The influence of extrusion process parameters such as moisture content, temperature and speed of screw on bulk density and porosity of extrudates has investigated by many researchers.

Thymi *et al.* (2005) examined the impact extrusion variables such as feed rate, screw speed, temperature and feed moisture content, on structural properties of extrudates from corn starch. The result revealed that, the responses apparent density and porosity affected by temperature, residence time and moisture content but they were not influenced by screw speed. Density of extrudates increased with increased moisture content and residence time but reduced with temperature. Increased temperature produced extrudates with higher porosity while porosity decreases with increase in moisture content and residence time.

The impact of extrusion variables on physiochemical properties of wheat extruded snack was studied by Ding *et al.* (2006). The result showed that the extrudate density decreased with increasing temperature and screw speed where as extrudate density increased with moisture content. The feed rate had no significant effect on density of the extrudates.

Altan *et al.* (2008) developed extruded snacks from combination of barley flour and tomato pomace and investigated the impact of extrusion variables on bulk density of extruded samples. The result indicated that bulk density reduced with increment in temperature but bulk density increased with increment in pomace level. The bulk density of developed extrudates varied from 0.370 to 1.111 g/cm^3. Screw speed had no effect on bulk density of extrudates.

Chakraborty *et al.* (2011) described the impact of extrusion variables such as blend ratio, moisture content, temperatures of barrel and die head and speed of screws on density of millet- legume based extrudates and reported that all the process parameters except temperature of die head and blend ratio had predominant effect on density.The density increased with increases in the levels of all the processing variables except screw speed. The density reduced with increment in speed of screws.

Faisal *et al.* (2017) explained the impact of extrusion variables on bulk density of apple pomace blended RTE snacks. The bulk density of RTE extudates ranged between 0.069 to 0.195 g/cm^3. The process parameter moisture content had a foremost impact on density at linear and quadratic level.

Pardhi *et al.* (2017) explained the extrusion performance of brown rice grits. Extrusion conditions includes feed moisture content (14-18%), barrel temperature (130-170°C) and screw speed (400-550 rpm) and reported that the bulk density of extruded product were varied between 0.065 to 0.188 g/ml. The bulk density showed a positive relation with moisture content and a negative relation with both temperature and screw speed.

2.11.2. Colour parameters

Colour is an important property which greatly affects consumer acceptability and satisfaction. The extrusion process variables and raw material also affect the colour of extrudates.

Bisharat *et al.* (2014) investigated the influence of extrusion parameters on colour parameters of corn/broccoli and corn/olive paste extrudates. The values of color parameters viz. L*,a* and b* ranged from 60.0-48.1, 7.3-3.8 and 27.0-22.5, respectively for corn/broccoli extrudates and for corn/olive paste extrudates the values ranged from 56.4-45.8, 11.9- 5.76 and 13.4-16.6, respectively. The L* increased with temperature for corn/olive paste extrudates but remain almost unchanged for corn/broccoli extrudates. a* value showed slight changes with temperature but b* value decreased for corn/broccoli extrudates and for corn/olive paste extrudates there was increment in yellowness counter balanced by a decrease in redness.

Nissar *et al.* (2017) studied the influence of extrusion conditions on the colour parameters of corn honey based snacks and reported that barrel temperature had a considerable impact on colour parameters. The "L*", "a*" and "b*" value of the produced extrudates varied from 52.10 to 57.42, 1.02 to 6.83 and 36.83 to 42.86 respectively. Increasing temperature decreased L* (luminosity) but increased a* (redness) and b*(yellowness).

Yusuf (2018) examined the effect of extrusion process parameters on colour of extruded snacks from sorghum, groundnut and Tigernut blends and concluded that moisture content had significant effect on L* value and the L* value reduced from 39.48 to 36.49 with an increment in moisture content from 18 to 26%. Temperature and groundnut level had predominant impact on a* value and a* value enhanced from 15.73 to 17.65 with increment in temperature from 90 to 110°C and decreased with increasing groundnut level from 20 to 30%. The b* value also increased with temperature and groundnut level.

2.11.3. Textural Properties

Textural properties are very important in view of sensory attributes, packaging and transporting aspects. Shear strength gives information about tenderness to the bite (Harman and Harper, 1973). Hardness and crispness are the most important textural properties of RTE extruded products. Webb *et al.* (1986) measured hardness (kg) in the 20 mm long cut portions of the extrudates using a Kiya

Hardness Tester. Crispness is related with rapid drop of force during mastication process, attribute that is based on fracture propagation in brittle products (Vincent, 1998). Chaudhury and Gautam (1999) stated that the force necessary for the breakage of product into two pieces was termed as hardness.

Chiu *et al*. (2013) explained the effect of process parameters on hardness of corn extrudates and reported that feed moisture content had significant effect on hardness and the hardness was increased with increasing moisture content and yam flour level. The hardness of the developed extrudates varied between 3.69±0.09 to 7.63±0.11N. Increasing yam flour content also increased the hardness.

The effect of extrusion temperature and addition of tomato powder and ascorbic acid on the textural properties of corn extrudate was investigated by Obradovic *et al.* (2015). The determination of hardness was done by texturometer and concluded that lower temperature increased hardness whereas addition of tomato and ascorbic acid reduced hardness.

Kanojia *et al.* (2016) developed extruded snacks with broken rice and okara and examined the impact of extrusion variables viz. barrel temperature (120-160°C), die head temperature (160-200°C), screw speed (50-90 rpm), blend ratio of broken rice and okara (70:30-90:10) and moisture content of feed (14-22 % w.b) on textural properties. The hardness and crispness of the extrudates ranged from 1032.6 to 2069 g and 2 to 7, respectively. Increased hardness and decreased crispness was observed due to the presence okara. Temperature of extruder (i.e. barrel temperature and die head temperature) had positive effect on crispness and negative effect in hardness. Moisture content of feed material had positive effect on extrudate hardness and had negative effect on crispness of extrudate.

Kanojia and Singh (2016) explained the impact of extrusion variables on textural properties like hardness and crispness of rice based extruded products. From the study hardness and crispness of the extruded products ranged from 2.6 to 9.69 kg and 4- 22, respectively. The result indicated that screw speed showed positive effect for crispness and negative for hardness. Barrel temperature showed the negative effect whereas die head temperature has the positive effect on hardness.

2.12. FUNCTIONAL PROPERTIES

Hagenimana *et al.* (2006) examined the impact of extrusion process parameters on functional properties of rice flour modified by extrusion and reported that WSI increased from 9.16 to 50.13% with increase in temperature and screw speed but reduced with increment in moisture content. In case of WAI, linear terms of screw speed and interaction level between temperature and screw speed had a negative effect but linear terms of temperature and moisture content and interaction level between screw speed -moisture content and temperature- moisture content had a positive effect.

Yagci and Gogus (2008) described the influence of extrusion process variable on the functional properties of extruded products developed from food by products. Partially defatted hazelnut flour had most predominant impact on both WAI and WSI. The values for WAI varied from 3.65± 0.06 to 5.59 ± 0.05 g/g and the WSI varied from 15.73 ± 1.11 to 37.19± 0.38%. An increment in partially defatted hazelnut content reduced WAI but WSI increased. Increasing moisture content at lesser amount of partially defatted hazelnut caused a higher WAI.

Gulati *et al.* (2015) explained the impact of extrusion parameters viz. moisture content, screw speed and temperature on functional properties extruded proso millet flour and reported that among the process variables speed of screws had predominant effect on WAI and WSI. Water solubility index enhanced with increment in screw speed and water absorption index increased with initial increment in screw speed and then lowered.

Arivalagan *et al.* (2018) explained the effect of incorporation of coconut haustorium on WSI and WAI of corn and maize extrudates. The study revealed that

WAI and WSI predominately affected by the addition of coconut haustorium. The WAI of the extrudates reduced from 8.67 to 4.83 g/g with increment in haustorium from 0 to 30%. But WSI increased from 18.7 to 22.4 % with increment in haustorium from 0 to 30%.

2.13. PROXIMATE COMPONENTS

Proteins are a group of highly complex organic compounds that are made up of a sequence of amino acids. Protein nutritional value is dependent on the quantity, digestibility and availability of essential amino acids (Singh *et al.,* 2007). Digestibility is measured as the most significant determinant of protein quality. Extrusion cooking will enhance protein digestibility by denaturating proteins and exposing enzyme accessible sites (Colonna *et al.,* 1989).

Gelatinization of starch is an important phenomena that occur during extrusion of starch based materials. Starch granules are made of amylose and amylopectin molecules associated inter and intramolecularly by hydrogen bonding either directly or through water hydrate bridges, to form micellar regions. When an aqueous suspension of starch is heated, the water molecules around the granules disrupt hydrogen bonding; enter the granules and they swell (Singh *et al.,* 2007).

Extrusion of ingredients having high amount of fat content is usually not preferable, particularly in the case of expanded food, as lipid levels more than 5–6% damage extruder performance (Singh *et al.,* 2007).

Contradictory conclusions have been described about the consequence of extrusion on dietary fibre. Negligible modification in dietary fibre content were found in case of both untreated and twin-screw extruded wheat flour and whole-wheat meal at 161–180°C mass temperature, 15% feed moisture and 150–200 rpm screw speed by Varo *et al.* (1983). Siljestrom *et al.* (1986) also concluded that no major change was found in dietary fibre content during the extrusion of wheat was, but the fibre present in the extrudates became somewhat more soluble. But Vasanthan *et al.* (2002)

reported that total dietary fibre content is increased during extrusion cooking. Rashid *et al.* (2015) also reported that as extrusion temperature increases dietary fibre content also increases.

The effect of extrusion parameters like temperature (110, 120 and 130°C), screw speed (100, 120 and 140 rpm) and moisture content (44, 47 and 50%) on nutritional characteristics of meat analogue of Mucuna beans was investigated by Omohimi *et al.* (2013) and reported that carbohydrate content increased (50.49 to 66.93%) with increment in temperature and screw speed but reduced with increase in moisture content. The protein content (20.11 to 27.88%) was decreased with higher temperature and increased with higher screw speed. The extrusion parameters do not affect the fat content of the extrudates. The crude fibre content showed an increasing pattern with temperature and decreasing pattern with screw speed.

According to Shruthi *et al.* (2016) the extrusion parameters such as feed moisture (15, 17.5 and 20%), feed composition (corn: pigeon pea: rice bran) and temperature (110, 120 and 130°C) had a considerable impact on nutritional characteristics of corn based extrudates. The fat and protein content had a positive relation with moisture and negative relation with temperature. Addition of pigeon pea and rice bran content increased both fat (0.84 to 1.92%) and protein content (10.52 to 12.80%). The total ash, crude fibre and carbohydrate content reduced with increase in temperature. The optimised sample contained 12.26% protein, 66.01% carbohydrates, 1.28% fat, 10.58% crude fibre and 2.34% ash content.

Khot *et al.* (2018) investigated the effect of extrusion process parameters such as temperature (120, 150 and 180°C), screw speed (200, 300 and 400 rpm) and moisture content (12, 14 and 16%) on nutritional components of maize based extruded snacks and reported all the process variables significantly affect the nutritional quality. The ash content (3.94- 6.48%) was increased with increase in temperature but both oil content (9.75-4.25%) and protein (12.93- 7.56) reduced at higher temperature. Screw speed had a predominant effect on nutritional quality and there was an increment in ash, oil, protein, carbohydrate and fibre with higher screw speed.

2.14. OPTIMISATION OF EXTRUSION PROCESS PARAMETERS

Optimization of extrusion process parameters are done by Response surface methodology.

According to Bas and Boyacı (2007), response surface methodology (RSM) consists of a group of statistical and mathematical techniques that can be utilized for defining the relationship between the independent variables and responses. It can define the effect of independent variables, alone or in combination, on the processes.

According to Ferreira *et al.* (2007), the Box-Behnken design is a best design for response surface methodology because it allows: (i) estimation of the parameters of the quadratic model; (ii) building of sequential designs; (iii) detection of lack of fit of the model; and (iv) use of blocks.

Application of RSM for the optimisation of analytical procedures is largely diffused and consolidated today due to its advantages to classical one-variable-a-time optimisation. It is possible to generate huge amounts of information from few numbers of experiments and can evaluate the interaction effect between the variables on the responses (Bezerra *et al.*, 2008).

RSM is a dominant statistical procedure which is frequently used in many engineering applications to construct accurate models in an optimisation design (Aghbashlo *et al.*, 2012).

RSM is used for developing and enhancing optimisation of process parameters. It is most broadly applied in numerous stages like determination of multi-response parameters and their effective levels, experimental design selection, prediction and verification of model equations, generating response surfaces, contour plots and determination of optimum conditions. With minimum cost and time, RSM can be used for obtaining high efficiency for the development of improved or new process or products (Balasubramani *et al*., 2015).

Omwaba and Mahungu (2014) used RSM for the optimization of extrusion parameters such as temperature (110-150°C), feed moisture (12-14%) and screw speed (350- 450 rpm) by Box-Behnken design for the production of RTE extrudates. The optimum condition obtained were 120°C temperature, 444 rpm screw speed and 13% moisture content.

2.15. STORAGE STUDIES

Sumathi *et al.* (2007) conducted the storage studies of pearl millet based extruded products stored in different packaging materials such as HDPE, biaxially oriented polypropylene and metallized polyester polyethylene under ambient and accelerated conditions. The result indicated that moisture content was increased in all samples but the increment was more in HDPE, moderate in biaxially oriented polypropylene and negligible for metallized polyester polyethylene. The increment in free fatty acid content was resultant to the increment in moisture content.

Storage stability of carrot pomace based extruded snacks was conducted by Dar *et al.* (2012) and reported that *L*-value, *b*-value, crispiness, b-carotene and vitamin C decreased from 66.22 to 62.53, 23.66 to 22.28, 40.33 to 22.00, 34.23 to 16.0 and 14.07 to 7.04 mg/kg, respectively, with the increase in storage period, whereas *a*-value and hardness increased from 6.31 to 6.59 and 13.78 to 45.80 N, respectively, with the increase in storage period.

Alam *et al.* (2015) conducted the storage studies of rice based extruded snacks using different packaging materials (LDPE, PP,HDPE and laminated alumimium) under different packaging medium(N2 flushing and vacuum). The result indicated that moisture content increased in all treatments. Protein content doesn’t show too much variation throughout the storage period. Whereas the hardness lowered during the storage period. Colour parameter such as L* value exhibited a decreasing pattern while a* and b* values showed increasing pattern in all the treatments. Overall acceptability of the extrudates was within acceptable range.

Shelf life studies of walnut kernel mixed rice based extruded products conducted by Hussain *et al.* (2015). The extruded products were stored in LDPE packets for three months under ambient condition and the result indicated that moisture content, free fatty acid and water activity increased from 3.42 to 4.75%, 0.139 to 0.189% 0.40 to 0.56 respectively during storage but hardness and overall acceptability reduced from 52 to 40 N and 4.8 to 4. TPC of extrudates after storage period found to be within permissible limit.

Sharma *et al.* (2015) investigated the self life characteristics of extruded products prepared from pearl millet-cowpea blends. The result showed that moisture content and water activity increased from 5.9 to 8.8% and 0.49 to 0.62 after four months storage. The free fatty enhanced from 0.049 to 0.13% storage period. Whereas hardness (58.20- 48.86 N) and overall acceptability (8.6- 7.4) showed a decreasing trend during the total storage period.

Wani and Kumar (2016) studied the storage stability of rice and corn based extrudates in different packaging materials (LDPE and laminated pouches) under ambient conditions. The quality parameters such as hardness, L* value, b* value decreased during storage where as bulk density and a* value increased during storage period. More changes in quality parameters were observed in extrudates packed in LDPE than laminated pouch. The TPC in the extrudates were observed in the range of 2×10^2 to 9.4×10^4 cfu/g and 2×10^2 to 3.51×10^4 cfu/g for LDPE and laminated pouches respectively.

Ajitha and Jha (2017b) studied the effect of nitrogen flushing on quality and storage life of pearl millet based snacks and reported that snacks stored with nitrogen flushing showed good quality compared to snacks stored without nitrogen flushing.

Ali *et al.* (2017) investigated the storage stability of maize based extruded weaning foods kept HDPE bags for six months at room temperature. The result indicated that moisture content was raised during storage but the colour parameters such as L*, a* and b* do not have significant variations.

Nazir *et al.* (2017) conducted shelf life studies of apricot and date incorporated rice based extruded snacks and concluded that moisture content, water activity and fatty acid content increased from 4.31 to 5.07%, 0.42 to 0.50 and 0.007 to 0.01% respectively but hardness and overall acceptability reduced from 85.02 to 75.95 N and 4.50 to 3.83 during storage period. Total plate count during storage was found within the permissible limit.

Sahu *et al.* (2018) conducted the shelf life studies of maize millet based soy enriched extruded products in different packaging materials (LDPE, aluminium foil, HDPE and metalized polyethylene teraphthalate) and reported that both storage period and packaging material significantly affect the quality characteristics such as moisture content, hardness and crispness of the extrudate during storage. The packaging material LDPE showed more changes in quality characteristics and minimum changes were found in metalized polyethylene teraphthalate.

Syed *et al.* (2019) investigated the storage stability of corn based extrudates stored in HDPE for four months under ambient conditions and reported that moisture content, water activity and free fatty acid were increased from 4.00to 5.75%, 0.20 to 0.40, 0.18 to 0.14% respectively during storage period but hardness was reduced from 27.89 to 19.00 N during storage period. TPC of extrudate found to be within permissible limit.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the different materials and methods adopted for the development of protein enriched RTE extruded food products by extrusion technique. It also explains the quality parameters *viz.,* physical, functional, structural and engineering characteristics of the developed extruded products and its storage characteristics based on objective and subjective evaluation.

3.1. RAW MATERIALS

The raw materials utilized for the production of RTE extruded food products are rice (Jaya variety), ragi, defatted groundnut, defatted soybean and bengal gram. Jaya variety of rice was obtained from RARS, Pattambi and other raw materials were procured from the local markets at Kuttippuram.

3.1.1. Preparation of Samples for Extrusion

The Jaya variety of raw paddy was milled using a mini rice mill (Plate 3.1) to obtain rice for the production of extrudates. The milled rice was collected, cleaned and then dried using the cabinet dryer at 60ºC for half an hour. Further, the dried rice was pulverized into rice flour of 85 micron size using a hammer mill (Plate 3.2). Ground nut kernal free from damage, procured from local market were then roasted, de-skinned. Oil was extracted by using oil extraction machine at the local market in Tavanur. Defatted ground nut cake was then collected and further dried in the cabinet dryer at 85 ºC for half an hour. The dried cake was then ground into powder using a hammer mill. Good quality ragi, defatted soybean and bengal gram purchased from the local markets were pulverized in the hammer mill to obtain flours. All the flours then sieved manually using ISS 85 mesh in order to get uniform particle size.

Plate 3.1 Mini mill

Plate 3.2 Hammer mill

3.2. DEVELOPMENT OF PROTEIN ENRICHED RTE EXTRUDED FOOD PRODUCTS

Ready to eat (RTE) crispy products were prepared from rice, ragi, defatted ground nut, defatted soybean and bengal gram by hot extrusion technology using a Laboratory model Twin screw extruder.

3.2.1. Laboratory Model Twin Screw Extruder

The laboratory model Twin screw extruder (make: M/s Basic Technologies, Kolkatta; model: L-TSE) is a small but robust food processing machine that can be utilized for technical small scale extrusion product manufacture (Plate 3.3). The important parts of the equipment consist of two stainless steel screws of equal diameter which is counter rotating within a stationary stainless steel barrel. The "*main drive"* (10 hp motor; 440 V, 3 Ph) is axially joined to a "*reduction gear box"*. The out-put shaft of "*worm reduction gear"* of the gear box is connected with a "*torque limiter coupling"*.

The "*torque limiter"* is act as a protective tool which consists of spring loaded friction surfaces. If there is a chance of excess load, the friction surfaces slides and smoke may produced. A feed hopper is fitted just above main extruder and the feed is then transferred into the extruder barrel from this adjustable speed feeder. By using a knob on the feeder controller, the feed rate of the feeder can be adjusted. There are two water cooling jackets and electric heaters which are attached to the barrel. The extruder is fitted with two temperature sensors and first one is fixed adjacent to the die plate and second sensor is fixed adjacent to the feed section and both these sensors are attached to temperature controllers located on the control board. The die plate is attached to the barrel by using a screw nut which is fastened with a particular wrench. A mechanical cutting knife is fitted on a revolving shaft of knife cutter which is driven by a direct current motor. The cutter is really powered by an adjustable speed controller and this controller is regulated with the help of a knob situated on the control board.

The "*automatic knife cutter assembly*" is enclosed with in a safety shield. While operating, care should take that this safety shield should be kept in position and a "*limiting switch*" assures that the cutter do not run if the safety shield is not in correct position. Majority of the controls of the machine can be done using a panel board. In case of any emergency situations, an emergency brake is provided at the middle of the machine in order to end the working of extruder.

3.2.2. Twin Screw Extruder Operation

The temperature for the extrusion process was set by put on the heater control switches on the panel board. In order to fix the desired temperature of barrel, temperature controllers were provided at the die and feed section. After reaching desired temperature, the valve for cooling water was opened to keep constant temperature of the barrel. The equipment was then started and permitted to rotate unfilled for some time. At this period, the speed of screws was set to preferred level with the help of the knob on the control board. While start the experiment, flour with large moisture content (30% w.b.) called start up flour was transferred to the barrel. This was prolonged till the occurrence of usual flow of extrudate from the extruder. Then the prepared flour mix which was already conditioned with preferred amount of water was put into the feeder continuously with no break in feeding. A continuous extrudate was obtained through the die. The knob of the cutter was then turned into on position to receive the extrudates.

Plate 3.3 Laboratory model twin screw extruder

3.3. DESIGN OF THE EXPERIMENTS

3.3.1. Standardisation of the Feed Composition

3.3.1.1. Independent variables

Feed mix: F1, F2, F3, F4, F5, F6, F7, F8, F9 and F10.

3.3.1.2. Dependent variables

- Expansion ratio
- Bulk density

3.3.2. Optimisation of Process Variables

3.3.2.1. Independent variables

(1) Temperature (°C)

  (a) T1: 120
  (b) T2: 130
  (c) T3:140

(2) Feed moisture content (%w b)

  (a) M1: 12
  (b) M2: 14
  (c) M3:16

(3) Screw speed (rpm)

  (a) S1: 300
  (b) S2: 350
  (c) S3:400

3.3.2.2. Dependent variables

1. Physical properties

  a) Moisture content
  b) Expansion ratio
  c) Water activity

2. Engineering properties

  a) Colour

b) Texture
c) Bulk density
d) True density
e) Porosity

3. Functional properties
  a) Water absorption index
  b) Water solubility index

4. Proximate components
  a) Protein
  b) Carbohydrate
  c) Fat
  d) Dietary fibre

3.3.3. Storage Studies of RTE Extrudates

3.3.3.1. Independent variables

- Packaging materials: LDPE and laminated aluminum pouch
- Packaging technology: Passive MAP, Active MAP with N_2 filling

3.3.3.2. Dependent variables

- Moisture content
- Water activity
- Colour (L*, a* and b*)
- Textural properties (Hardness, crispness and fracturability)

3.4. STANDARDISATION OF THE FEED COMPOSITION OF RTE FOOD FROM RAGI, RICE, SOYBEAN, BENGAL GRAM AND GROUNDNUT FLOUR.

In order to standardise the feed composition of RTE foods from ragi flour, rice flour, soybean flour, bengal gram flour and groundnut flour, 10 feed compositions were prepared by mixing these raw materials in different proportions. Based on the previous studies by Guha *et al*. (1997), Hagenimana *et al*. (2006) and

Omwamba and Mahungu (2014), the extrusion conditions *viz.,* barrel temperature (120°C), feed moisture content (14%) and screw speed (350 rpm) were selected and the prepared feed compositions were extruded under those conditions. The extrudates were then analysed for various physical parameters like expansion ratio and bulk density. Based on the high expansion ratio and low bulk density, one feed composition was selected and was considered for further experiments. The various proportions of raw materials used under each combination are described below. The quantity of raw materials used to make different flour blends constituted 1000 g.

Table 3.1. Raw material used to prepare the ten blends

Feed composition	Blends (%)	Quantity of raw materials
F1	$R_{60}:Rg_{20}:S_{15}:B_{5}$	$R_{600g}:Rg_{200g}:S_{150g}:B_{50g}$
F2	$R_{60}:Rg_{20}:S_{10}:B_{10}$	$R_{600g}:Rg_{200g}:S_{100g}:B_{100g}$
F3	$R_{60}:Rg_{15}:S_{15}:G_{10}$	$R_{600g}:Rg_{150g}:S_{150g}:G_{100g}$
F4	$R_{60}:Rg_{15}:S_{10}:G_{15}$	$R_{600g}:Rg_{150g}:S_{100g}:G_{150g}$
F5	$R_{60}:Rg_{20}:B_{10}:G_{10}$	$R_{600g}:Rg_{200g}:B_{100g}:G_{100g}$
F6	$R_{60}:Rg_{15}:B_{15}:G_{10}$	$R_{600g}:Rg_{150g}:B_{150g}:G_{100g}$
F7	$R_{60}:Rg_{10}:B_{10}:G_{10}:S_{10}$	$R_{600g}:Rg_{100g}:B_{100g}:G_{100g}:S_{100g}$
F8	$R_{55}:Rg_{10}:B_{10}:G_{15}:S_{10}$	$R_{550g}:Rg_{100g}:B_{100g}:G_{150g}:S_{100g}$
F9	$R_{50}:Rg_{25}:S_{15}:B_{10}$	$R_{500g}:Rg_{250g}:S_{150g}:B_{100g}$
F10	$R_{50}:Rg_{25}:B_{10}:G_{15}$	$R_{500g}:Rg_{250g}:B_{100g}:G_{150g}$

R= Rice flour, Rg=Ragi flour, B= Bengal gram flour, S= Soybean flour, G= Groundnut flour.

3.4.1. Physico-Chemical Analysis of the Optimised Feed Mix

The feed composition $R_{60}:Rg_{10}:B_{10}:G_{10}:S_{10}$ ($\text{Rice}_{600g}:\text{Ragi}_{100g::}$Bengal gram$_{100g}$:Groundnut$_{100g}$:Soybean$_{100g}$) was optimised based on the preliminary studies and the same alone had been considered for further experiments. The physico-chemical properties of the selected feed mix *viz.,* moisture content, water activity, bulk density, colour, protein, carbohydrate, fat, dietary fibre and energy content was analysed and discussed below.

3.4.1.1. Moisture content

The moisture content of the feed mix was computed by hot air oven method (AOAC, 2005). Approximately 2 g of feed sample were taken in a pre-weighed petridish and dried at 105°C. The drying was prolonged until a steady weight was achieved. The dried products were then taken out from the oven and cooled using a desiccator and final weight was noted using an electronic balance (M/s Contech Instruments Ltd.) with a precision of 0.001 g. From the readings, the moisture content was calculated using the following equation.

$$\text{Moisture content (M) (\%.w.b)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \qquad \text{........ (3.1)}$$

Where,

M = Moisture content (%.w.b)

W_1= Weight of empty petridish (g)

W_2= Initial weight of sample + petridish (g)

W_3= Final weight of sample + petridish (g)

3.4.1.2. Water activity

Water activity of the feed mix was determined by using Aqua lab water activity meter (M/s Aqua lab, Decagon device Inc., Pullman (Wa), USA) which is shown in Plate 3.4a. The sample was put into the disposable cups of water activity meter and turned the sample drawer knob into OPEN or LOAD position. Then the drawer was pulled to open and the cup along with sample was placed in the drawer. While placing samples in the drawer, care should be taken that top lip of the cup must free from sample residue. Then closed the drawer and turned the knob to READ position. The water activity of samples was displayed on the LCD display and the values were recorded.

3.4.1.3. Bulk density

The bulk density of the feed mix was found by the procedure explained by Jhoe *et al.* (2009). A known weight of feed mix was taken and transferred into a graduate cylinder. The cylinder along with the feed mix was then tapped on a flat surface until a constant volume was achieved. The final volume was noted and bulk density was calculated by dividing the sample weight by the final volume of the sample in the cylinder as given below. The bulk density was expressed in g/cm^3.

$$\text{Bulk density} = \frac{Weight\ of\ the\ sample\ (g)}{Volume\ of\ the\ sample\ (cm^3)} \qquad \ldots\ldots\ (3.2)$$

3.4.1.4. Colour

Colour of the feed mix was measured by using Hunter lab colour flex meter (made by: Hunter Associates Laboratory, Reston, Virginia, USA) (Plate 3.4b). This instrument works on the theory of accumulating the light and estimate energy from the product reflected across the complete visible spectrum. The instrument utilize filters and mathematical models which depend up on standard observer curves that describe the quantity of green, red and blue primary lights needed to equal a series of colour across the whole visible spectrum. It gives measurements in terms of “L”, “a” and “b”. The L coordinate estimates the value or luminance of a colour and extend between black at zero to white at hundred. The positive and negative value of a” coordinate indicate red and green respectively and similarly positive and negative value of “b” coordinate indicate “b” yellow and blue respectively. All the three standard colour parameters “L”, “a” and “b” were observed for day light colour. The standardization of the instrument was done with white and black ceramic calibration tiles. Readings were observed from three replicates of each sample and the average values of “L”, “a” and “b” were reported.

3.4.1.5. Protein

The crude protein content of the sample was estimated using micro Kjeltec distillation unit (AOAC, 2005, 920.86). The nitrogen in protein or any other organic material is converted to ammonium sulphate by H_2SO_4 during digestion. On steam-distillation, it liberates ammonia which is collected in boric acid solution and titrated against standard acid. Since 1ml of 0.1 N acid is equivalent to 1.401mg N, calculation is made to arrive at the nitrogen content of the sample.

Accurately weighed l00 mg of the extruded sample (having 1-3mg nitrogen) was put into a 30 ml digestion flask and digested. To this sample, 1.9 ± 0.l g potassium sulphate and 80 ± l0 mg mercuric oxide was added along with 2 ml con. H_2SO_4 and digested. As sample size was larger than 20 mg dry weight, 0.l ml H_2SO_4 was added for each l0 mg dry material. Boiling chips were also added and digested till sample solution becomes colourless. The solution was cooled and diluted with a small quantity of distilled ammonia-free water and transferred to the distillation apparatus When the nitrogen content of the sample is high, the digest was made up to a known volume and an aliquot transferred to the distillation flask. The Kjeldahl flask was rinsed with successive small quantities of water. An l00 ml conical flask containing 5 ml of boric acid solution with a few drops of mixed indicator was placed at the tip of the condenser. Sodium hydroxide solution (10 ml) was added to the test solution in the apparatus. After distillation, ammonia was accumulated (as a minimum of 15-20 ml of distillate should be accumulated). Using distilled water, tip of the condenser was rinsed. After that the titration of the solution was carried out against the standard acid till the first emergence of violet colour as the end point. The blank was prepared with distilled water containing equal volume and subtracted the titration volume from that of sample titre volume.

$$\text{Protein}\,(\%) = \frac{(\text{ml of HCl - ml of blank}) \times \text{molarity} \times 14.007 \times 100}{\text{mg test portion}} \times 6.25 \ldots.. \quad (3.3)$$

3.4.1.6. Carbohydrate

The carbohydrate was determined as per the procedure given by Hedge and Hofreiter (1962).100 mg of sample was put in a test tube and it was hydrolysed by using five ml of 2.5N HCL by keeping it in a boiling water bath for 3 hours. After cooling to room temperature the sample was neutralized with sodium carbonate till the effervescence ends. Then make up the volume to 100 ml and centrifuge at 6000rpm for 10 minutes. After that accumulate the supernatant and take 0.5 and 1ml aliquots for experiment. Make the standards by taking 0, 0.2, 0.4, 0.6, 0.8 and 1ml of the working standard and zero serves as blank. By the addition of distilled water, make up the volume to 1ml in every tube as well as the samples tubes by adding distilled water. After that add four ml of anthrone reagent in each test tube and heat it for eight minutes in a boiling water bath. Cool the test tubes rapidly and read the green to dark green colour at 630nm using a spectrophotometer (make: Systronics; model: PC based double beam spectrophotometer 2202) (Plate 3.4c). Draw a standard graph between concentration of standard on the X- axis and absorbance on the Y-axis. The carbohydrate present in the sample was calculated from the standard graph.

$$\text{Carbohydrate (\%)} = \frac{mg\ of\ glucose}{Volume\ of\ the\ test\ sample} \times 100 \qquad \text{……..(3.4)}$$

3.4.1.7. Fat

The crude fat of extrudates was estimated as per AOAC (2005, 920.85) by Soxhlet extraction method using SOCS – PLUS apparatus (make: Pelican Equipments, SCS-08, Chennai, India). Two gram of powdered sample weighed and put into a thimble. The empty beaker weight was noted and all the beakers were transferred into the system. The acetone was poured into the beaker and boiled for about 30 min at 80°C. Once the process completed the temperature was increased to 160° C for 15-20 min to collect the acetone. All the beakers with residue were kept in a hot air oven at 100 °C for 1 hour and cooled in a desiccator and weighed. Final weight of the beaker was taken and fat content was determined by the equation:

$$\text{Fat}(\%) = \frac{W_2 - W_1}{W} \times 100 \qquad \text{...... (3.5)}$$

Where,

W_1 = Initial weight of the beaker, g

W_2 = Final weight of the beaker, g

W = Weight of the sample taken, g

3.4.1.8. Dietary fibre

Dietary fibre analysis of the sample was conducted at the laboratory, College of Horticulture, Kerala Agricultural University, Vellanikkara. Dietary fibre is the sum of lignin and polysaccharide that are not digested by androgenous secretions of human digestive track. The estimation method is based on removal of protein and starch from residue insoluble in alcohol (Ranganna 1986). One gram of sample was taken in a clean thimble and the thimble is covered with a filter paper. The thimble was then kept in a soxhlet apparatus and extraction was done using 90% ethanol for 16 hours. Dry the residue insoluble in alcohol, weigh it and grind it into fine powder. Analyze the fine powder for protein and starch. The total dietary fibre was calculated by using the equation;

$$\text{Dietary fibre }(\%) = \frac{W1-(W2+W3)}{W} \times 100 \qquad \text{........ (3.6)}$$

W= weight of sample taken (g)

W_1= Dry weight of residue insoluble in alcohol

W_2= Amount of starch present in sample (g)

W_3= Amount of protein present in the sample (g)

3.3.1.9. Energy content

The energy content of a sample is the energy released from carbohydrates, fats, proteins and other organic compounds which is expressed in kcal or kJ. It is an important parameter deciding the nutritive value of food. Energy content of food can be computed from the available nutrient information of food components *viz.,* protein, carbohydrate and fat content using formula given by Ekanayake *et al*., 1999.

Energy (kJ/100 g) = (protein × 16.7) + (fat × 37.7) + (carbohydrates × 16.7) … (3.7)

3.4. EXPERIMENTAL DESIGN FOR THE OPTIMISATION OF PROCESS VARIABLES *VIZ*; TEMPERATURE, FEED MOISTURE CONTENT AND SCREW SPEED FOR THE PRODUCTION OF RTE EXTRUDATES

In the present study, Response Surface Methodology (RSM) was used in the experimental design. This technique is applied to explain the individual and interactive influence of independent variables on the response. It is a set of statistical and mathematical techniques which are helpful for developing, improving and optimizing processes. RSM approach is widely used in the particular conditions where a number of input variables significantly affect some performance measure or quality features of the process. By precise design of experiments, the objective is to optimise an output variable or response which is influenced by a number of input variables or independent variables. An experiment is a series of tests, called runs, in which changes are made in the independent variables in order to recognize the cause for changes in the output response (Morshedi and Akbarian, 2014).

The experiments were designed based on Box-Behnken design in RSM with three factors at three levels (-1, 0 and +1). The independent or the process parameters selected for the optimisation were barrel temperature (°C), feed moisture content (% w.b) and screw speed (rpm). The number of experiments (N) or runs in the Box-Behnken design is obtained from the equation $N= 2\ k\ (k-1)\ +C_0$ (where k is the number of factors and C_0 is the number of central points). In the present investigation there were 18 experiments with 6 central points. The Design- Expert software (Trail version 7.0.0) was used for the statistical analysis.

Table 3.2. Coded and un-coded values of independent variables in Box-Behnken design for optimisation of process variables for the production of RTE extrudates

Independent variables	Code variables	Levels in coded form		
		-1	0	+1
Temperature (°C)	A	120	130	140
Moisture content (%w.b)	B	12	14	16
Screw speed (rpm)	C	300	350	400

Table 3.3 Box-Behnken experimental design for the optimisation of process variables for the production of RTE extrudates.

	Coded variables			Un- coded variables		
Run	Temperature (°C)	Moisture content (%w.b)	Screw speed (rpm)	Temperature (°C)	Moisture content (%w.b)	Screw speed (rpm)
1	0	0	0	130	14	350
2	+1	0	-1	140	14	300
3	-1	-1	0	120	12	350
4	+1	0	+1	140	14	400
5	0	+1	+1	130	16	400
6	+1	+1	0	140	16	350
7	+1	-1	0	140	12	350
8	0	0	0	130	14	350
9	0	-1	-1	130	12	300
10	0	0	0	130	14	350
11	0	+1	+1	130	12	400
12	-1	+1	+1	120	14	400
13	0	0	0	130	14	350
14	0	0	0	130	14	350
15	-1	0	-1	120	14	300
16	0	0	0	130	14	350
17	-1	+1	0	120	16	350
18	0	+1	-1	130	16	300

3.5. DEVELOPMENT OF RTE FOOD PRODUCTS BY EXTRUSION PROCESS.

Development of RTE food products was carried out using extrusion technology. In order to start the extrusion process, the extruder was primed before actual operation and 3 mm circular die was fixed at the barrel end. The first heater was set either at 120, 130 and 140ºC and second heater was fix at 60ºC and both heaters were turned on for heating of the barrel. The cooling water line was kept in off position until necessary temperature was attained. The rest of the operational settings *viz.,* screw speed (300, 350 and 400 rpm), feed rate (35% of maximum) and cutter (30% of maximum) were fixed in the control panel board. After reaching the necessary temperature the cooling water valve was opened to regulate the temperature. Then the switches of extruder screws, feeder and cutter were turned on and simultaneously "start up flour" (30 %wb) was put into the barrel in order to lubricate the screws and barrel. When the extrudates just begin to coming out of die, immediately the actual feed mix was fed with the help of automatic feeder. The evenly cut, RTE exturates was collected using trays. The products were dried for one hour in a mechanical dryer at 40°C temperature and then packed in PE pouches, sealed and stored for further analyses. The different processes utilized for the production of RTE extruded products are shown in Figure 3.1.

3.6. QUALITY PARAMETERS OF RTE EXTRUDED FOOD PRODUCTS

3.6.1 Physical Properties of RTE Extruded Food Products

3.6.1.1. Moisture content

Moisture content of the developed extrudates was determined using the method described in section 3.4.1.1. The initial and final weights of ground extrudates were noted and the same was used to calculate the moisture content of the RTE extrudates.

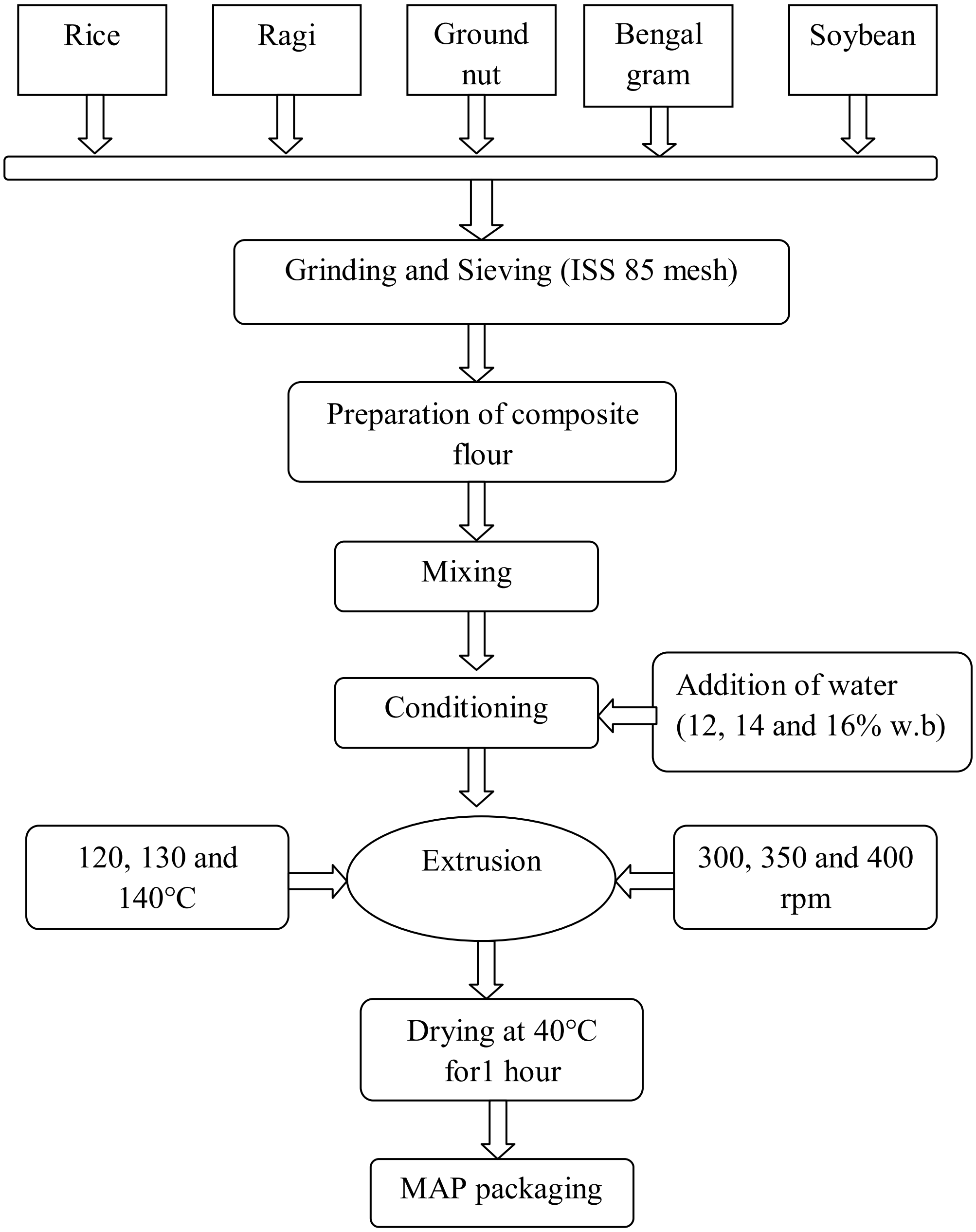


Fig 3.1. Process flow chart for the development of RTE extrudates.

3.6.1.2. Water activity

Water activity of RTE extudates were measured using Aqua lab water activity meter (model: Aqua lab, Decagon Devices Inc., Pullman (Wa), USA) as explained in section 3.4.1.2.

3.6.1.3. Expansion ratio

The expansion ratio of extrudate is the "ratio of diameter of extrudate to the diameter of die hole" (Fan *et al.,* 1996). Ten extruded samples were randomly selected and mean diameter was measured with a vernier caliper. The equation for finding expansion ratio is given below.

$$\text{Expansion ratio} = \frac{\text{Diameter of extruded product (mm)}}{\text{Diameter of die hole (mm)}} \quad \ldots\ldots(3.8)$$

3.6.2. Engineering Properties of RTE Extruded Food Products

3.6.2.1. Colour

Colour of the extrudates was measured by using Hunter lab colour flex meter (made by: Hunter Associates Laboratory, Reston, Virginia, USA) as explained in section 3.4.1.4.

3.6.2.2. Texture

Textural properties of RTE expanded products were analysed using a Texture Analyzer (TA.XT texture analyser, Stable micro systems Ltd.) (Plate3.4d).The three dimensional analysis of the product was done by textural analyser by measuring force, distance and time. The force was measured in opposition to a fixed distance whereas distance was deliberated to attain fixed forces. The results was obtained directly or transferred to a computer. There was a probe carrier which consists of a sensitive cell and this load cell also consists of a mechanical under and overload load safety mechanism and an electronic supervising network that off the motor drive whenever an overload situation was noticed. Speed control and distance was attained by utilizing a step motor fitted to the thin lead screw that binds the probe carrier upward and downward.

For RTE extruded products, the experiments were done by performing different tests that produce plots of force (N) vs. time (s), from which texture values for extruded samples were obtained. Three replications of each combination were taken for analysis. During the testing, the extruded samples were put manually against the base plate and different tests were performed according to TA settings. The textural properties such as hardness and fracturability were determined by using penetration test. Crispiness was determined by using shear test (Seema, 2016).

Penetration test by using cylindrical probe

The penetration test is expressed as one in which the depth of penetration (or the time required to reach a particular depth) is measured under a constant load. In the penetration test, the 5 mm cylinder probe was used to pierce into the extrudate test sample and the force required attaining a specific piercing depth or the depth of piercing in a particular time, under definite conditions, was estimated and indicated as hardness. The TA setting for penetration test includes "Mode: Measure Force in Compression, Pre Text speed: 1mm/s, Option: Return to Start, Distance (compression): 4 mm, Post Test speed: 10 mm/s, Data Acquisition Rate: 400 pps and Test speed: 1 mm/s" (Seema, 2016).

Shear test by using Kramer shear cell five-blade probe

Kramer shear cell five-blade probe was used, with test speed of 1 mm/s. Adequate amount of extruded products was used to cover the bottom of the cell, without overlapping of the pieces, and shearing was performed until the probe had completed its travel. The peak force obtained (in newtons) was noted.

3.6.2.3. Bulk density

The bulk density (BD) was determined using the method described by Chinnaswamy and Bhattacharya, (1986). The values of diameter and length of extruded samples are measured with a digital vernier caliper with least count of 0.01 mm. The weight per unit length of extrudate was determined by weighing measured lengths (1 cm). The bulk density was determined by using the following formula, considering a cylindrical shape of extrudate (Launay and Lisch, 1983). Ten pieces of extruded samples were randomly chosen and the average was taken (Ding *et al.,* 2005).The experiments were repeated thrice and the bulk density was calculated by following equation:

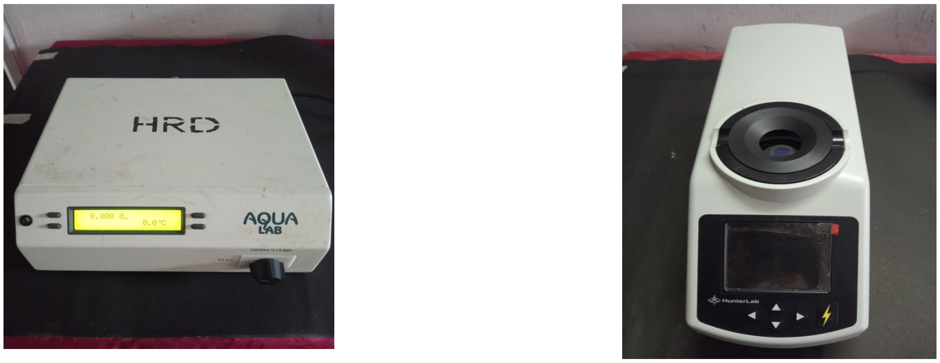
$$\text{Bulk density}(\text{g/cm}^3) = \frac{4\text{m}}{\pi d^2 L} \qquad \text{….. (3.9)}$$

Where, m is the mass (g) of the extruded sample, L is the length (cm) of extrudate and d is diameter (cm) of the extruded sample.

3.6.2.4. True density

True density of developed extrudate was calculated by the method explained by Deshpande and Poshadri (2011). About 1g of extruded sample was crushed and the crushed extruded sample was put into a burette filled with toluene. The increase in volume in the burette was taken as the true volume of the extruded sample. True density was determined by the equation:

$$\text{True density}\,(\text{g/cm}^3) = \frac{\text{Weight of ground sample of extrudate (g)}}{\text{Rise in toulene level (cm}^3)} \qquad \text{…..(3.10)}$$



a) Water activity meter

b) Colorimeter

d) Texture Analyser

c) Spectrophotometer

Plate.3.4. Instruments for measuring quality parameters

3.6.2.5. Porosity

Porosity is defined as the ratio of the volume of the void space to the volume of the product. It depends on the void space existing in the extrudates. The porosity also depends on the quantity of moisture escaped during extrusion cooking. A known weight of the extruded products was taken and the volume was noted by using a measuring cylinder. After that the same extrudates were powdered in a grinder and its volume was noted. The volume of the void space in the extruded product was calculated by subtracting the volume of the powder from the initial volume (Jhoe *et al*., 2009).

$$\text{Porosity}\,(\%) = \frac{V_p - V_{po}}{V_{po}} \times 100 \qquad \dots (3.11)$$

Where

V_p - volume of the product

V_{po} - volume of the product after it is powdered

3.6.3. Functional Properties of the RTE Extruded Food Products

3.6.3.1. Water absorption index (WAI) and water solubility index (WSI)

WAI and WSI were calculated by the method explained by Anderson (1982). The extrudates were milled and sieved in ISS 90 mesh in order to get uniform particle size. 1g of sample was weighed and shifted into a centrifuge tube and 10ml distilled water was added. Using a test tube shaker the centrifuge tube with sample was shaken for 15 minutes. After that the samples was centrifuged at four thousand rpm for fifteen minutes. The supernatant was accumulated into petri dish for finding its solid content by keeping the petri dish in an oven at 100°C for 2-3 hr and final weight of the petri dish was noted. The weight of the wet sediment was also recorded and WAI and WSI were determined by using the following equations;

$$\text{Water absorption index (g/g)} = \frac{\text{Weight of wet sediment}}{\text{Intial weight of dry solids taken}} \qquad \dots (3.12)$$

$$\text{Water solubility index (\%)} = \frac{\text{Weight of dissolved solids in supernatant}}{\text{Weight of dry solids}} \times 100 \dots (3.13)$$

3.6.4. Proximate Components

The proximate components such as protein, carbohydrate, fat and dietary fibre of RTE extruded food products are determined using the procedures explained in section 3.4.1.5, 3.4.1.6, 3.4.1.7 and 3.4.1.8 respectively.

3.7. QUALITY PARAMETRS OF OPTIMALLY PRODUCED RTE EXTUDED FOOD PRODUCTS.

The quality parameters such as moisture content, water activity, colour (L*,a* and b*), Textural properties (Hardness, Crispness and fracturability), proximate components like protein, carbohydrate, fat, dietary fibre and energy content of the optimally produced RTE extrudates was found by the procedure explained in previous sections 3.4.1.1, 3.4.1.2, 3.4.1.4, 3.6.2.2, 3.4.1.5, 3.4.1.6, 3.4.1.7, and 3.4.1.9 respectively.

Total ash content and the selected minerals such as calcium, iron and potassium of optimally produced RTE extrudates were also determined.

3.7.1 Total Ash

The total ash content of the sample was conducted at the laboratory, College of Horticulture, KAU, Vellanikkara. The procedure explained by Ranganna (1986) was followed for the estimation of total ash. Took 5- 10g of the sample into three silica dishes after note down their empty weights. It was ignited using a Bunsen burner. Ash the material at not more than 525°C for 4 to 6 hour. Cool the dishes and weigh. The difference in weights gives the total ash content and is expressed as percentage.

$$\text{Total ash} = \frac{w1-w2}{w3} \times 100 \ldots\ldots (3.13)$$

W1= Weight of crucible with ash (g)

W2= Empty weight of crucible (g)

W3= Weight of the sample (g)

3.7.2 Calcium

The estimation of calcium content was done at the laboratory, College of Horticulture, KAU, Vellanikkara by the procedure given by Ranganna (1986). Pipette an aliquot of the ash solution obtained by dry ashing to a 250 ml beaker. Two drops of methyl red indicator and 10ml of saturated ammonium oxalate solution were added. Make the solution lightly alkaline by adding dilute ammonia and then lightly acidic with little amount of acetic acid up to the colour is turned into faint pink. Heat the solution to the boiling point. Cool the solution at room temperature for at least 4 hour. Filter the sample using Whatman No. 42 paper and wash with water up to the filtrate is free from oxalate. Using a platinum wire or pointed glass rod break the point of the filter paper. Wash the precipitate initially by hot dilute H_2SO_4 from wash bottle into the beaker at which calcium was precipitated. Then wash with hot water and titrate while still hot with 0.01 N $KMnO_4$ to the first permanent pink colour. Lastly add filter paper into solution and finish the titration. The amount of calcium is given by the following equation;

$$\text{Calcium (mg/100g)} = \frac{Titre \times 0.2 \times Total\ volume\ of\ ash\ solution \times 100}{volume\ taken\ for\ estimation \times wt\ of\ sample\ taken\ for\ ashing} \ldots\ (3.14)$$

3.7.3. Iron

The estimation of iron content in the sample was done at the laboratory, College of Horticulture, KAU, Vellanikkara by the procedure given by Ranganna (1986). The iron content in food samples was estimated by converting the iron into ferric form using oxidizing agents such as potassium persulphate or hydrogen peroxide and treating thereafter with potassium thiocyanate to form the red ferric thiocyanate which is measured colorimetrically at 480 nm. Ash solution of the extrudate sample made by dry ashing used for colour appearance. Three different measuring cylinders were taken and pipette out the solution as given below

	Blank (ml)	Standard (ml)	Sample (ml)
Standard iron solution	0.0	1.0	0.0
Sample ash solution	0.0	0.0	1.0
Water	5.0	4.0	0.0
Conc.H_2SO_4	0.3	0.5	0.5
Potassium persulphate	1.0	1.0	1.0
Potassium thiocynate	2.0	2.0	2.0

In each of the above cases make up the volume into 15 ml with water. Measure the colour at 480 nm setting the blank at 100% transmission. The equation for finding iron is given by

$$\text{Iron (mg/100g)} = \frac{OD\ of\ the\ sample \times 0.1 \times Total\ volume\ of\ the\ ash\ solution \times 100}{OD\ of\ standard \times 5 \times Wt\ of\ sample\ taken\ for\ ashing} \quad \text{.....(3.15)}$$

3.7.4 Potassium

The estimation of potassium content in the optimised extruded sample was done at the laboratory, College of Horticulture, KAU, Vellanikkara by the procedure given by Ranganna (1986). Flame photometric method is used for the estimation of potassium content. Dilute an aliquot of ash solution so that it contains less than 150 ppm potassium. Adequate amount of HCL was added so that the concentration of acid is equal as that in the standard solution. Atomize the diluted extract in a calibrated in a calibrated flame photometer with the wave length dial set at 768 nm and the transmittance set at 100% for the top standard solution of potassium. Check the instrument periodically with the top standard solution. From the standard curve concentration was obtained. The potassium content is calculated by using following equation

Potassium(mg/100g)=

$$\frac{ppm\ found\ from\ standard\ curve \times volume\ made\ up \times Dilutions\ if\ any \times 100}{Wt\ of\ sample \times 1000} \quad \ldots.(3.16)$$

3.8. STORAGE STUDIES OF OPTIMALLY PRODUCED RTE EXTRUDED PRODUCT

Storage stability of optimised RTE extruded product was studied at ambient conditions by storing it in different packaging materials and packaging technologies. The optimally produced extruded sample was stored for three months at ambient conditions. The stored products were periodically analysed at 15 days intervals.

The independent variables selected were packaging materials (LDPE and laminated aluminum pouch) and packaging technology (Passive MAP, Active MAP with N_2 filling).

3.9. QUALITY ANALYSIS OF OPTIMALLY PRODUCED RTE EXTRUDED PRODUCTS DURING STORAGE

The quality analysis of stored RTE products was conducted in terms moisture content, water activity, colour and textural properties and these quality parameters are determined by the procedure explained in section 3.4.1.1, 3.4.1.2, 3.4.1.4 and 3.6.2.2 respectively.

3.10 MICROBIAL ANALYSIS OF OPTIMALLY PRODUCED RTE EXTRUDED PRODUCTS AFTER 3 MONTHS STORAGE

Microbial analysis of stored samples was conducted using total plate count method (TPC) after three months of storage period. The sample was ground into powder using a sterile mortar and pestle. 1g of powdered sample is weighed accurately and transferred into a conical flask containing 100 ml of sterile distilled water. It was then mixed very well by using an incubator shaker. From it 1 ml was taken and added to 9 ml of sterile distilled water in a test tube to make a sample of 10^{-3} dilution and again from which 1 ml was taken and added to 9 ml of sterile distilled water to make a sample of 10^{-4} dilution. All the glass wares, ancillary equipments were must sterilised before use. One ml of aliquot from both dilutions was transferred to sterile petri plates by using a micro pipette for the enumeration of bacteria and triplicates were taken. Nutrient agar for bacteria was taken as the growth media and about 15-20 ml of this growth media of temperature 45-50°C was poured into each petri plate and then the plates were rotated clockwise and anticlockwise directions on the flat surface in order to have a uniform distribution of colonies. Petri plates are the allowed for solidification of agar and then the plates were inverted and incubated at room temperature for 24-48 h. The colonies were counted after the incubation period by using a colony counter and the number of colony forming units per ml of sample were calculated by using formula:

$$\text{CFU/ml} = \frac{Mean\ number\ of\ CFUs \times dilution\ factor}{Volume\ of\ the\ sample\ (ml)} \quad \ldots\ldots(3.16)$$

3.11 SENSORY ANALYSIS OF OPTIMALLY PRODUCED RTE EXTRUDED PRODUCTS AFTER 3 MONTH STORAGE PERIOD

Sensory analysis of extruded products after three month storage period was conducted using the 9 point Hedonic scale test. Before serving to sensory panel the RTE extrudates were toasted with three teaspoonful of oil (per hundred grams) and two teaspoonful of "*chat masala*" as a flavouring component. Characteristics such as colour and appearance, texture, flavour, taste, overall acceptability were scored by expert panel and the average sensory score of the samples were analysed. Commercially available *kurkure* product was taken as control sample.

3.12. STATISTICAL ANALYSIS

"Response surface methodology (RSM)" was used for the analysis data for the optimisation of process parameters. The analysis of variance (ANOVA) was used as the statistical tool to find out the level of significance. The Design- Expert software (version 7.0.0) was used for statistical analysis. In case of storage studies SPSS software was used for the statistical analysis.

3.13. COST ANALYSIS

The cost analysis of optimally produced RTE extrudates was conducted by considering fixed and variable cost. The cost estimation of extruded RTE product was given in Appendix E.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the results and discussion of the experiments conducted for the development of protein enriched RTE extruded food products from rice, ragi, groundnut, soybean and Bengal gram. The optimised treatments and storage studies of optimally produced RTE extudates were also studied and discussed in this chapter.

4.1. STANDARDIZATION OF THE FEED COMPOSITION OF RTE FOOD FROM RAGI FLOUR, RICE FLOUR, SOYBEAN FLOUR, BENGAL GRAM FLOUR AND GROUNDNUT FLOUR

In the present study, preliminary trails were conducted for standardizing the feed composition. Ten different feed compositions were made and they were extruded at 120°C temperature, 14% moisture content and 350 rpm screw speed. The expansion ratio and bulk density of the developed extrudates were analysed and presented in Table 4.1. The expansion ratio and bulk density of the extrudates ranged from 2.22 to 2.98 and 0.751 to 0.93 g/cm^3, respectively. In an extrusion process, the extrudate expansion is a primarily important property, relating product quality and is directly connected to the degree of cooking. Unless the extudate expansion meets a certain specification, the product is not acceptable (Ajitha and Jha 2017a). The exteudates developed from feed composition F7 (R_{60}:$Rg_{10:}B_{10}$:G_{10}:S_{10}) showed higher expansion ratio of 2.98 and lowest bulk density of 0.751 g/cm^3. So the feed composition F7 was selected for further experiments.

4.2. PHYSICO-CHEMICAL ANALYSIS OF THE FEED MIX

The physico-chemical properties such as moisture content, water activity, bulk density colour, protein, carbohydrate, fat, dietary fibre and energy content of the selected feed mix were found and the values are tabulated in Table 4.2.

Table 4.1. Expansion ratio and bulk density of the extrudates developed using rice, ragi, soybean, Bengal gram and groundnut flour

Feed Composition	Expansion Ratio	Bulk Density(g/cm^3)
F1	2.72	0.810
F2	2.58	0.870
F3	2.54	0.873
F4	2.60	0.864
F5	2.68	0.830
F6	2.62	0.862
F7	2.98	0.751
F8	2.22	0.930
F9	2.34	0.890
F10	2.40	0.880

Table 4.2. Physico-chemical properties of the feed mix

Physico-chemical properties	Value
Moisture content (%wb)	8.95
Water activity	0.562
Bulk density (g/cm^3)	0.690
Colour	
L*	72.80
a*	3.71
b*	17.22
Protein (%)	16.01
Carbohydrate (%)	71.54
Fat (%)	3.51
Dietary fibre (%)	8.61
Energy content(kJ/100 g)	1594.41

The standardised feed mix had an average moisture content of 8.95% (wb). The water activity and bulk density of the feed mix is 0.562 and 0.690 g/cm^3, respectively. The colour values *viz.,* L*, a* and b* values were 72.80, 3.71 and 17.22, respectively. The proximate components such as carbohydrate, protein, fat and dietary fibre content of the feed mix is 71.54%, 16.01%, 3.51% and 8.61%, respectively. The feed mix had an energy content of 1594.41 kJ/100 g.

4.3. OPTIMISATION OF PROCESS VARIABLES *VIZ*; TEMPERATURE, FEED MOISTURE CONTENT AND SCREW SPEED FOR THE PRODUCTION OF RTE EXTRUDATES

Box-Behnken experimental design was used for the selection of best combination of process parameters in the present extrusion processes. The RTE expanded snacks were developed by extrusion process with different combination of temperature, feed moisture content and screw speed as described in the section 3.3. The process parameters *viz.,* temperature, moisture content and screw speed were optimised based on the quality of the final product. Eighteen experiments were conducted and the quality of the extruded products was examined with reference to the physical, functional, engineering properties and proximate components. Analysis of variance (ANOVA) was carried out to determine the significant effects of independent variables or process variables on each dependent variables or responses. The ‘p’ value is used to indicate whether the mathematical relationship between each independent and dependent variables are statistically significant. The model terms become significant when the ‘p’ value is less than 0.05. The lesser ‘p’ value indicates that the respective coefficient is more significant. The capability of regression model was examined by “R^2, Adjusted R^2, Adequate Precision and Fisher’s F-test” (Montgomery, 2001).

R^2 and adjusted R^2 implies an idea of how many data points fall within the line of regression equation. Adjusted R^2 is a measure of the quantity of variation around the mean expressed by the model, adjusted for the number of terms in the model. As the number of terms in the model rises, the adjusted R^2 reduces, if that extra term does not contribute value to the model. Adequate precision connects the limit of predicted terms at design points to the mean prediction error.

The significance of every terms included in the polynomial was decided statistically by calculating the F-value at probability (p) of 0.1 to 0.01 In order to fit the given data, an absolute second order quadratic model was utilized. R^2, adjusted R^2, predicted R^2 (which is an estimation of how good the model anticipates a response value) and Fischer F-test were used to test the adequacy of the model (Haber and Runyon, 1977). If the value of R^2 becomes lesser, then there is less importance in the dependent variables in the model describing the behavior deviation. Optimisation of process variables was done by the partial differentiation of the model with reference to every parameter, equating to zero and at the same time solving the resulting function. The regression coefficients were then applied to produce statistical computation to create three-dimensional graphs which represent the regression model. Three-dimensional response surface was plotted to see the interaction between the significant ($p<0.05$) effects of independent variables and response variables.

4.3.1 Physical Properties

4.3.1.1. Moisture content of RTE extrudates

Moisture or water content showed the total amount of water present in a food. It is one of the important characteristics which influence the stability of the product during storage. The effects of process parameters on moisture content of the extrudates are presented in Appendix A (Table A1). The same illustrated in 3D graphs representing the response surface generated by the model (Equation. 4.1) are depicted in Fig.4.1.

Analysis of variance (Table B1) showed that the process parameters *viz.,* moisture content of feed and barrel temperature had a significant effect ($p\leq 0.01$) on final product moisture content, but screw speed had no significant effect on moisture content of the product. Also the second order interaction level between moisture content and temperature also found to be highly significant ($p\leq 0.01$). The R- squared value of the model was 0.99.

From Fig 4.1, it was found that the moisture content of the products varied between 4.47 to 6.31%. The maximum value of moisture content obtained at 120°C barrel temperature, 16% moisture content and 350 rpm screw speed where as minimum obtained at 140°C barrel temperature, 12% moisture content and 350 rpm screw speed, respectively.

From Table A1, it was found that feed moisture content exerted maximum influence on moisture content of extrudates. The final moisture content of the extrudates increased from 4.47 to 6.31% (wb) as the feed moisture increased from 12 to16% (w.b). Identical findings also described by Badrie and Mellows (1991b) for cassava based extrudates and Lo *et al.* (1998) for molten corn meal.

The barrel temperature was found to have an adverse effect on the product moisture content. As the barrel temperature increased from 120 to 140°C, the moisture content of the extrudates decreased from 6.31 to 4.47% (w.b). It may be due to increased extrusion temperature leading to larger moisture loss as the product flows through the die. Identical results were described by Ansah *et al.* (1982) for corn extrudates and Badrie and Mellows (1991b) for cassava based extrudates and Rajesh *et al.* (2014) for rice – fish extudates.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict the moisture content of extruded products.

$$\text{Moisture content} = 5.50-0.47A+0.45B-0.035C-0.042AB-0.015AC-5000E-003BC-0.35A^2+0.093B^2+0.16C^2 \quad \ldots\ldots(4.1) \quad (R^2 = 0.99)$$

Where,

A- Temperature, B- Moisture content and C- Screw speed

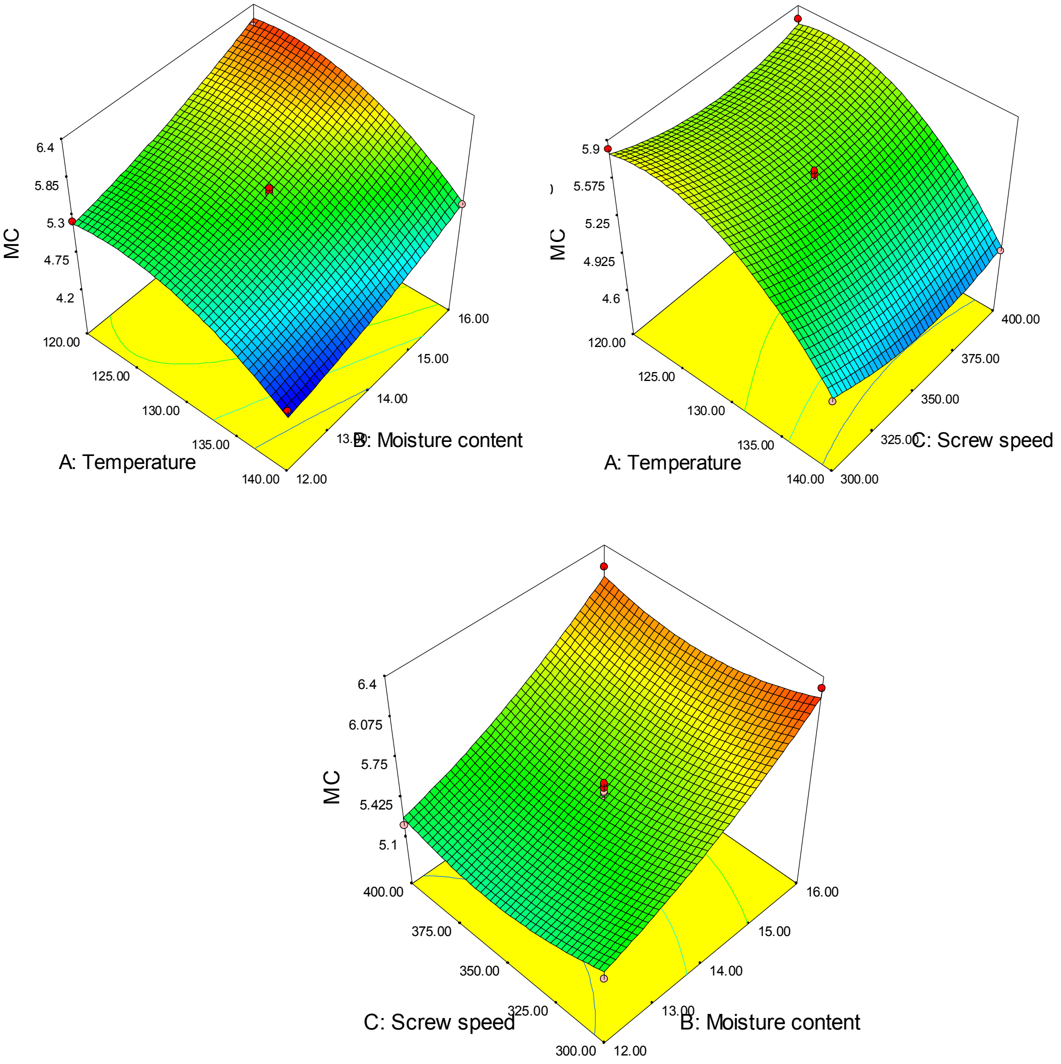


Fig 4.1.Effect of process parameters on moisture content of the extruded products

4.3.1.2. Water activity of RTE extrudates

Water activity determines the available water in the food. It is an important parameter which affects the storage stability of the extrudates. The effects of process parameters on water activity of the extrudates are represented in Appendix A (Table A1). Also the 3D graphs representing the response surface are depicted in Fig.4.2.

Analysis of variance (Table B2) showed that the process parameters *viz.,* moisture content and temperature had a significant effect ($p \leq 0.01$) on water activity of RTE extrudates but screw speed had no significant effect on water activity of final product. Also the second order interaction level between moisture content and temperature also found to be significant ($p \leq 0.05$). The R- squared value of the model was 0.99.

From Fig 4.2 it was found that the water activity of the extrudates varied between 0.423 to 0.538. The extrudates prepared at 120°C barrel temperature, 16% moisture content and 350 rpm screw speed had the maximum value of water activity and minimum value obtained at 140°C barrel temperature, 12% moisture content and 350 rpm screw speed, respectively.

Table A1 shows that moisture content of the feed had a positive relationship with water activity of extrudates. The water activity of the extrudates increased from 0.423 to 0.538 with an increase in feed moisture from 12 to16% (wb). Identical observations were described by Fallahi *et al.* (2013) for extrudates from distillers dried grains.

The barrel temperature was found to have an adverse effect on water activity of extrudates. As the temperature increased from 120 to 140°C, the water activity of the extrudates decreased from 0.538 to 0.423. Identical observations were explained by Foley and Rosentrater (2013) for corn extrudates and Seema (2016) for millet based extrudates.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict the water activity of extruded products.

$$\text{Water activity} = +0.48-0.041A+0.015\,B-7.500E-004C-2.250E-003\,AB-2.500E-004AC+2.500E-004\,B\,C+2.625E-003\,A^{2}-8.750E-004\,B^{2}+2.625E-003\,C^{2} \quad .....(4.2) \qquad (R^{2} = 0.99)$$

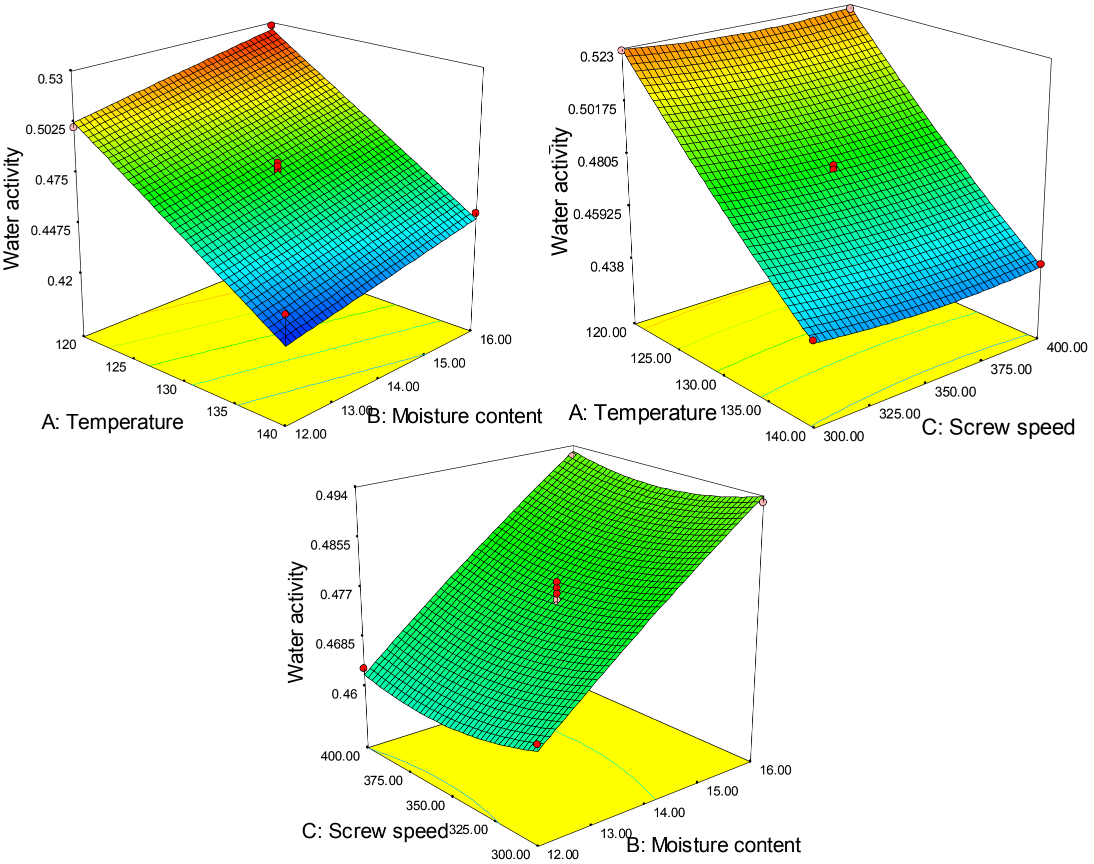


Fig 4.2.Effect of process parameters on water activity of the extruded products

4.3.1.3. Expansion ratio of RTE extrudates

Expansion ratio is the most imperative physical characteristics of the developed RTE food and is considered as an indicator of puffing of extruded snacks. Starch in cereals plays a vital role during extrusion cooking (Bordoloi and Ganguly, 2014). During extrusion, the starch material got gelatinized and the plasticized mass exit through the die. The rapid movement of plasticized mass from high pressure to atmospheric pressure creates a pressure drop, causes a flash-off of internal moisture and the water vapor pressure, which is nucleated to form bubbles in the molten extrudate, leads to the expansion of the molten mass (Arhaliass *et al*., 2003).

The effects of process parameters on expansion ratio of the extrudates are interpreted in Appendix A (Table A1). The 3D graphs representing the response surface generated by the model (Equation. 4.3) and are depicted in Fig.4.3.

From the Analysis of variance (Table B3), it can be seen that all the process parameters *viz.,* moisture content of feed ($p \leq 0.01$), barrel temperature ($p \leq 0.01$) and screw speed had a significant effect ($p \leq 0.05$) on the expansion ratio of RTE extrudates with a R- squared value of 0.98.

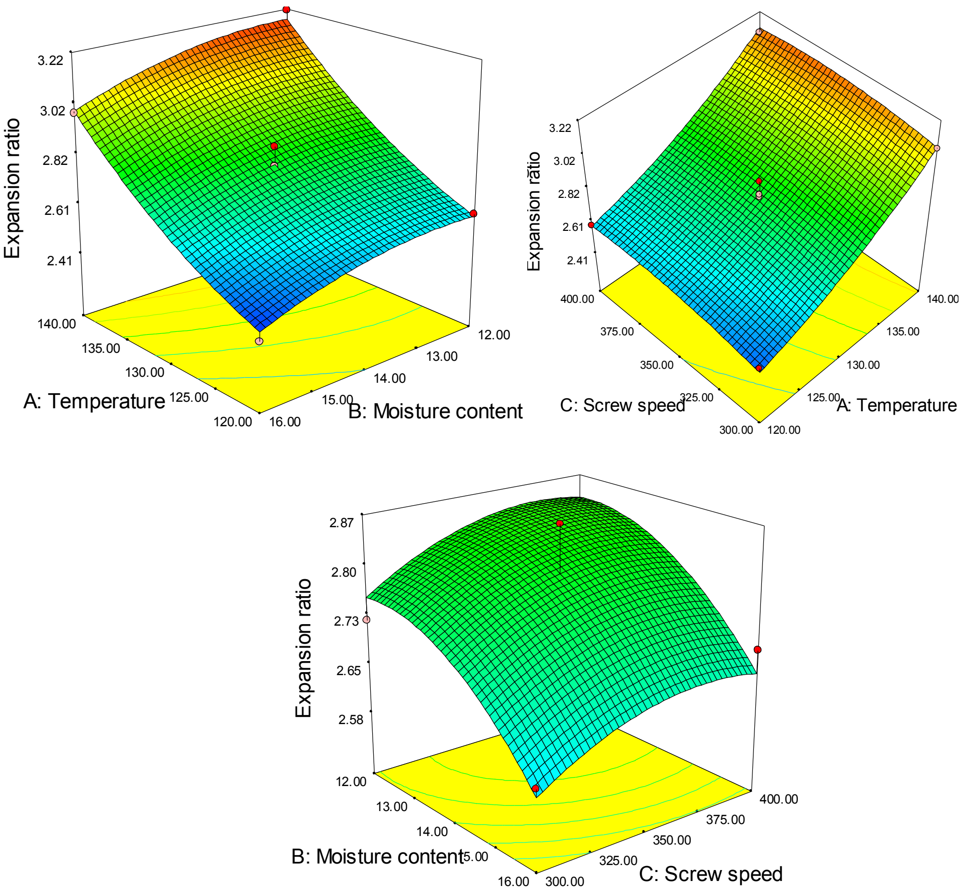


Fig 4.3.Effect of process parameters on expansion ratio of the extruded products

The expansion ratio of the produced extrudates ranges between 2.42 to 3.21. The minimum value of expansion ratio of 2.42 was obtained at 120°C barrel temperature, 16% feed moisture content and 350 rpm screw speed and maximum expansion ratio of 3.21 obtained at 140°C temperature, 12% moisture content and 350 rpm screw speed, respectively.

Table A1 shows that the barrel temperature had a positive impact on expansion ratio of the extrudate. An increment in temperature from 120 to 140°C, increased the expansion ratio of the extrudates from 2.42 to 3.21. The reason for expansion at higher barrel temperature can be attributed to the starch gelatinization and strengthening of structure (Ainsworth *et al.*, 2007). Case *et al.* (1992) explained that, there was a rise in volume of extrudate with increase in starch gelatinization. Identical results were described by and Ali *et al.* (1996) for corn extrudates and Thymi *et al.* (2005) for corn extrudates.

The moisture content of feed showed a negative relationship with expansion ratio of the extrudates, *ie,* the expansion ratio decreased from 3.21 to 2.42 as the moisture content of feed increased from 12 to 16% (w.b). This may be due to the decrease in moisture content increases the drag force and therefore exerts more pressure at the die resulting in greater expansion of extrudate at the exit (Oke *et al.,* 2012). The increase in feed moisture content can reduce the elasticity of the mass by plasticizing the melt and, therefore, reduces gelatinization, decreases expansion and increases density (Korkerd *et al.*, 2016). Identical findings were explained by Armenta *et al.* (2018) for extruded snacks with bagasse of naranjita fruit and Gujral *et al.* (2001) for sweet and flint corn.

The process parameter screw speed also found to have a positive influence on expansion ratio of the extrudates. The expansion ratio varied from 2.42 to 3.21 while the screw speed elevated from 300 to 400 rpm. Elevated screw speeds may be likely to reduce melt viscosity of the mixture enhancing the elasticity of the dough, causing increased expansion and deplition in the density of the extrudate (Ding *et al.,* 2006). Identical findings were explained by Mezreb *et al.* (2003) for corn and wheat based extrudates.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict the expansion ratio of extruded products.

$$\text{Expansion ratio} = 2.80+0.28\ A-0.084\ B+0.039\ C-9.250E\text{-}003\ AB-7.500E\text{-}003\ AC-2.500E\text{-}003\ BC+0.060\ A^2-0.050\ B^2-0.037\ C^2 \quad \text{.......}(4.3)\ (R^2 = 0.98)$$

4.3.2. Engineering Properties

4.3.2.1. Bulk density of RTE extrudates

Bulk density is an essential physical characteristic of RTE snacks which represent the severity of expansion occurring throughout extrusion process. The heat generation occurred at the extrusion raises the temperature of water in the material up to boiling point and when product leaving from the extruder die, water suddenly flashes off and formation of expanded structure with big pores and lesser density were take place. But, if the heat produced was inadequate because of lesser temperature or higher feed moisture, the degree of expansion is lower and the product become denser (Sharma *et al.*, 2016).

The effects of process parameters on bulk density of the extrudates are described in Appendix A (Table A2). The 3D graphs representing the response surface are depicted in Fig.4.4.

Analysis of variance (Table B4) indicates that all the process parameters such as moisture content ($p \leq 0.05$), temperature ($p \leq 0.01$) and screw speed ($p \leq 0.05$) had a significant effect on the bulk density of RTE extrudates. The R- squared value of the model was found to be 0.99.

The bulk density values of the developed RTE extrudates were in the range of 0.652 to 0.858 g/cm^3. The maximum and minimum values of bulk density obtained at a barrel temperature of 120°C, 16% feed moisture content, 350 rpm screw speed and barrel temperature 140°C, 12% feed moisture content and 350 rpm screw speed, respectively.

Table A2 shows that moisture content had a positive correlation with bulk density. From the table, it was understood that an increment in feed moisture content from 12 to 16% (w.b) cause an increase in bulk density of the extrudates from 0.652 to 0.858 g/cm^3. An increase feed moisture content during extrusion process may lower the elasticity of the dough through plasticization of the melt, resulting in decreased specific mechanical energy and thereby lesser gelatinization, reducing the expansion and an increase in the density of extrudate (Ding *et al.,* 2006). Identical trend was observed by Patil *et al.* (1990) for soy rice blend extrudate and Koksel *et al.* (2004) for waxy barley extrudates.

The process parameter barrel temperature had a negative correlation with bulk density. The bulk density of extrudates decreased from 0.858 to 0.652 g/cm^3 as the barrel temperature increased from 120 to 140°C. The viscosity of plasticized mass inside the extruder decrease with increase in barrel temperature and it would enhance the bubble enlargement throughout extrusion cooking and thus lessening the density (Mercier and Fillet, 1975). Elevated temperature imparts additional thermal input, which activate full gelatinization of starch even at larger screw speed that lowered residence time. Identical pattern was observed by Altan *et al*. (2008) for barley flour and tomato pomace and Lin *et al*. (2003) for rice based extrudates.

Screw speed was also found to have a negative correlation with bulk density. From table, it was seen that, increasing screw speed from 300 to 400 rpm decreases the bulk density of extrudates from 0.858 to0.652 g/cm^3. The higher screw speeds may reduce the melt viscosity of the mix which causes an increase in elasticity of the dough and thus producing extrudates with lower density (Fletcher *et al.,* 1985). Identical result was described by Ding *et al.* (2006) for wheat based extrudates and Sharma *et al*. (2016) for protein enriched multi grain exrudates.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict the bulk density of extruded products.

Bulk density = 0.77-0.086 A+9.500E-003 B-7.750E-003 C-6.500E-003 A B-5.000E-004 A C-3.500E-003 B C-0.012 A^2-8.750E-003 B^2+2.500E-004 C^2 ….(4.4) ($R^2 = 0.99$)

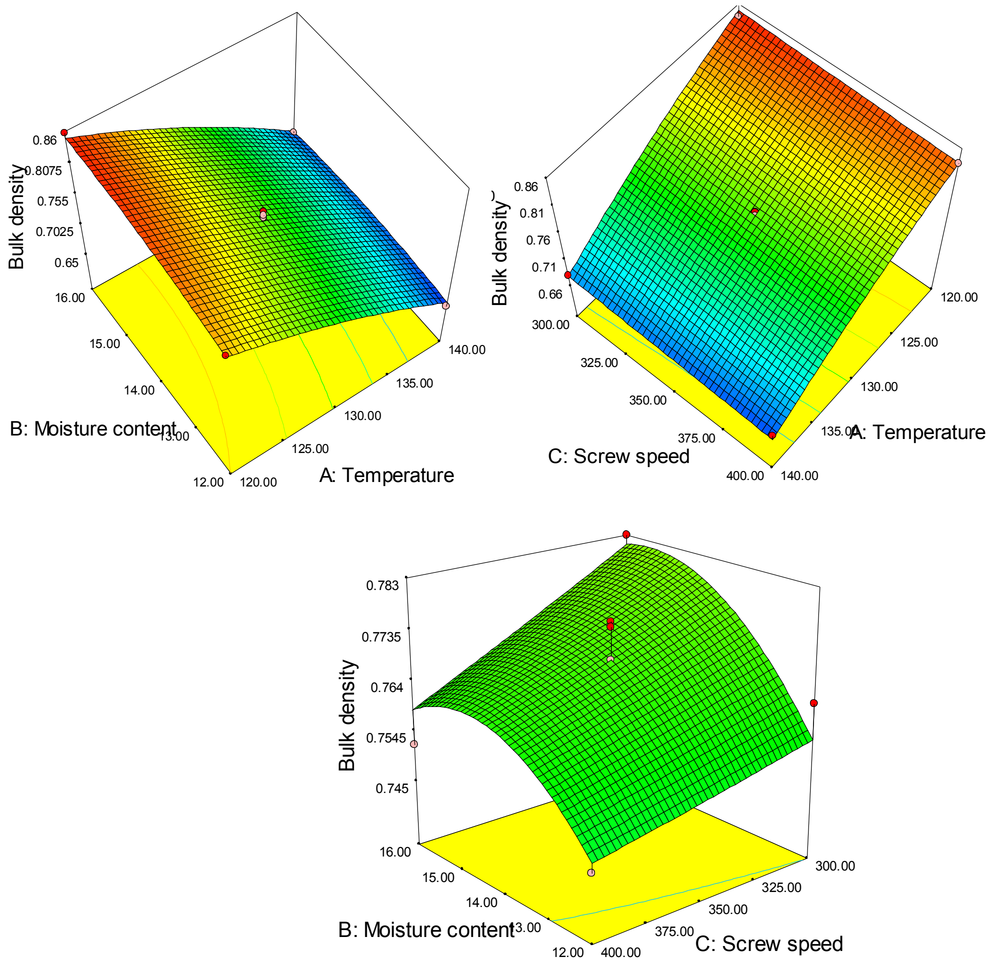


Fig 4.4.Effect of process parameters on bulk density of the extruded products

4.3.2.2. True density of RTE extrudates

True density is a measurable index of the degree of expansion of the extrudates. The effects of process parameters on true density of the extrudates are described in Appendix A (Table A2). The corresponding 3D graphs representing the response surface generated are depicted in Fig.4.5.

Analysis of variance (Table B5) showed that the process parameters *viz.,* moisture content ($p \leq 0.05$), temperature ($p \leq 0.01$) and screw speed ($p \leq 0.05$) had a significant effect on true density of RTE extrudates with an R- squared value of 0.97.

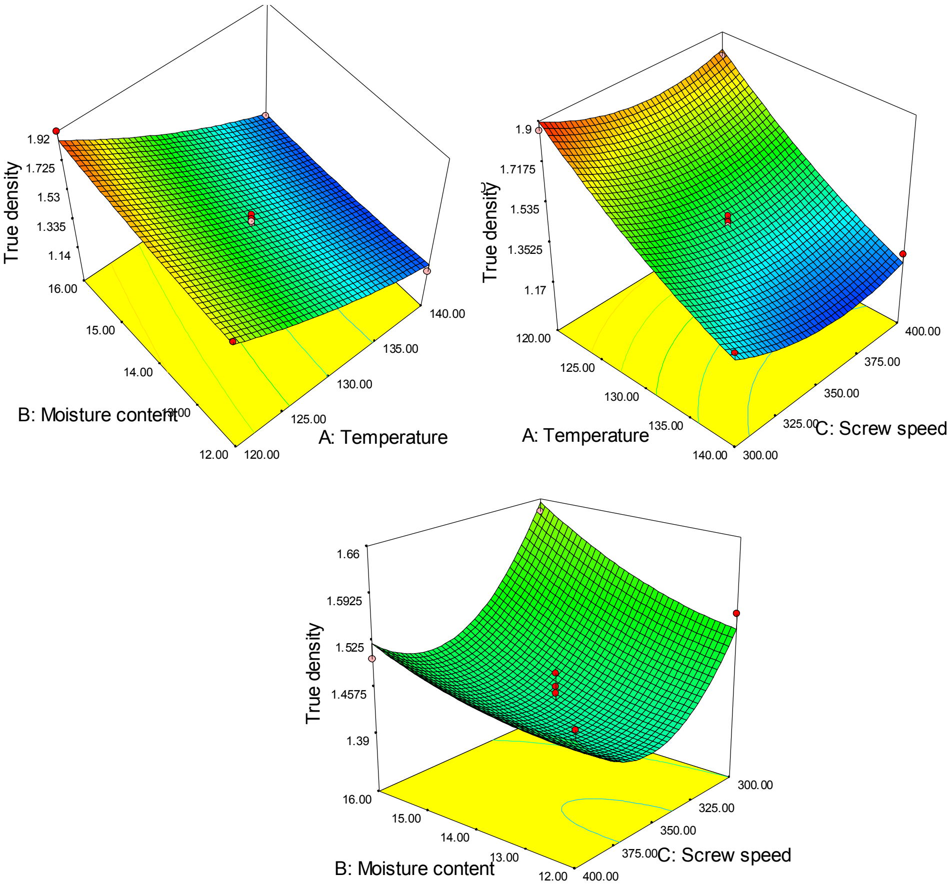


Fig 4.5.Effect of process parameters on true density of the extruded products

Moisture content of feed exerts maximum influence on true density of RTE extrudates. From Fig 4.5 it was found that true density of the developed extrudates varied between 1.15 to 1.92 g/cm^3. The extrudates prepared at a barrel temperature of 120°C, 16% moisture content and 350 rpm screw speed got the maximum true density of 1.92 g/cm^3 and the extrudated prepared at 140°C barrel temperature, 12% moisture content and 350 rpm screw speed had a minimum value of 1.15 g/cm^3.

Table A2 shows that true density has a lowering effect with rise in barrel temperature. The true density of the extrudates decreased from 1.92 to1.15 g/cm^3 with increase in temperature from 120 to 140°C. At higher temperature and screw speed the true density of the extruded products was reduced. The reason may be due to the rapid moisture evaporation at the exit leading to high expansion and low density. Identical findings were reported by Kasprzak and Rzedzicki (2008) for pea extrudates and Thymi *et al*. (2005) for corn extrudates.

The independent variable moisture content had a positive influence on true density of the extrudates. An increment in moisture content of feed from 12 to 16% (w.b), results an increase in true density from 1.15 to 1.92 g/cm^3. The increase in moisture content changes the amylopectin molecular structure in the starch-based material reduce the elasticity of the plasticized mass results a decrease of radial expansion ratio and increase in density (Thymi *et al.,* 2005). Identical findings were reported by Park *et al.* (1993) for single screw extrusion of defatted soy flour, corn starch and raw beef blends and Ilo *et al.* (1999) for rice- amaranthus based extrudates.

Table A2 shows the effect of screw speed on true density of extrudates. It is seen that, an enhancement in screw speed produced a negative impact on the true density of extrudates. The true density of the extrudates decreased from 1.92 to1.15 g/cm^3 with increase in screw speed from 300 to 400 rpm. This may be due to the higher expansion of extrudates at higher screw speed (Fletcher *et al.,* 1985). Identical results were explained by Alam *et al.* (2015) for soy carrot pomace incorporated with wheat extrudates and Sharma *et al*. (2016) for maize based extrudates.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict the true density of extruded products.

True density =1.43-0.29 A +0.044 B -0.046 C -0.037 AB -7.500E-003A C -0.020B C +0.048 A^2 + 0.020 B^2+ 0.095C^2 ….. (4.5) ($R^2 = 0.97$)

4.3.2.3. Porosity of RTE extrudates

Porosity is one of the imperative property of extruded snacks. When the extrudates are leaving from the die due to quick discharge of pressure, numerous minute air pores are developed within the extruded samples (Suknark *et al*., 1997).

The effects of process parameters on porosity of the extrudates are given in Appendix A (Table A2) and the 3D graphs representing the response surface are depicted in Fig.4.6.

Analysis of variance (Table B6) showed that the process parameters such as moisture content ($p \leq 0.01$), temperature ($p \leq 0.01$) and screw speed ($p \leq 0.05$) had a significant effect on porosity of RTE extrudates with an R- squared value of 0.99. The second order interaction level between temperature and moisture content ($p \leq 0.01$), screw speed and moisture content ($p \leq 0.05$) also found to be significant.

The porosity of the extrudates varied between 57.38 to 58.57 %. The minimum porosity obtained at 120°C barrel temperature, 16% moisture content and 350 rpm screw speed and maximum obtained at 140°C barrel temperature, 12% moisture content and 350 rpm screw speed, respectively.

The process parameter barrel temperature had a positive effect on porosity of the extrudates .The porosity of extrudates increased from 57.38 to 58.57 % with increase in barrel temperature from 120 to 140°C. The expansion properties of the extrudates are related to porosity of the extuded product (Yanniotis *et al.,* 2007). Elevated barrel temperature and screw speed results extrudates with larger amount of pores with appreciable amount of porosity. Identical findings were described by Artz *et al.* (1990) and Chaiyakul *et al*. (2009) for rice based extrudates.

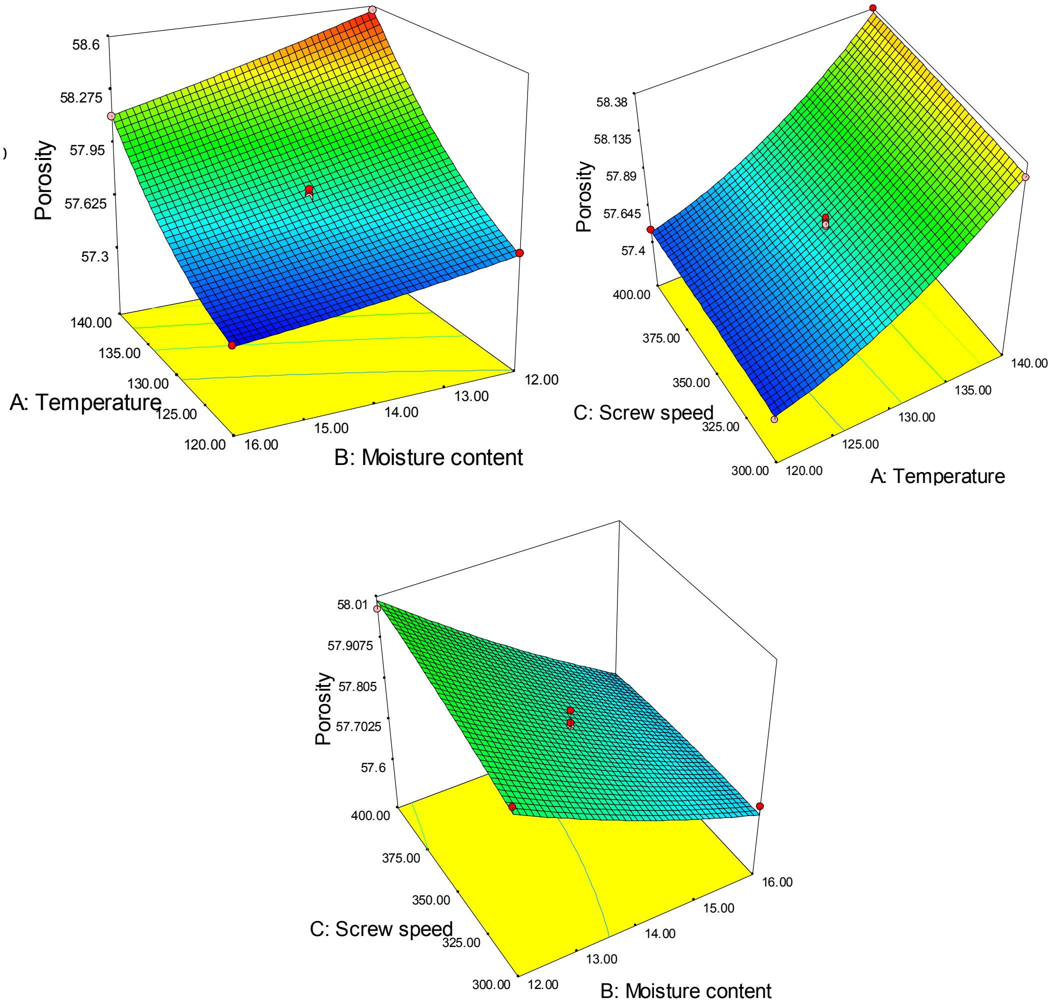


Fig 4.6.Effect of process parameters on porosity of the extruded products

Moisture content of feed had a negative impact on porosity of extrudates. The porosity of the extrudates decreased from 58.57 to 57.38 % with an increase in moisture content from 12 to 16% (w.b). Lower expansion and higher density extrudates were obtained from high moisture content feed (Yanniotis *et al.,* 2007). Identical results were found by Pardhi *et al.* (2017) for brown rice grits and Hagenimana *et al.* (2006) for rice extrudates.

The process parameter screw speed had a positive impact on porosity. The porosity of extrudates increased from 57.38 to 58.57 % with increase in screw speed from 300 to 400rpm. The reason may related to larger expansion and lower density at higher screw speeds (Yanniotis *et al.,* 2007). Identical result was explained by Lin *et al.* (2003) for rice based expanded snacks.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict the porosity of extruded products.

$\text{Porosity} = 57.78 + 0.44\,A - 0.16\,B + 0.026\,C - 0.062\,A\,B + 0.000\,A\,C - 0.032\,B\,C + 0.12\,A^2 + 0.015\,B^2 - 7.500\text{E-}003\,C^2$ …….(4.6) $(R^2 = 0.99)$

4.3.2.4. L Value of RTE extrudates*

Colour is one of the vital property of extruded food products which is related to consumer acceptability. The effects of process parameters on L* value of the extrudates are described in Appendix A (Table A3). The same are illustrated in 3D graphs representing the response surface which is depicted in Fig.4.7.

Analysis of variance (Table B7) showed that the process parameters such as moisture content ($p \leq 0.05$), temperature ($p \leq 0.01$) and screw speed ($p \leq 0.05$) had a significant effect on the L* value of RTE extrudates. The R- squared value of the model was 0.96.

From Fig 4.7 it was observed that L* value of the RTE extrudates ranged from 63.99 to 69.92. The maximum L* value of 69.92 was obtained at 120°C barrel temperature, 14% moisture content and 400 rpm screw speed whereas minimum L* value of 63.99 was obtained at 140°C barrel temperature, 14% moisture content and 300 rpm screw speed, respectively.

The effect of barrel temperature on L* value of RTE extrudates are shown in Table A3. From table, it is observed that the barrel temperature has an inverse effect on L* of the extrudates. An increase in barrel temperature from 120 to 140°C, the L* value of extrudates reduced from 69.92 to 63.99. It may be due to occurrence of Maillard reaction at higher temperature (Sacchetti *et al.,* 2004). Identical result was reported by Fernandez *et al*. (2004) and Kamal (2012) for rice and cassava based extrudates.

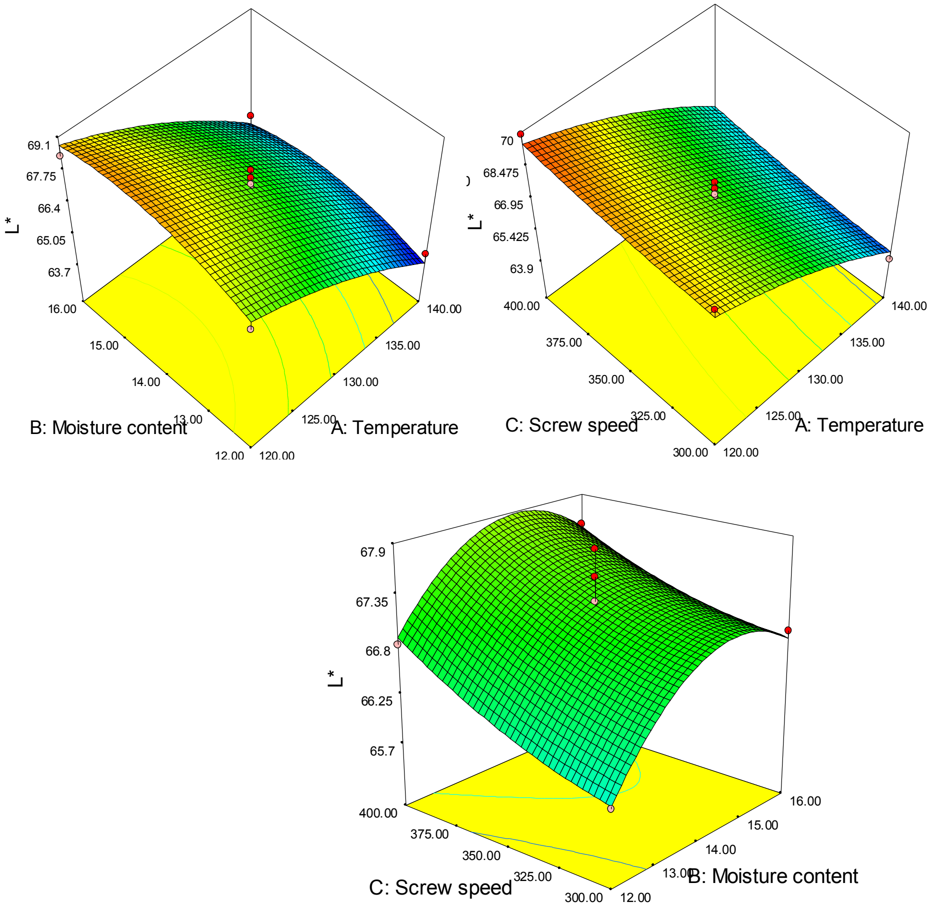


Fig 4.7.Effect of process parameters on L* value of the extruded products

Moisture content of the feed had a positive interaction with L* value of the extrudates. The L* value increased from 63.99 to 69.92 with an increment in moisture content from 12 to 16%. It may be due to the lesser possibility of occurrence of Maillard reaction at higher moisture content. Sacchetti *et al.* (2004) reported that changes in colour intensity may be attributed to the non enzymatic browning reaction between the reducing sugars (dextrinised starch) and amino groups from proteins and it largely occur at lower moisture content. Identical findings were reported by Wen *et al*. (1990) for corn extrudates and Yusuf (2018) for Sorghum based extrudates.

Screw speed also found to have a positive impact on L* value of the extrudates. The L* value increased from 63.99 to 69.92 with increase in screw speed from 300 to 400 rpm. It may probably due to lower residence time at higher screw speed. Identical results were explained by Nissar *et al.* (2017) for the corn- honey extruded breakfast snacks.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict the L* value of extruded products.

$L^* = 67.27 - 2.12\ A + 0.39\ B + 0.45\ C - 0.075\ A\,B + 0.022\ A\,C - 0.078\ B\,C - 0.42\ A^2 - 0.64\ B^2 + 0.13\ C^2$……(4.7) $(R^2 = 0.96)$

4.3.2.5. a Value of RTE extrudates*

The effects of process parameters on a* value of the extrudates are described in Appendix A (Table A3). Also the 3D graphs representing the response surface are depicted in Fig.4.8.

Analysis of variance (Table B8) showed that the process parameters such as moisture content ($p \leq 0.01$), temperature ($p \leq 0.01$) and screw speed ($p \leq 0.05$) had a significant effect on the a* value of RTE extrudates. Also second order interaction level between temperature and moisture content ($p \leq 0.01$) also found to be significant. The R- squared value of the model was 0.99.

The colour parameter a* value of the extruded products varied from 4.21 to 5.32. The maximum a* value obtained at 140°C temperature, 12% moisture content and 350 rpm screw speed and minimum a* obtained at 120°C temperature, 16% moisture content and 350 rpm screw speed, respectively.

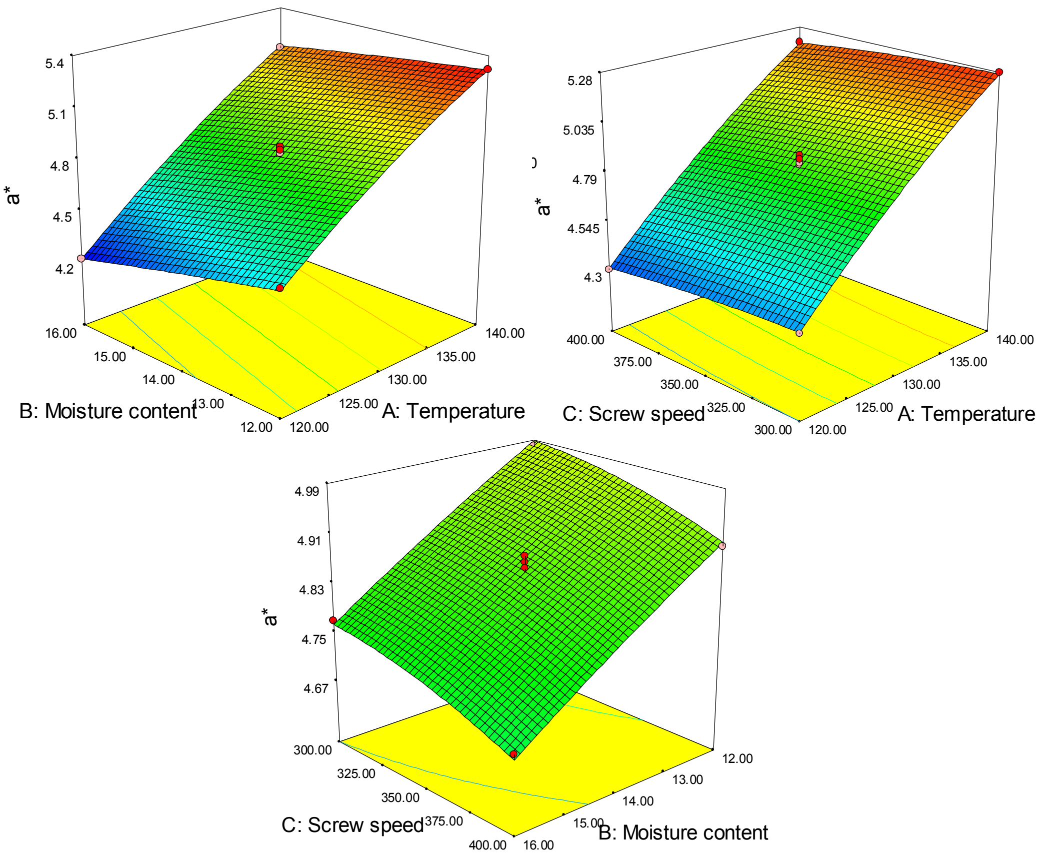


Fig 4.8.Effect of process parameters on a* value of the extruded products

Table A3 shows that temperature had a positive effect on a* value of the extrudates. The a* value rised from 4.21 to 5.32 with increase in temperature from 120 to 140°C. It may be due to the fact that degradation of pigment was accelerated at higher temperature (Altan *et al.,* 2008). Identical observations was described by Ilo *et al*. (1999) for rice – amaraths extrudates .

The process parameter moisture content had a negative influence on a* value of the extrudates. The a * value decreased from 5.32 to 4.21 with increment in moisture content from 12 to 16%. It may be due to higher L* at higher moisture content. Also, increases in moisture reduced the residential time, which led to less non-enzymatic browning of RTE extrudates (Gutkoski and El-Dash, 1999). Identical result was found by Yusuf (2018) for Sorghum based extrudates.

The screw speed had negative influence on a* value of the extrudates. The a * value decreased from 5.32to 4.21 with increase in screw speed from 300 to 400rpm. The low a* value observed at high screw speed may related to shorter residence time (Nissar *et al.,* 2017). Identical result was found by Maga and Kim (1989) for rice extrudates.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict a* value of extruded products.

$a^* = 4.86 + 0.44\ A - 0.11\ B - 0.041\ C + 0.035\ A\ B + 2.500E{-}003\ A\ C + 0.000\ B\ C - 0.049\ A^2 - 6.250E{-}003\ B^2 - 0.014\ C^2$ ……. (4.8) ($R^2 = 0.99$)

4.3.2.6. b Value of RTE extrudates*

The effects of process parameters on b* value of the extrudates are described in Appendix A (Table A3) and the corresponding 3D graphs representing the response surface are depicted in Fig.4.9.

Analysis of variance (Table B9) reveals that the process parameters such as moisture content ($p \leq 0.01$), temperature ($p \leq 0.01$) and screw speed ($p \leq 0.05$) had a significant effect on the b* value of RTE extrudates with an R- squared value of 0.99. Also second order interaction level between temperature and moisture content ($p \leq 0.05$) found to be significant.

From Fig 4.9 it was found that, colour parameter b* value of the extruded products varied from 17.43 to 18.62. The maximum b* value of 18.62 was obtained at 140°C barrel temperature, 12% moisture content and 350 rpm screw speed. Similarly, the minimum b* value of 17.43 was attained at 120°C barrel temperature, 16% moisture content and 350 rpm screw speed, respectively.

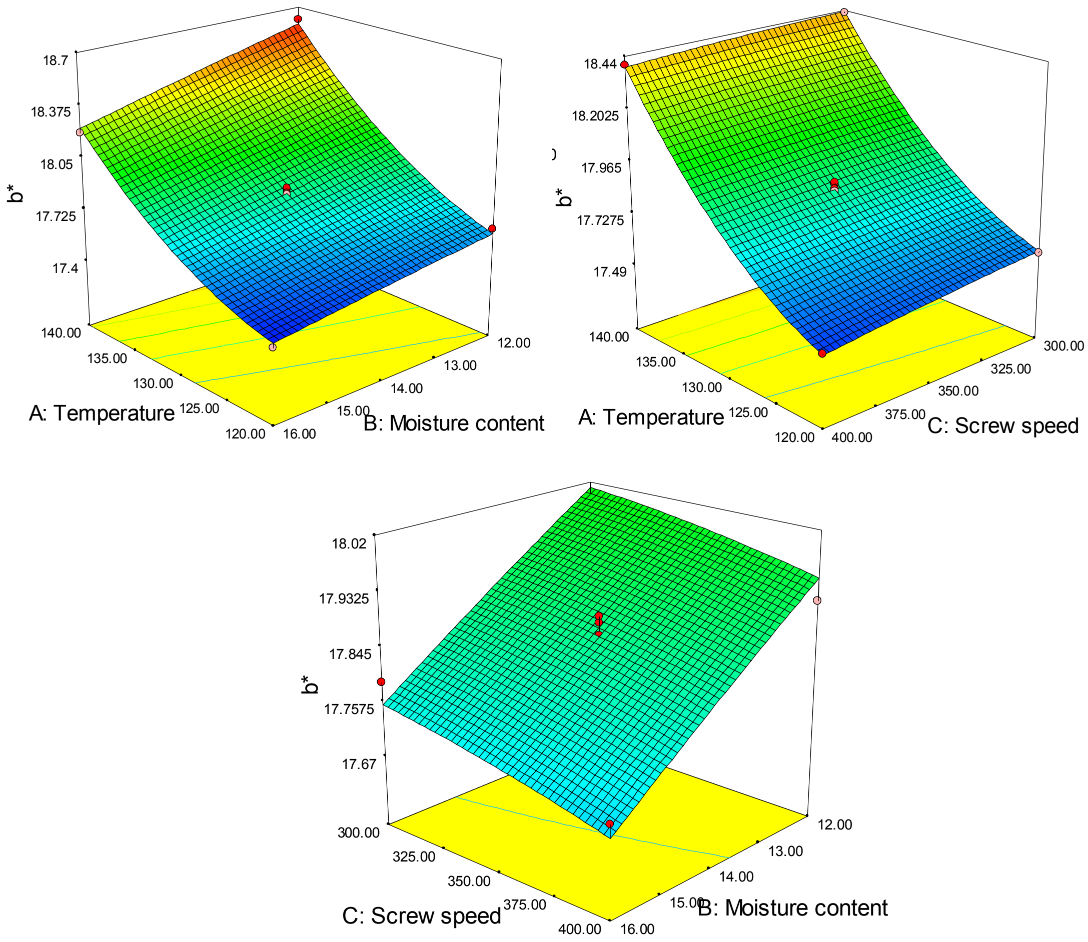


Fig 4.9.Effect of process parameters on b* value of the extruded products

The process parameter barrel temperature had a positive impact on b* value of the extrudates. As the barrel temperature raised from 120 to 140°C, the corresponding b* value raised from 17.43 to 18.62. It may be due to the fact that degradation of pigment was accelerated at higher temperature (Altan *et al.,* 2008). Identical results were described by Ilo *et al.* (1999) for rice – amaranths extrudates , Altan *et al.* (2009) for barley based extrudates and Ali *et al.* (2008). Generally with increasing temperature, the products had lesser L* values with larger a* and b* values (Kamal, 2012).

The moisture content of feed had a negative influence on b* value of the extrudates. As the moisture content of feed increased from 12 to 16%, b * value decreased from 18.62 to 17.43. Increases in moisture content reduced the residential time, which led to less non-enzymatic browning of RTE extrudates (Gutkoski and El-Dash, 1999). Identical result was found by Yusuf (2018) for Sorghum based extrudates and Bardie and Mellowes (1991b) for cassava extrudates.

The screw speed had negative influence on b* value of the extrudates. The b * value decreased from 18.62 to 17.43 with increase in screw speed from 300 to 400rpm. The low b* value observed at high screw speed may related to shorter residence time (Nissar *et al.,* 2017). Identical result was found by Gutkoski and El-Dash (1999) and Bardie and Mellowes (1991b) for cassava extrudates.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict b* value of extruded products.

$$b^* = 17.86 + 0.44\ A - 0.13\ B - 0.035\ C - 0.045\ A\ B + 0.012\ A\ C - 2.500E\text{-}003\ B\ C + 0.13\ A^2 - 4.167E\text{-}003\ B^2 - 6.667E\text{-}003\ C^2 \ldots\ldots (4.9) \quad (R^2 = 0.99)$$

4.3.2.7. Hardness of RTE extrudates

Hardness is one of the important textural property which indicates the peak force requires to compress an extruded product (Varsha and Mohan, 2016). The effects of process parameters on hardness of the extrudates are described in Appendix A (Table A4). Also the 3D graphs representing the response surface are depicted in Fig.4.10.

Analysis of variance (Table B10) showed that all the process parameters *viz.,* moisture content ($p \leq 0.05$), temperature ($p \leq 0.01$) and screw speed ($p \leq 0.05$) had significant effect on hardness of RTE extrudates. The R- squared value of the model was found to be 0.97.

The hardness of the RTE extrudates varied from 23.52 to 33.86 N. The maximum and minimum hardness of 33.86 and 23.52 N were attained for the extrusion conditions of 120°C barrel temperature, 16% moisture content, 350 rpm screw speed and 140°C barrel temperature, 12% moisture content and 350 rpm screw speed, respectively.

Moisture content of the feed highly influences the hardness of extrudates (Table A4). From table, it was understood that moisture content of feed had a positive effect on hardness. As the moisture content of feed increase from 12 to 16%, hardness values of the samples were increased from 23.52 to 33.86 N. The reason may due to plasticizing characteristics of starch containing ingredients causing viscosity reduction and the mechanical energy liberation in the extruder and thus producing the product somewhat denser and suppress the bubble development (Chiu *et al*., 2013). Identical results were found by Kanojia *et al.* (2016) for extruded snacks with broken rice- okara and Rajesh *et al.* (2014) for rice-fish extrudates.

Hardness of the extrudates showed a negative relation with barrel temperature. Table A4 indicates a reduction in hardness value of extrudates with increment in barrel temperature. The hardness value decreased from 33.86 to 23.52 N with increment in barrel temperature from 120 to 140°C. It may be related with the expansion of plasticized mass. An increase in temperature increased the degree of superheating of water in the extruder, enhancing bubble development and also decreased melt viscosity, leading to reduce density and hardness of extrudate (Mercier and Feillet, 1975). Identical findings were reported by Chaiyakul *et al.* (2009) for high-protein, glutinous rice-based extrudates and Obradovic *et al.* (2015) for corn extrudates enriched with tomato powder and ascorbic acid.

Screw speed was also found to have a negative relation with hardness of the extrudates. Hardness of the extrudates decreased from 33.86 to 23.52 N with increase in screw speed from 300 to 400 rpm. It may be related to higher expansion and lower density of extrudates at higher screw speed (Ding *et al.,* 2005; Sharma *et al.,* 2016).

Identical results were described by Altan *et al.* (2008) for barley based extrudates and Liu *et al.* (2000) for oat- corn extrudates.

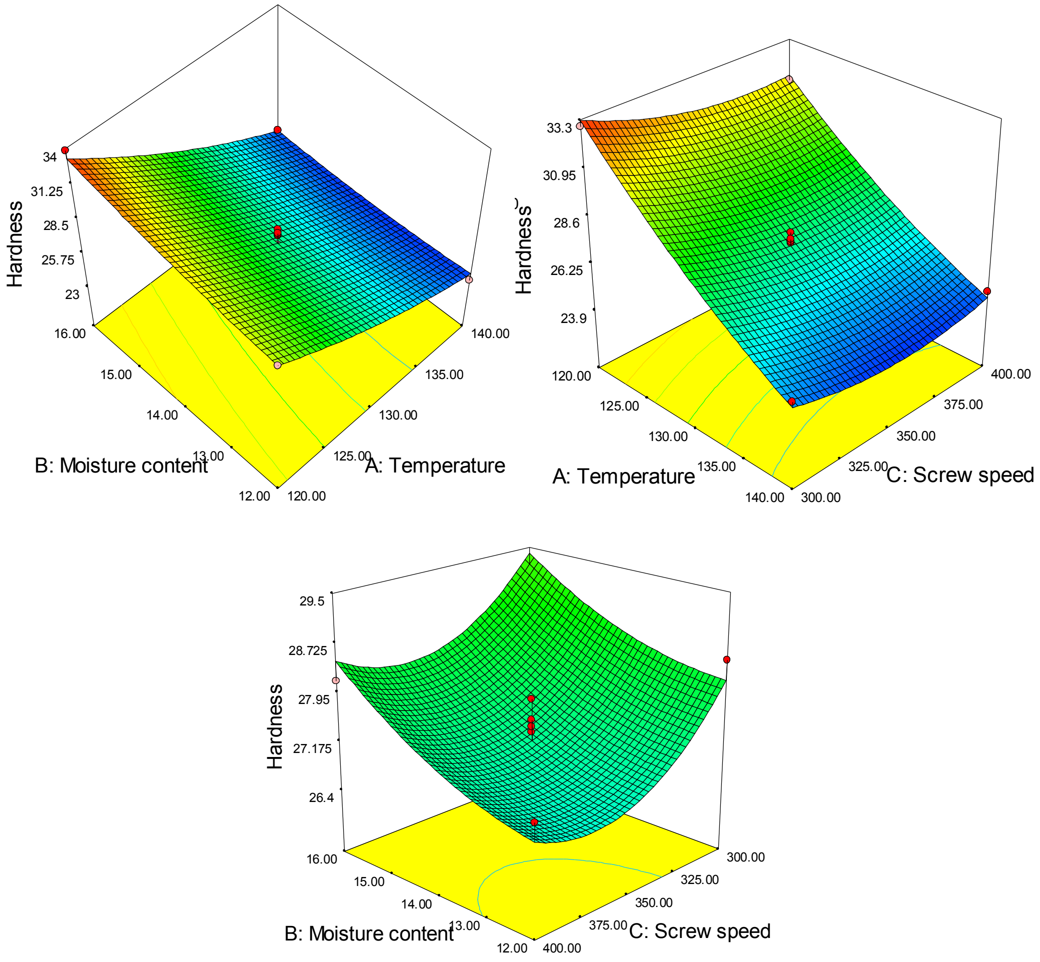


Fig 4.10.Effect of process parameters on hardness of the extruded products

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict hardness of extruded products.

$$\text{Hardness} = 27.19 - 3.86\,A + 0.72\,B - 0.56\,C - 0.63\,AB + 0.35\,AC + 0.090\,BC + 0.60\,A^2 + 0.28\,B^2 + 0.74\,C^2 \quad \ldots\ldots(4.10) \qquad (R^2 = 0.97)$$

4.3.2.8. Fracturability of RTE extrudates

Fracturability is the force with which a material fractures, usually displayed by a product of high degree of hardness. The effects of process parameters on fracturability of the extrudates are described in Appendix A (Table A4). The same are illustrated in 3D graphs representing the response surface generated by the model (Equation. 4.11) and are depicted in Fig.4.11.

Analysis of variance (Table B10) showed that the process parameters such as moisture content ($p \leq 0.05$), temperature ($p \leq 0.01$) and screw speed ($p \leq 0.05$) had significant effect on the fracturability of RTE extrudates. The R- squared value of the model was found to be 0.96.

The fracturability of the RTE extrudates varied from 10.30 to 20.54 N. Extrudates produced at a barrel temperature of 120°C, 16% moisture content and 350 rpm screw speed had the highest fracturability value and that prepared at 140°C temperature, 12% moisture content and 350 rpm screw speed was found to be minimum fracturability.

From Table A4, it was revealed that fracturability had a positive effect on moisture content of feed material. Fracturability of the extrudates increased from 10.30 to 20.54 N with increase in moisture content from 12 to 16%. It may be due to reduced expansion and larger density at higher moisture content (Badrie and Mellowes, 1991a). Identical result was explained by Pardhi *et al.* (2017).

Fracturability of the extrudates showed a negative relation with temperature. Fracturability of the extrudates decreased from 20.54 to 10.30 N with increasing temperature from 120 to 140°C. It may be related with their effect on expansion and higher temperature leads to higher expansion. Choudhury and Gautam (1998) stated that increase in radial expansion decrease the breaking strength. Identical results were described by Nino *et al.* (2018) for taro flour extruates and Ding *et al.* (2006) for wheat exrudates.

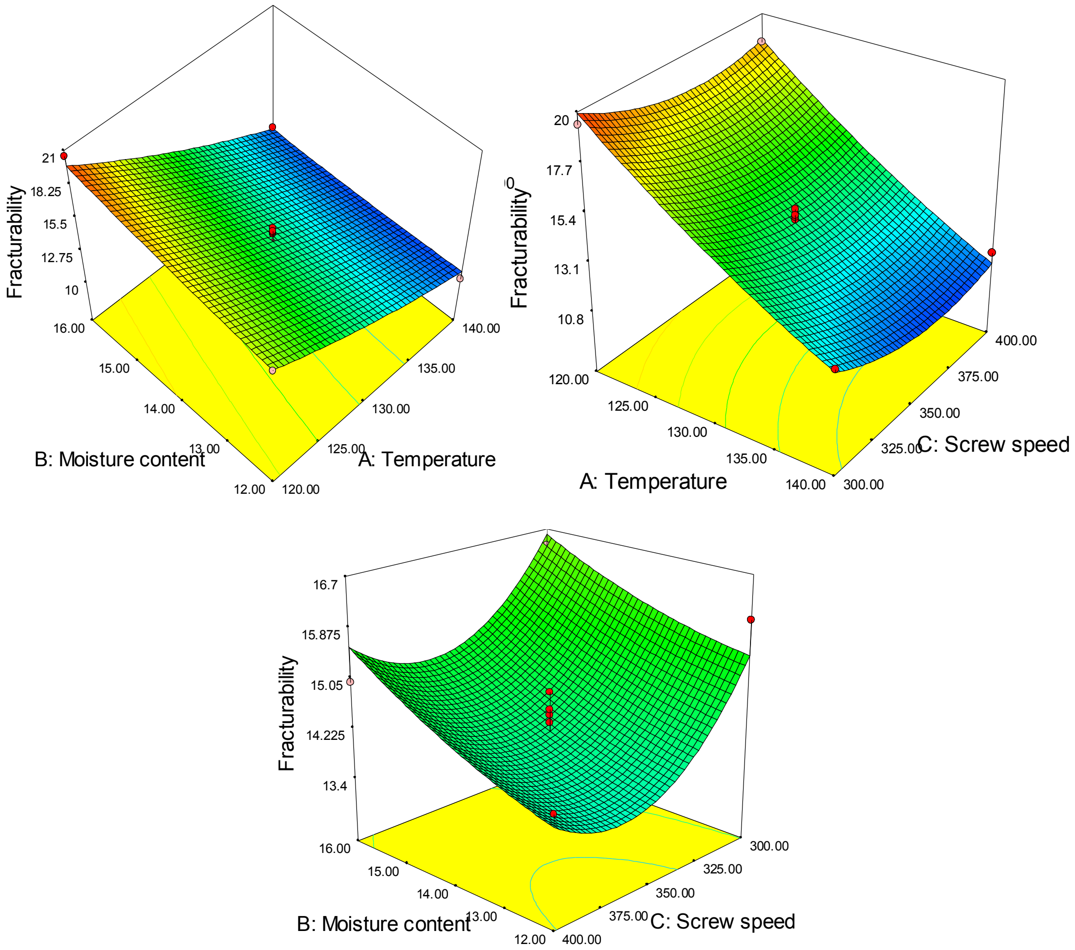


Fig 4.11.Effect of process parameters on fracturability of the extruded products

Screw speed was also found to have a negative relation with fracturability of the extrudates. Fracturability of the extrudates decreased from 20.54 to 10.30 N with increasing temperature from 300to 400rpm. It may be related to higher expansion and lower density of extrudates at higher screw speed (Ding *et al.,* 2005). Identical results were explained by Altan *et al.* (2008) for barley based extrudates and Liu *et al.* (2000) for oat- corn extrudates.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict fracturability of extruded products.

$$\text{Fracturability} = 14.17 - 3.69\,A + 0.71\,B - 0.63\,C - 0.63\,AB - 0.035\,AC + 0.11\,BC + 0.45\,A^2 + 0.17\,B^2 + 1.04\,C^2 \ldots\ldots (4.11) \qquad (R^2 = 0.96)$$

4.3.2.8. Crispness of RTE extrudates

Crispness is a textural property manifested by a tendency when subjected to an applied force to yield suddenly with a characteristics sound. Foods described as crisp favour not to show signs of deformation prior to fracture (Vickers and Bourne, 1976). The effects of process parameters on crispness of the extrudates are described in Appendix A (Table A4) and the 3D graphs representing the response surface are depicted in Fig.4.12.

From the analysis of variance (Table B12), it was obvious that all the process parameters such as moisture content, temperature and screw speed affecting the crispness of extrudates significantly at 1% ($p \leq 0.01$). The R- squared value of the model was 0.98.

The crispness of the extrudates varied from 45.23 to 55.72 N. The maximum crispness of extrudates was obtained at process parameters 140°C barrel temperature, 12% moisture content and 350 rpm screw speed and minimum crispness was obtained for process parameters 120°C barrel temperature, 16% moisture content and 350 rpm screw speed.

Table A4 shows that the crispness of extrudates increased significantly with an increase in barrel temperature. Crispness increased from 45.23 to 55.72 N with increase in temperature from 120 to 140°C. It may due to, at high temperatures, the feed moisture flashes off as steam and causes bubble growth resulting a higher crispy texture of extrudates (Mercier and Feillet, 1975). Identical findings were described by Kumar *et al*. (2015) for sorghum and soya extrudates and Hussain *et al.* (2017) for rice extrudates.

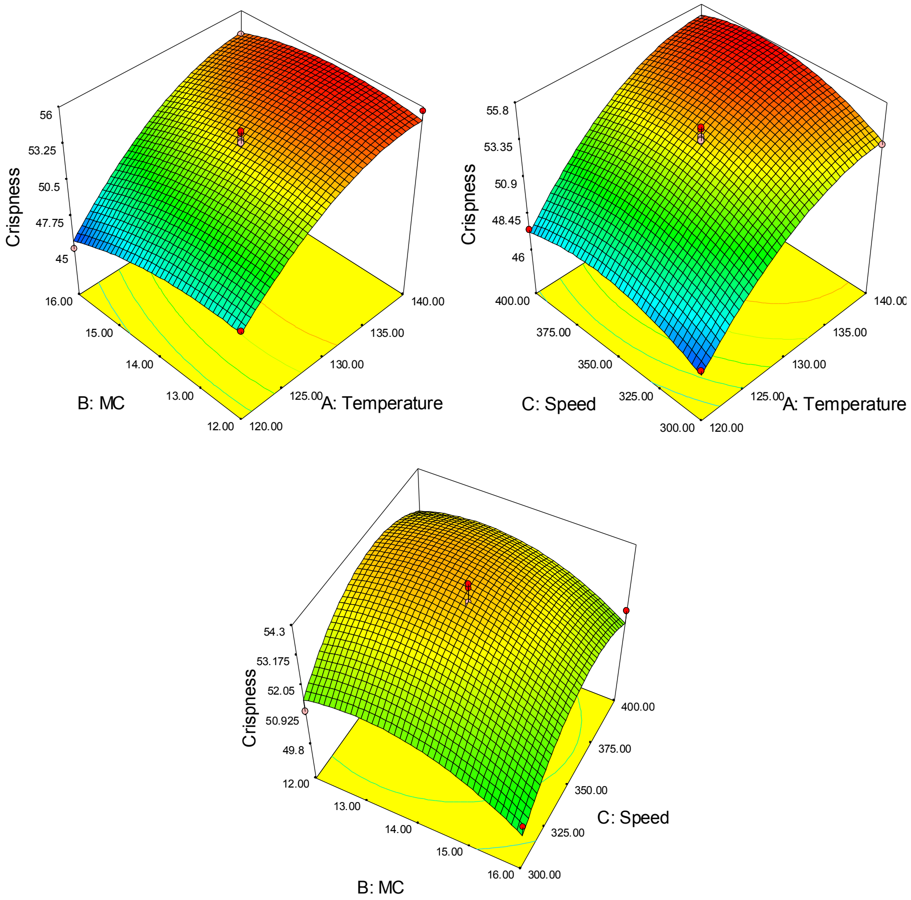


Fig 4.12.Effect of process parameters on crispness of the extruded products

Crispness of the extrudates was found to have a reverse effect with moisture content of the feed. The crispness of the extrudates decreased from 55.72 to 45.23 N with increase in feed moisture from 12 to 16% (wb). The water plays as a plasticizer to the starch containing ingredients lowering its viscosity and also the mechanical energy liberation in the extruder and consequently the product becomes more denser and bubble growth is suppresses and reducing crispness (Ding *et al*., 2005). Identical observations were reported by Kanojia *et al.* (2016) for rice and okra based extrudates and Kanojia and Singh (2016) for rice based extrudates.

The process parameter screw speed had a positive relation with crispness of the extrudates. Crispness of the extrudates increased from 45.23 to 55.72 N with increase in screw speed from 300 to 400 rpm. Increasing screw speed improved the expansion of extrudate and increased mechanical energy delivered to the material. At higher screw speed, due to enhanced starch conversion, products become more crispy (Kumar *et al.,* 2015). Identical result were found by Seker (2005) for modified maize starch-soy protein mixtures, Meng *et al*. (2010) for chickpea based extrudates and Hussain *et al.* (2017) for rice extrudates.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict crispness of extruded products.

$$\text{Crispness} = 53.71 + 3.80\,A - 0.78\,B + 0.73\,C + 0.45\,AB + 0.14\,AC + 0.11\,BC - 1.88\,A^2 - 0.90\,B^2 - 1.37\,C^2 \ldots\ldots(4.12) \quad (R^2 = 0.98)$$

4.3.3. Functional Properties

4.3.3.1. Water solubility index (WSI)

Kirby *et al.* (1988) stated that WSI frequently used as an index of degradation of molecular constituents. WSI estimates the quantity of soluble constituents liberated from the starch following extrusion process. Higher WSI is an in vitro indicator of better starch digestibility as it implicit the level of dextrinization and gelatinization (Guha *et al.,* 1997). It can also estimate the magnitude of starch transformation occurring at the time of extrusion, which correlates to the quantity of soluble polysaccharide liberated from the starch (Ding *et al*., 2005).

The effects of process parameters on WSI of the extrudates are given in Appendix A (Table A5). The same are illustrated in 3D graphs representing the response surface generated by the model (Equation. 4.13) and are depicted in Fig.4.13.

Analysis of variance (Table B13) shows that the effect of process parameters such as moisture content of feed, barrel temperature and screw speed on WSI of extrudates was highly significant at 1% ($p \leq 0.01$) with a R- squared value of 0.97.

The WSI of RTE snacks ranged from 15.68 to 30.25%. The maximum WSI obtained for the extrusion condition of 140°C temperature, 12% moisture content and 350 rpm screw speed and minimum value obtained at 120°C temperature, 16% moisture content and 350 rpm screw speed.

From Table A5, it was obvious that barrel temperature had a positive correlation with WSI of the extrudates. WSI increased from 15.68 to 30.25% with increase in temperature from 120 to 140°C. It may be due to the fact that elevated temperature imparts additional soluble constituents leads to increment in WSI (Ding *et al.,* 2005). The results were also supported by the findings of Sobukola *et al.* (2012) and Anderson *et al.* (1969) for corn grits extrudates.

The process parameter moisture content had an inverse effect on WSI. WSI decreased from 30.25 to 15.68% with increase in moisture content from 12to 16% (w.b). This trend was created by lesser shear disintegration of the starch at the time of extrusion at elevated moisture contents causing lower WSI (Pardhi *et al*., 2017). Identical results were described by Ding *et al*. (2005), Harper (1979) and Mercier and Feillet (1975).

The screw speed had a positive relation with WSI of the extrudates. As the screw speed increased from 300 to 400rpm, WSI of extrudates increased from 15.68 to 30.25%.The increment in screw speed causes increment in specific mechanical energy which leads to the breakdown of macromolecules and thus causing rise in soluble constituents after extrusion cooking. The higher mechanical shear enhanced breakdown of macromolecules to micro molecules with elevated solubility (Dogan and Karwe, 2003). Identical findings were explained by Choudhury and Gautam (1998) and Gonzales *et al.* (2007).

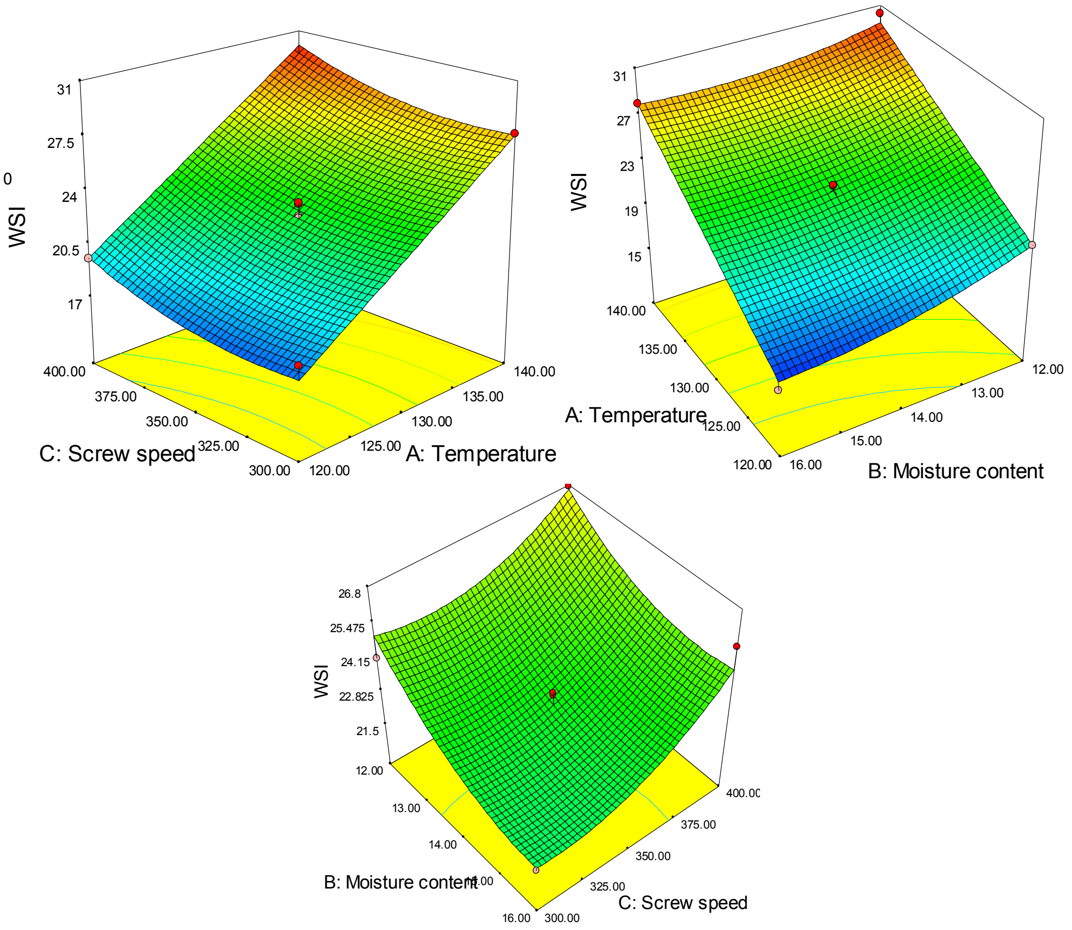


Fig 4.13.Effect of process parameters on WSI of the extruded products

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict WSI of extruded products.

$$WSI = 22.73 + 5.15\ A - 1.36\ B + 1.15\ C + 0.62\ A\ B + 0.062\ A\ C + 0.33\ B\ C + 0.024\ A^2 + 0.83\ B^2 + 0.90\ C^2 \quad \ldots\ldots.(4.13) \qquad (R^2 = 0.97)$$

4.3.3.2. Water absorption index (WAI)

Water absorption index (WAI) measures the volume taken by starch polymer after swelling in additional water. It normally indicates the dispersion of starch in excess water, and the dispersion is enhanced by the amount of starch damage due to gelatinization and extrusion-induced fragmentation, ie., molecular weight reduction of amylose and amylopectin molecules (Duarte *et al.,* 1998).

The effects of process parameters on WAI of the extrudates are given in Appendix A (Table A5). The 3D graphs representing the response surface are depicted in Fig.4.14. Analysis of variance (Table B14) showed that the process parameters such as moisture content ($p \leq 0.05$), temperature ($p \leq 0.01$) and screw speed ($p \leq 0.01$) had significant effect on WAI of RTE extrudates. The R- squared value of the model was found to be 0.98.

The WAI of extrudates samples varied from 3.40 to 5.61 g/g. Fig. 4.14 shows that WAI of extrudates increased significantly with an increase in barrel temperature. However, a reverse effect was observed with moisture content of feed and screw speed. The maximum WAI value of 5.61 g/g was obtained for sample extruded at 140°C barrel temperature, 12% moisture content and 350 rpm screw speed and minimum value of 3.40 g/g was obtained for 120°C temperature, 14% moisture content and 400 rpm screw speed, respectively.

From Fig. 4.14, it was understood that WAI increased from 3.40 to 5.61 g/g as the barrel temperature increased from 120 to 140°C. As temperature rises, the starch got damaged because of gelatinization and extrusion process. Also, elevated temperature produced dextrinization, which create additional hydrophilic space and therefore increased WAI (Mercier and Feillet, 1975). Identical results were explained by Sharma *et al.* (2016) for multigrain expanded products and Kumar *et al.* (2010) for rice based extrudates.

The process parameter moisture content had a negative effect on WAI of the extrudates. WAI decreased from 5.61 to 3.40 g/g with increase in moisture content from 12 to 16% (w.b). It may due to the fact that at higher moisture situations cause lesser shear debasement of starch throughout extrusion (Anastase *et al.*, 2006). Identical results were observed by Ding *et al.* (2006) for wheat extrudates, Sharma *et* *al*. (2016) for multigrain extrudates and Kumar *et al*. (2015) for sorghum- soy extrudates.

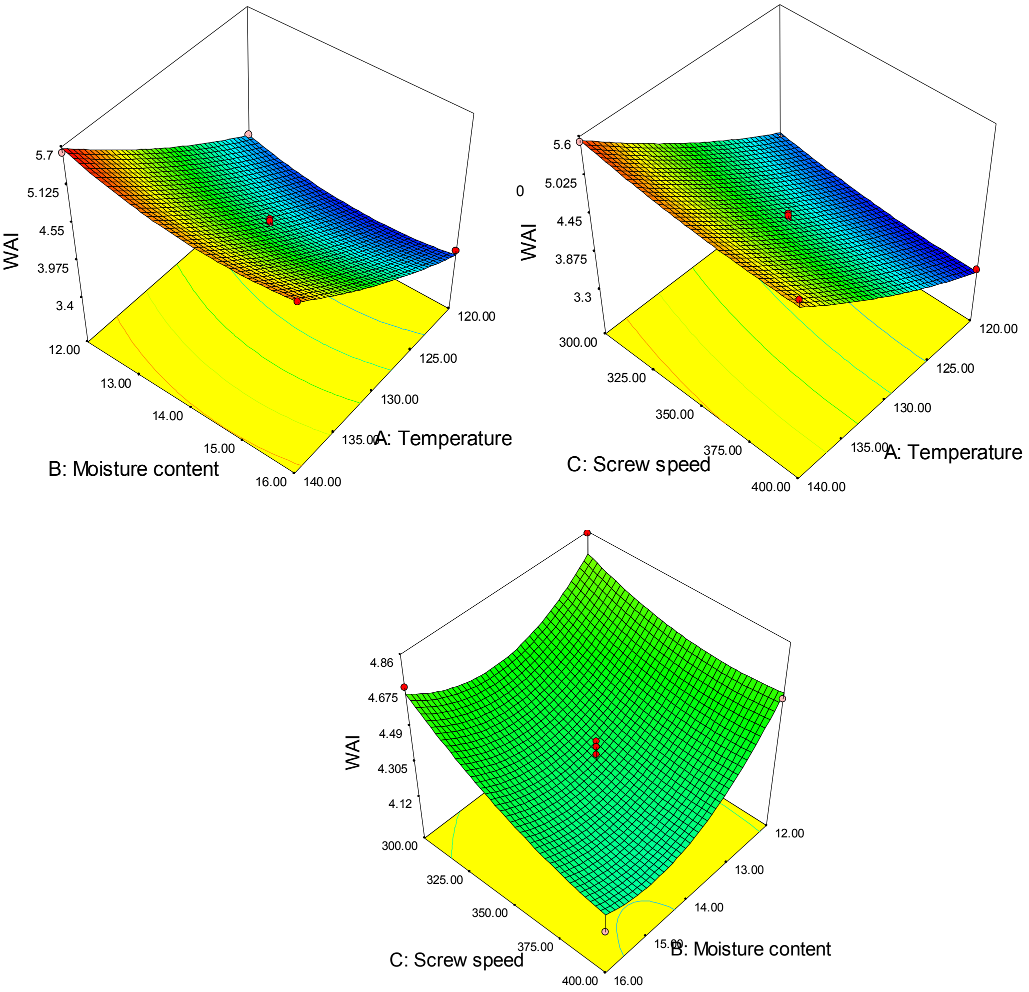


Fig 4.14.Effect of process parameters on WAI of the extruded products

Screw speed also found to have a negative effect on WAI of the extrudates. WAI increased from 3.40 to 5.61 g/g with decrease in screw speed from 400 to 300rpm. This is due to the fact that high input of thermal energy due to high residence time ie., at low screw speeds may cause enhanced level of starch degradation and increased WAI (Yagcı *et al.,* 2008). Identical results were explained by Yousf *et al*. (2017) for extruded products from rice and carrot, Pardhi *et al*. (2017) and Hussain *et al.* (2017) for rice extrudates.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict WAI of extruded products.

$WAI = 4.29 + 0.94\ A - 0.12\ B - 0.15\ C - 0.020\ A\ B + 7.500E{-}003\ AC - 0.078\ B\ C + 0.11\ A^2 + 0.20\ B^2 + 0.072\ C^2$ ……(4.14) ($R^2 = 0.98$)

4.3.4. Proximate Components

4.3.4.1. Carbohydrate content of RTE extrudates

The effects of process parameters on carbohydrate content of the extrudates are described in Appendix A (Table A6) and the 3D graphs representing the response surface are depicted in Fig.4.15.

Analysis of variance (Table B15) showed that the process parameters *viz.,* temperature and screw speed had significant effect on carbohydrate content of RTE extrudates at 1% ($p \leq 0.01$), but moisture content had no significant effect ($p \geq 0.05$) on carbohydrate content. The R- squared value of the model was 0.99.

Carbohydrate content of the extruded products varied from 67.90 to 70.82%. The maximum carbohydrate value of RTE extrudates was obtained at 120°C temperature, 14% moisture content and 400 rpm screw speed and minimum value obtained at 140°C temperature, 14% moisture content and 300 rpm screw speed, respectively.

Barrel temperature had an inverse effect on carbohydrate content of extrudates (Table A6). Carbohydrate content decreased from 70.82 to 67.90% with increment in temperature from 120 to 140°C. This possibly owing to the degradation of starch at elevated temperatures. Identical findings were observed by Camire and King (1991) for corn meal based extruded snacks and Seema (2016) for millet based extrudates

Screw speed had a positive correlation with carbohydrate content of extrudates (Table A6). The total carbohydrate increased from 67.90 to 70.82% with increase in screw speed from 300 to 400 rpm. At higher the screw speed, the residence time is less causing less shear action results lowering of degradation of starch. Identical results were explained by Omohimi *et al.* (2013) for texturized meat analogue from Mucuna beans.

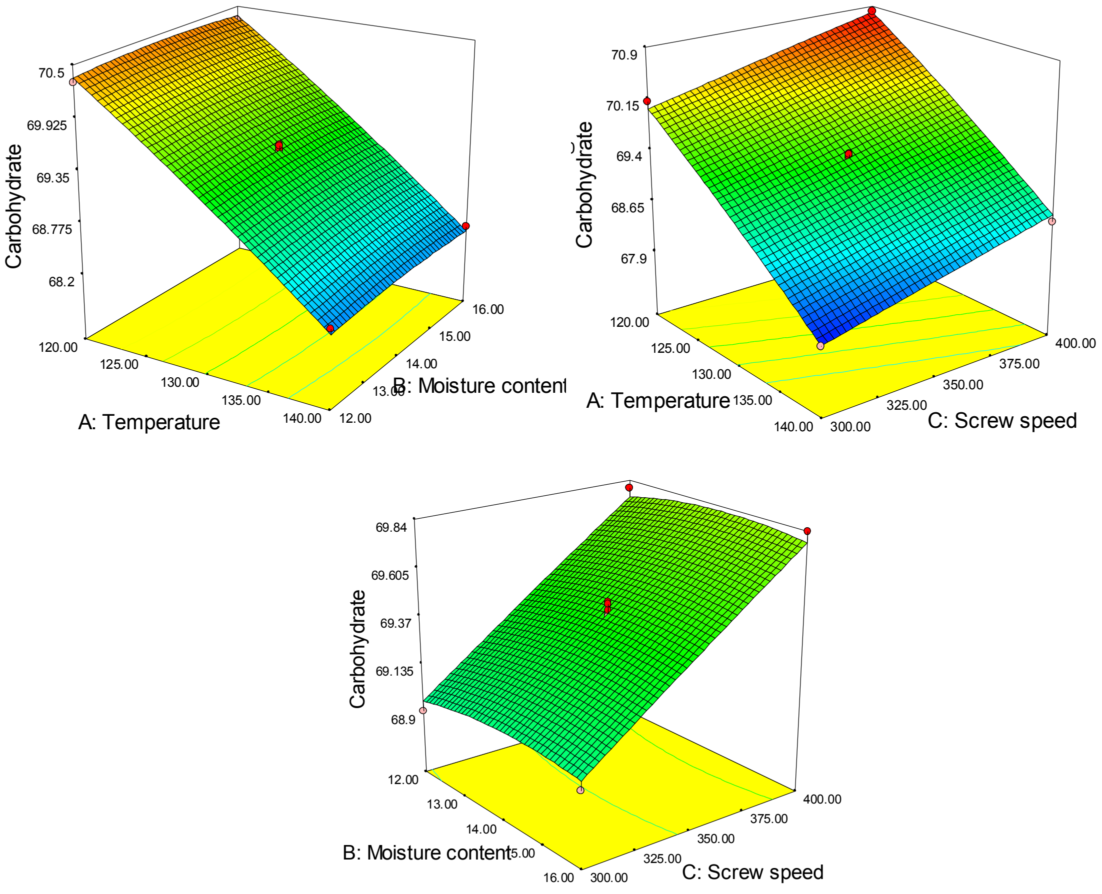


Fig 4.15.Effect of process parameters on carbohydrate content of the extruded products

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict carbohydrate content of extruded products.

Carbohydrate= 69.42 -1.05 A +0.019B +0.40 C +5.000E-003 A B +2.500E-003 A C -2.500E-003 B C -0.055 A^2 -0.045B^2 -7.500E-003 C^2…. (4.15) ($R^2 = 0.99$)

4.3.4.2. Protein content of RTE extrudates

The effects of process parameters on protein content of the extrudates are described in Appendix A (Table A6) and the 3D graphs representing the response surface are depicted in Fig.4.16.

From the analysis of variance (Table B16), it was apparent that all the process parameters are influencing the protein content of RTE extrudates significantly at 1% ($p \leq 0.01$) with an R- squared value of 0.99. Also second order interaction level between moisture content and screw speed ($p \leq 0.01$) was found to be significant.

Protein content of the extruded products varied from 13.95 to 15.91% (Table A6). The maximum protein content of 15.91% was obtained at barrel temperature 120°C, 14% moisture content and 400 rpm screw speed and minimum value of 13.95% was obtained at 140°C temperature, 14% moisture content and 300 rpm screw speed, respectively.

Barrel temperature had a negative impact on protein content (Table A6). The protein content of the extudates decreased from 15.91 to 13.95% with an increment in barrel temperature from 120 to 140°C. The reason for this decrease may be due to the denaturation of protein at higher temperature. Low amount of protein was also due to the loss of nitrogen during extrusion due to the development of isopeptide bonds with instantaneous discharge of ammonia (Kasprzak and Rzedzicki, 2008, Jhoe *et al.*, 2009). Identical findings were explained by Stojceska *et al.* (2008) for cauliflower by-products incorporated cereals based ready to eat expanded snacks.

The protein content of the extrudates increased from 13.95 to 15.91% with an increment in screw speed from 300 to 400 rpm. It may due to that higher the screw speed, the residence time is less, causing less shear action thus reducing denaturation of protein. Identical result was described by Khot *et al.* (2018) for maize based extruded products

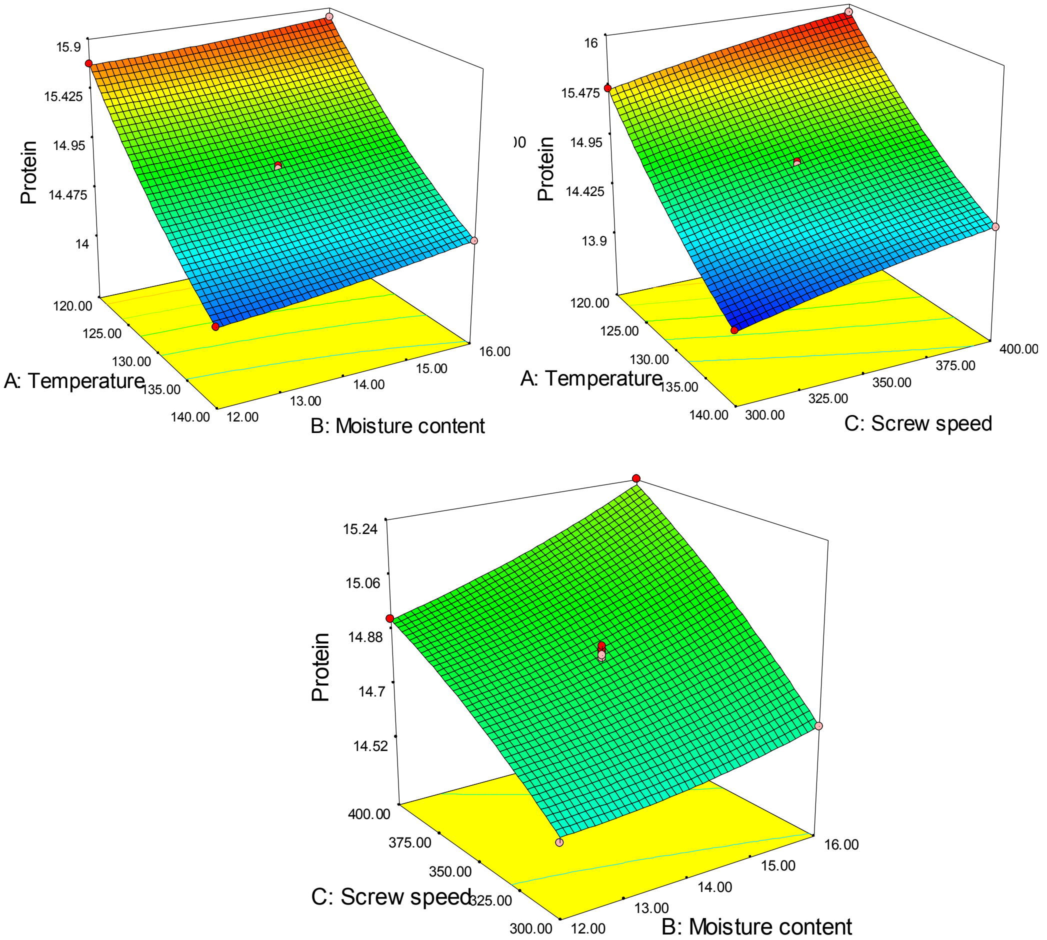


Fig 4.16.Effect of process parameters on protein content of the extruded products

Moisture content was also found to have a positive relation with protein content. As the moisture content of the feed increased from 12 to 16%, the protein content increased from13.95 to 15.91%. Shruthi *et al.* (2016) had conducted an experiment of extrusion with corn, pigeon pea and rice bran and they found that protein content of the extruded samples was increased with increment in moisture content. Identical trend was also explained by Gui *et al.* (2012) for extruded Red Ginseng.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict protein content of extruded products. Protein = 14.84 -0.76A +0.10 B +0.24 C +0.028A B -2.500E-003 A C +0.047 B C +0.12 A^2 +0.024 B^2 -0.031 C^2…….(4.16) ($R^2 = 0.99$)

4.3.4.3. Fat content of RTE extrudates

The effects of process parameters on fat content of the extrudates are described in Appendix A (Table A6) and the 3D graphs representing the response surface are depicted in Fig.4.17.

From the analysis of variance (Table B17), it was apparent that all the process parameters are influencing the fat content of RTE extrudates significantly at 1% ($p \leq 0.01$) with an R- squared value of 0.99.

Fat content of the extruded products varied from 1.90 to 3.23% (Table A6). The maximum fat content of 3.23% was obtained at 120°C temperature, 14% moisture content and 400 rpm screw speed and minimum value of 1.90% was obtained at 140°C temperature, 14% moisture content and 300 rpm screw speed, respectively.

Table A6 shows that temperature had an inverse impact on fat content. The fat content decreased from 3.23 to 1.90% with an increment in barrel temperature from 120 to 140°C. The possible reason may be due to the burning of fat at high extrusion process temperatures. This variation in fat content during extrusion was occurred by the development of starch-lipid and protein-lipid networks (Bhatnagar and Hanna, 1994 (a), 1994 (b), Singh *et al*., 2007). Identical results were explained Seema (2016) for millet based tuber fortified extruded foods and Shruthi *et al.* (2016) for corn extrudates.

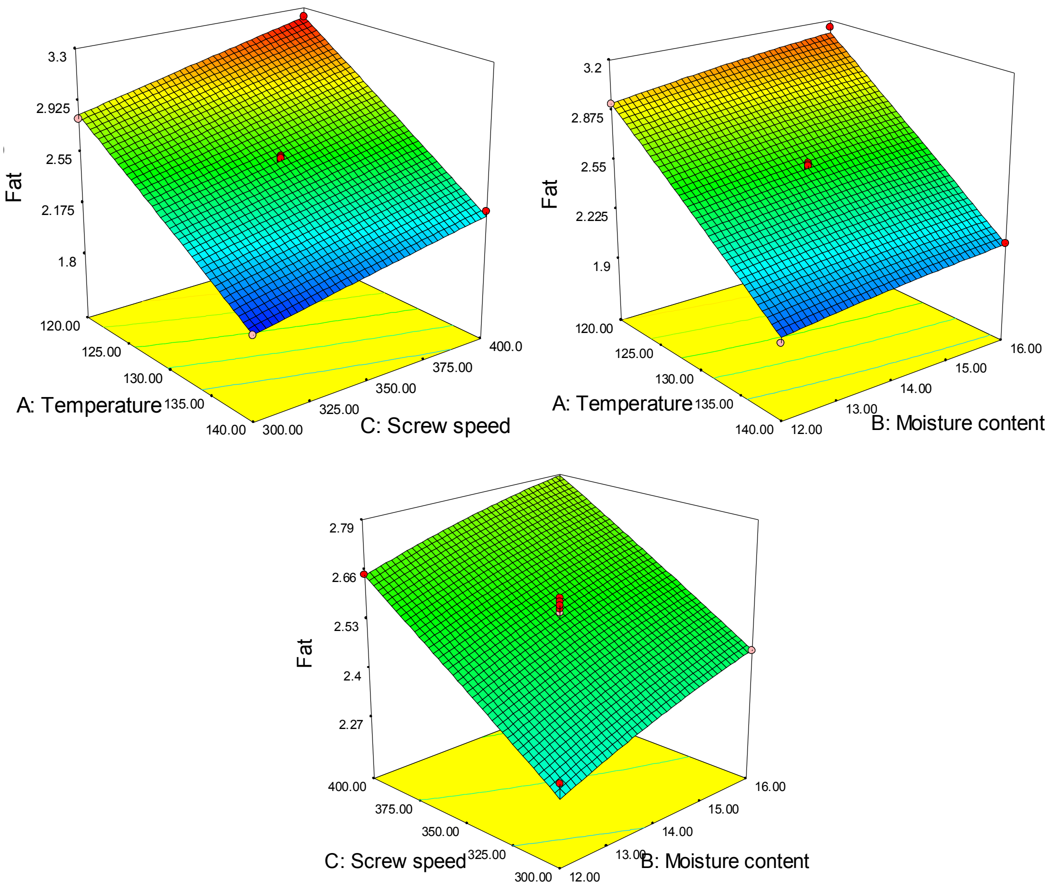


Fig 4.17.Effect of process parameters on fat content of the extruded products

Moisture content was found to have a positive relation with fat content (Table A6). Fat content of extrudates increased from 1.90 to 3.23% with an increment in moisture content from 12 to 16%. Shruthi *et al.* (2016) had conducted an experiment of extrusion with corn, pigeon pea and rice bran and they found that fat content of the extrudates was increased with increment in moisture content. Identical pattern was explained by Vasanthan *et al*. (2002) for barley flour based expanded snacks.

Screw speed also had a positive correlation with fat content (Table A6). Increment in screw speed from 300 to 400 rpm resulted an increase in fat content from 1.90 to 3.23%. The higher the screw speed, the residence time is less causing less shear action thus reducing denaturation of fat. Identical result was explained by Khot *et al.* (2018) for maize based extruded products.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict fat content of extruded products.
$\text{Fat} = 2.56 - 0.49\,A + 0.080\,B + 0.18\,C - 0.015\,A\,B - 0.020\,A\,C - 0.010\,B\,C - 8.333\text{E-}003\,A^2 - 0.013\,B^2 - 3.333\text{E-}003\,C^2$.....(4.17) $(R^2 = 0.99)$

4.3.4.4. Dietary fibre content of RTE extrudates

The effects of process parameters on dietary fibre content of the extrudates are described in Appendix A (Table A6). The same are illustrated in 3D graphs representing the response surface generated by the model (Equation. 4.18) and are depicted in Fig.4.18.

Analysis of variance (Table B18) showed that the process parameters such as temperature ($p \leq 0.01$) and screw speed ($p \leq 0.01$) had significant effect on dietary fibre content of RTE extrudates. But moisture content had no significant effect on dietary fibre content ($p \geq 0.05$). Also second order interaction level between temperature and screw speed ($p \leq 0.05$) also found to significant. The R- squared value of the model was found to be 0.99.

Dietary fibre content of the extruded products varied from 8.75 to 9.67% (Table A6). The maximum dietary fibre of 9.67% was obtained at 140°C barrel temperature, 14% moisture content and 300 rpm screw speed and minimum value of 8.75% was obtained at 120°C barrel temperature, 14% moisture content and 400 rpm screw speed.

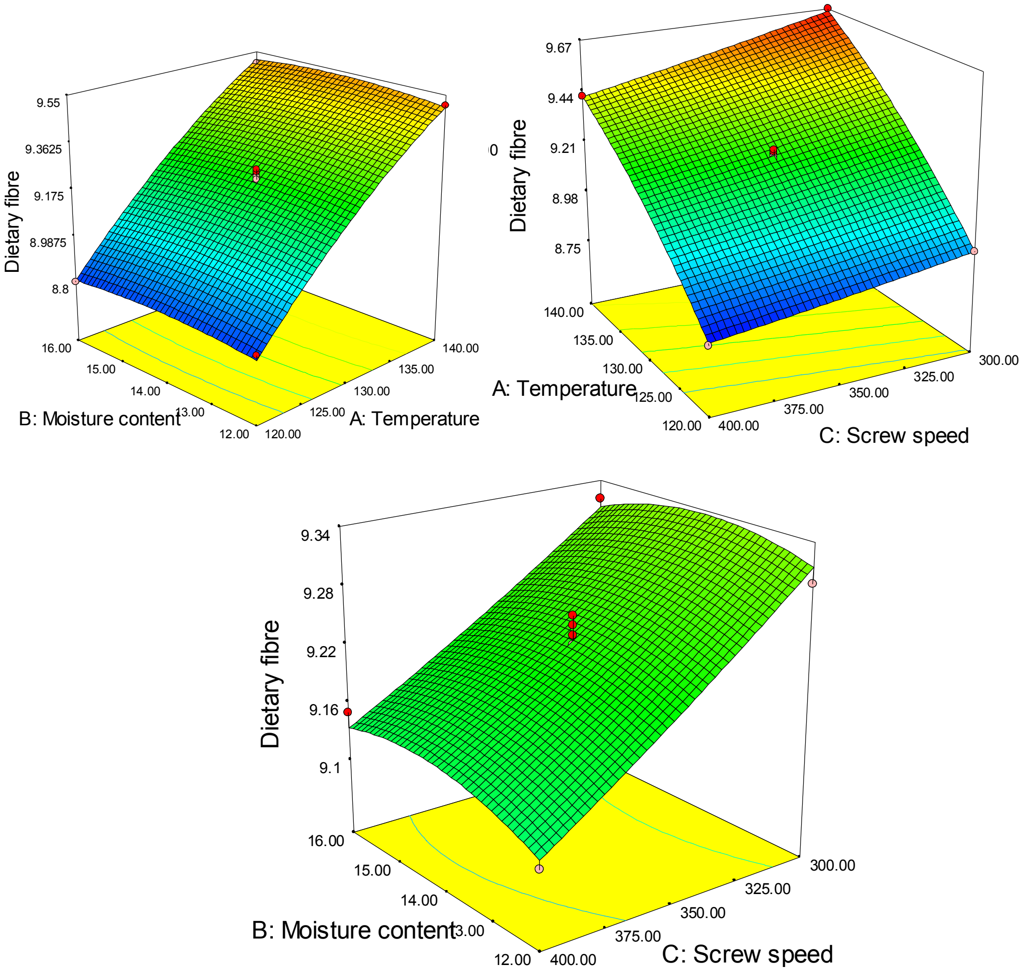


Fig 4.18.Effect of process parameters on dietary fibre content of the extruded products

Table A6 shows that, temperature had a positive impact on dietary fibre content of the extrudates samples. The dietary fibre content increased from 8.75 to 9.67% with increment in temperature from 120 to 140°C. It may due to increment in soluble dietary fibre due to disturbance in covalent and non covalent bonds presented in the carbohydrate and protein moieties causing smaller and more number of soluble molecular fragments in addition to the development of resistant starch and 'enzyme-resistant indigestible glucans' formed by transglycosidation. (Rashid *et al.,* 2015). Identical results were described by Vasanthan *et al.* (2002) for barley extrudates.

Screw speed had an opposite correlation with dietary fibre of the extrudates (Table A6). The dietary fibre content decreased from 9.67 to 8.75% with increase in screw speed from 300 to 400 rpm. This may be due to the reason that at higher screw speed causes lesser the residence time and shear force in the extruder barrel then reduces the success of breakdown of polysaccharides glucosidic bonds. Identical findings were explained by Omohimi *et al.* (2013) for texturized meat analogue from Mucuna beans.

A second order non-linear regression equation was fitted between dependent and independent variables using the experimental values. Following regression models were obtained to predict dietary fibre content of extruded products. Dietary fibre = 9.24 +0.35 A +5.000E-003 B -0.096 C +2.500E-003A B -0.025 A C +7.500E-003 B C -0.055 A^2 -0.022B^2 +5.000E-003C^2…..(4.18) ($R^2 = 0.99$)

T1

T2

T3

T4

T5

T6

T7

T8

T9

T10 **T11** **T12**

T13 **T14** **T15**

T16 **T17** **T18**

Plate 4.1. Extrudates made at different extrusion conditions

4.4. PROCESS OPTIMISATION FOR THE DEVELOPMENT OF PROTEIN ENRICHED RTE EXTRUDED FOOD PRODUCTS

The protein enriched RTE extruded food products were developed using extrusion technology and the various process variables which will affect the quality characteristics of the extruded products were studied. Optimisation of the three independent variables *viz.,* temperature (120, 130 and 140°C), moisture content (12, 16 and 16%) and screw speed (300, 350 and 400 rpm) were done by Box- Behnken design of response surface methodology in Design Expert Software 7.7.0. and the desirability analysis was done by using this software. Desirability ranges were fixed from zero to one for any given response. A zero indicates that one or more responses fall outside desirable limits and a value of one represents the ideal case (Maran *et al*., 2013). In this study, the independent variables were kept within the range and the dependent variables were selected as minimum, maximum or range depending upon the requirements. From the desirability analysis, the optimal level of various parameters were found and listed in Table 4.3. The optimum operating conditions for the development of extruded products were found as temperature of 140°C, moisture content of 12.20% and screw speed of 383.96 (384) rpm. The desirability of the optimisation of extrusion parameters was found to be 0.837. Since the desirability values are closer to one, the optimised values could be considered ideal.

Table 4.3 Optimal level obtained from desirability analysis

Sl No	Response	Desirability	Optimal level	Lower limit	Upper limit
1	Temperature	Is in range	140.00	120	140
2	Moisture content	Is in range	12.20	12	16
3	Screw speed	Is in range	383.96	300	400
4	MC	Minimize	4.46	4.47	6.31
5	Water activity	Minimize	0.426	0.423	0.538
6	Expansion ratio	Maximize	3.18	2.415	3.215
7	Bulk density	Minimize	0.658	0.652	0.858
8	True density	Minimize	1.22	1.15	1.92
9	Porosity	Maximize	58.57	57.38	58.57
10	L* value	Minimize	64.35	63.99	69.92
11	a* value	Is in range	5.27	4.21	5.32
12	b* value	Maximize	18.55	17.43	18.62
13	Hardness	Minimize	24.21	23.52	33.86
14	Fracturability	Minimize	10.94	10.30	20.54
15	Crispness	Maximize	55.09	45.23	55.72
16	WSI	Maximize	30.24	15.68	30.25
17	WAI	Maximize	5.61	3.40	5.61
18	Carbohydrate	Is in range	68.53	67.90	70.82
19	Protein	Maximize	14.22	13.95	15.91
20	Fat	Is in range	2.11	1.90	3.23
21	Dietary fibre	Is in range	9.42	8.75	9.67

4.5. QUALITY PARAMETRS OF OPTIMALLY PRODUCED RTE EXTUDED FOOD PRODUCT

Based on the Box- Behnken design of RSM, the optimum operating conditions for the development of extruded products were found as barrel temperature of 140°C, moisture content of 12.20% and screw speed of 383.96 (384) rpm. Accordingly, the extrusion process was conducted based on the optimised conditions (Plate 4.2).

The quality parameters of optimally produced extruded products are presented in Table 4.4. Extrudate product was light white in colour. It had an average moisture content of 4.39% (w.b) and water activity of 0.430. The colour values *viz.,* L*, a* and b* values were 63.94, 5.31 and 18.59, respectively. The hardness, crispiness and fraturability values were 24.05, 55.27 and 10.85 N, respectively. It had an energy value of 1467.54 kJ/100g (351.44 kcal/100g). The carbohydrate, protein fat and dietary fibre content present in 100 g of extrudates were 68.60, 14.31 2.2% and 9.49%, respectively. Total mineral content of the product was found to be 1.68%. The minerals *viz.,* iron, calcium and potassium present in 100 g of extrudate sample were 8.94, 55 and 372.5 mg, respectively.

According to Indian Council of Medical Research (ICMR), the recommended daily allowance (RDA) of energy, protein and fat for boys (up to 12 years) is 2190 kcal/day, 39.9 g/day and 35 g/day, respectively. In case of girls (up to 12 years) the corresponding RDA values are 2010 kcal/day, 40.4 g/day and 35 g/day respectively. Similarly, the RDA values for adult man and woman are 2730 kacl/day, 60 g/day, 30 g/day and 2230 kcal/day, 55 g/day and 25 g/day, respectively. From the above facts, it was understood that the extruded product of quantity 100 g developed at optimised condition will contribute 35.86% of RDA for protein in case of boys, 34% for girls, 23.85% for adult men and 26.01% for adult women, respectively.

Table 4.4. Quality parameters of optimally produced RTE extruded product

Quality parameters	Value
Moisture content (% w.b)	4.39
Water activity	0.430
L*	63.94
a*	5.31
b*	18.59
Hardness (N)	24.05
Crispness (N)	55.27
Fracturability (N)	10.85
Carbohydrate (%)	68.60
Protein (%)	14.31
Fat (%)	2.20
Dietary fibre (%)	9.49
Energy content(kJ/100 g)	1467.54
Total mineral content (%)	1.68
Iron (mg/100g)	8.94
Calcium (mg/100g)	55.0
Potassium (mg/100g)	372.5

Now a days commercially available extruded snack contain more amount of fat which cause several health problems. The developed extruded product contain less amount of fat (2.20%) which is good for health and not adversely affect its storage.

4.6. STORAGE STUDIES OF OPTIMALLY PRODUCED RTE EXTRUDED PRODUCT

The storage studies of optimally produced RTE extruded product were conducted using different packaging materials *viz.,* LDPE and laminated aluminum pouch and various packaging technologies *viz.,* passive MAP and active MAP with nitrogen flushing under ambient conditions. The type of packaging film/packaging technology which can protect the food materials for maximum number of days would be the best packaging film/technology. The quality parameters such as moisture content, water activity, colour and texture were analysed up to 90 days of storage with an interval of 15 days and the results are tabulated in Appendix C.

Plate 4.2. Optimally produced RTE extruded food product

LDPE

Laminated aluminum pouch

Plate 4.3 Packaging materials used for storage

4.6.1. Variation in Moisture Content during Storage of RTE Extrudates

The variations in moisture content during storage of extruded products are tabulated in Appendix C (Table C.1) and its graphical representation is depicted in Fig 4.19.

Analysis of variance (Table C9) showed that packaging materials and packaging technologies had a significant effect ($p \leq 0.01$) on moisture content during storage period at individual level. The initial moisture content of the stored product was 4.39% (w.b). After three months storage period, the respective moisture content of the sample stored in LDPE and laminated aluminum pouch under active and passive MAP were 6.78, 6.35and 6.89, 6.65% (w.b), respectively.

The moisture content of all the samples was gradually raised during storage period. This may be due to the hygroscopic nature of the products (Butt *et al.,* 2004). The moisture content gained by the sample packed in LDPE pouches was more as compared to laminated aluminum pouch. It may due to the fact that the permeability of water vapour in LDPE pouches was higher in comparison to laminated aluminum pouch. Identical result was found by Wani and Kumar (2016) in stored extruded snack made from fenugreek, oat and pea flour in different packaging materials. Syed *et al.* (2019) also reported the same trend in moisture content for corn based extrudates. When comparing moisture content gained by samples packed in different packaging material with nitrogen flushing and without nitrogen flushing, the result showed that increment in moisture gain was more in samples packed without nitrogen flushing than with nitrogen flushing. The lesser increase in moisture during storage in a nitrogen flushed package was mainly due to the flushing of nitrogen that replaced the oxygen (air) and water vapor from the package. Identical result was reported by Ajitha and Jha (2017b) for pearl millet based snacks packed with and without nitrogen flushing.

During storage period, minimum moisture gain was found in laminated aluminum pouch packaging with nitrogen flushing (4.39 to 6.35%) and maximum moisture gain was found in LDPE packet without nitrogen flushing (4.39 to 6.89%).

4.6.2. Variation in Water Activity during Storage of RTE Extrudates.

The variation in water activity of the extruded products during storage period is tabulated in Appendix C (Table C.2) and its graphical representation is depicted in Fig 4.20.

From analysis of variance (Table C.10), it was understood that the packaging materials and technologies affect the water activity of stored product significantly at 1% ($p \leq 0.01$).

The initial water activity of the optimally produced RTE extrudate was found to be 0.430. After three months of storage period, the water activity of the sample stored in LDPE and laminated aluminum pouch under active and passive MAP were 0.654, 0.632 and 0.665, 0.645 respectively.

The water activity value increased gradually with respect to storage period. The small increment in water activity during storage was probably due to change in humidity conditions of the surroundings. The increase in water activity was more in samples packed in LDPE compared to the samples packed in laminated aluminum pouch. Likewise water activity was maximum for samples packed without nitrogen flushing (passive MAP) than with nitrogen flushing packets (Active MAP). Manthey *et al.* (2008) reported a gradual increment in water activity of breads enriched with cereal bran throughout the storage period. Hussain *et al.* (2015) also reported an increasing water activity during storage period of walnut kernel mixed rice based extruded products.

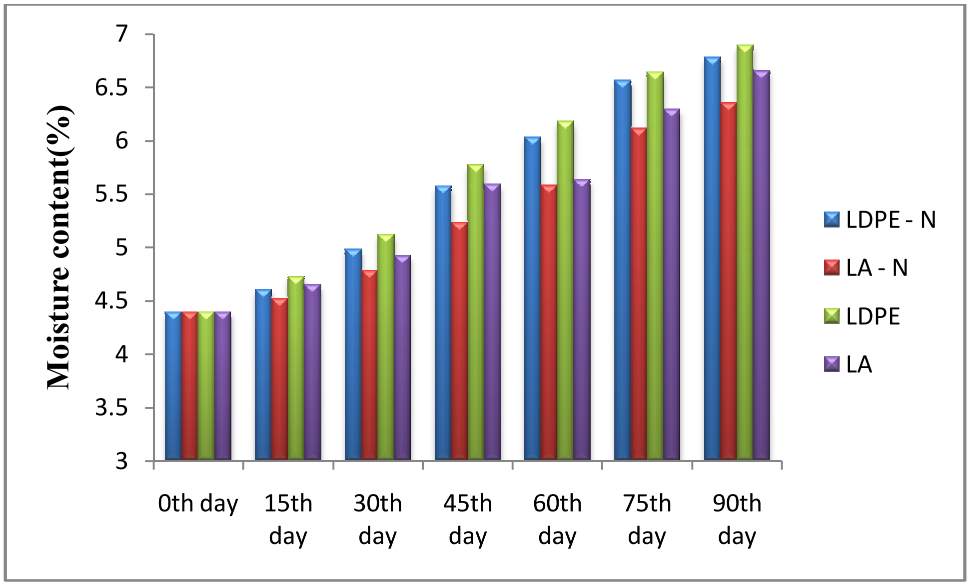


Fig.4.19. Variation in moisture content during storage period

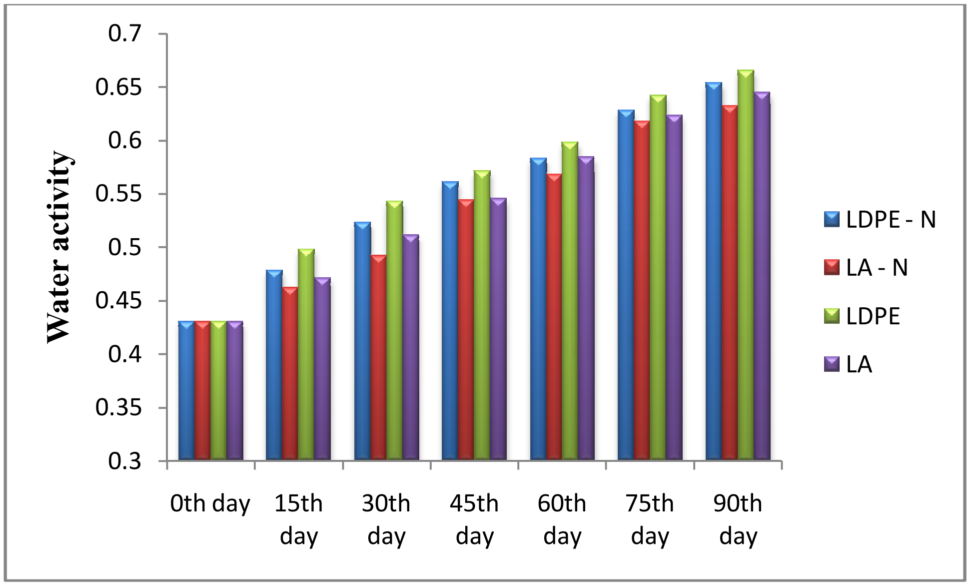


Fig.4.20. Variation in water activity during storage period

After three months of storage, minimum water activity was found in samples stored using laminated aluminum with nitrogen flushing (0.430 to 0.632) and maximum water activity was found in sample packed using LDPE without nitrogen flushing (0.430 to 0.665).

4.6.3. Variation in Colour Values during Storage of RTE Extrudates.

The changes in colour parameters(L*, a* and b*) of the extruded products during storage periods is tabulated in Appendix C (Table C.3, Table C.4, and Table C.5.) and the corresponding graphs are depicted in Fig 4.21, Fig 4.22 and Fig 4.23.

Analysis of variance showed that packaging materials had n't any significant effect on colour values during storage period ($p \geq 0.01$).

The initial L*, a* and b* value of optimally produced RTE extrudates was 63.94, 5.31 and 18.59, respectively. After three months of storage period the L* value of the sample packed in LDPE and laminated aluminum pouch under active and passive MAP were 62.74, 62.75and 62.73, 62.75, respectively. Similarly, the a* and b* values of the samples packed in corresponding packaging materials and packaging technologies were 6.23, 6.21, 6.24, 6.21 and 19.52, 19.51, 19.52, 19.51 respectively.

The result showed that, there was no significant effect in colour values during storage as well as among the packaging materials. Even though a slight decrease in L* value and a slight increase in a* and b*values observed during storage periods. Identical trend was explained by Alam *et al.* (2015) for rice based snacks and Ali *et al.* (2017) for extruded maize -pulse base weaning mixes. The decrease in L*value and increase in a* and b* value with storage period may be due to degradation of pigments during storage (Dar *et al.,* 2012).

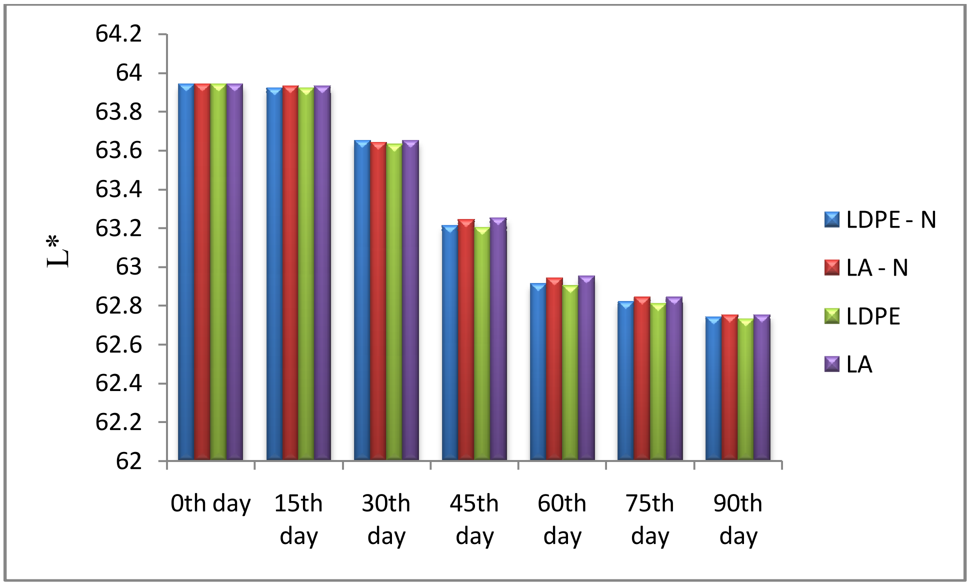


Fig.4.21. Variation in L* value during storage period

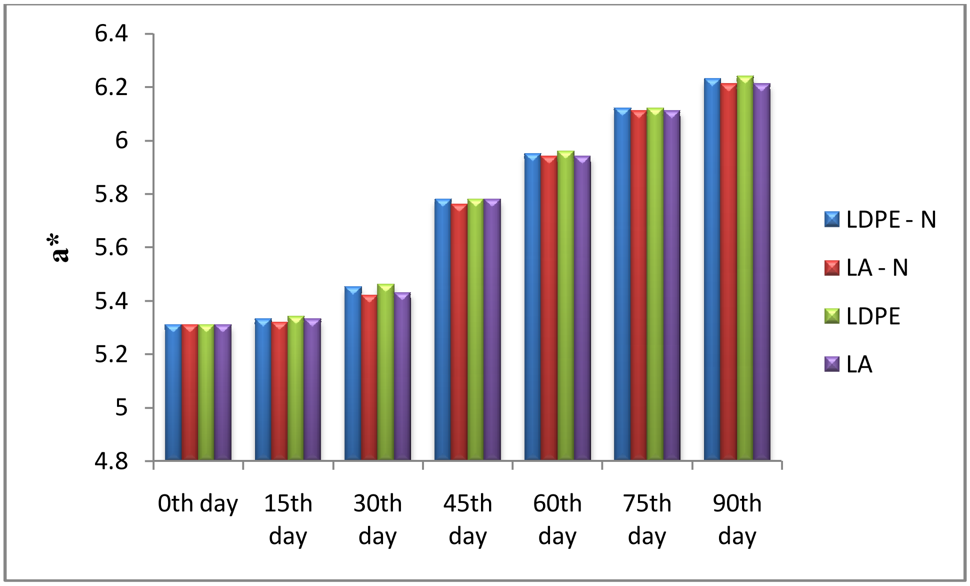


Fig.4.22. Variation in a* value during storage period

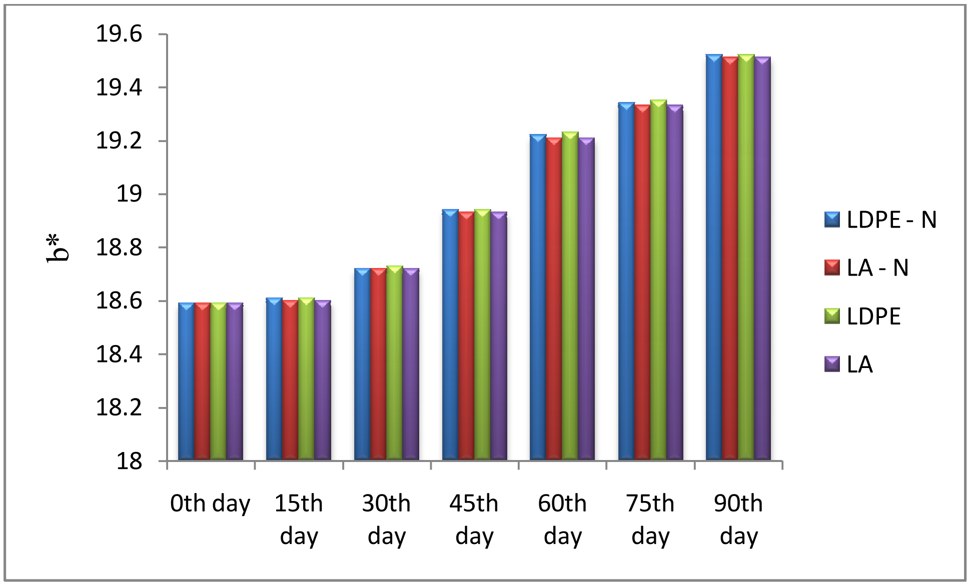


Fig.4.23. Variation in b* value during storage

4.6.4. Variation in Textural Properties during Storage of RTE Extrudates.

The changes in textural characteristics (hardness, crispness and fracturability) of the extruded products during storage periods tabulated in Appendix C (Table C.6, Table C.7, and Table C.8.) and the graphs related to the data are depicted in Fig 4.24, Fig 4.25 and Fig 4.26.

Analysis of variance showed that the effect of packaging materials and technologies on textural properties of stored products was found to be significant at 1% ($p \leq 0.01$) individual levels (Table C.14, Table C.15 and Table C.16).

The initial hardness, crispness and fracturablity of optimally produced RTE extrudate were 24.05, 55.27 and 10.85 N. After three months of storage period, the hardness of the sample packed in LDPE and laminated aluminum pouch under active and passive MAP were 17.55, 18.52 and 17.13, 18.12 N, respectively. The corresponding crispness and fracturability values for the samples packed using different packaging materials and packaging technologies were 53. 25, 53.64, 53.12, 53.55N and 9.26, 9.45, 9.12, 9.38 N, respectively.

The textural properties such as hardness, crispness and fracturablity values of stored sample were found to decrease during storage period. The decrease in textural properties might be related to gain in moisture of extruded snack. Moisture leads to plasticization and softening of the starch–protein matrix and thus alters the strength of the product (Navarraete *et al*., 2004).

The decrease in textural properties was more in sample packed in LDPE pouches as compared to laminated aluminum pouch. It may due to the fact that permeability of water vapour in LDPE pouches was higher in comparison to laminated aluminum pouch. Identical findings were described by Sahu *et al*. (2018) for maize millet based extruded sacks stored in different packaging materials. Nazir *et al.* (2017) and Sharma *et al.* (2015) also found the same result. Fig 4.25 showed that reduction in textural properties was more in samples packed under passive MAP than active MAP with nitrogen flushing. The lesser reduction in textural properties during storage in a nitrogen flushed package was mainly due to the flushing of nitrogen that replaced the oxygen (air) and water vapor from the package. Similar result was reported by Ajitha and Jha (2017b) for pearl millet based snacks packed with and without nitrogen flushing.

After three months of storage, the sample packed in laminated aluminum with nitrogen flushing (hardness 24.05 to 18.52 N, Crispness 55.27-53.64 N and fracturability 10.85-9.45 N) exhibit minimum textural changes whereas the sample packed in LDPE without nitrogen flushing (hardness 24.05 to 17.13 N, Crispness 55.27-53.12 N and fracturability 10.85-9.12 N) showed maximum textural changes.

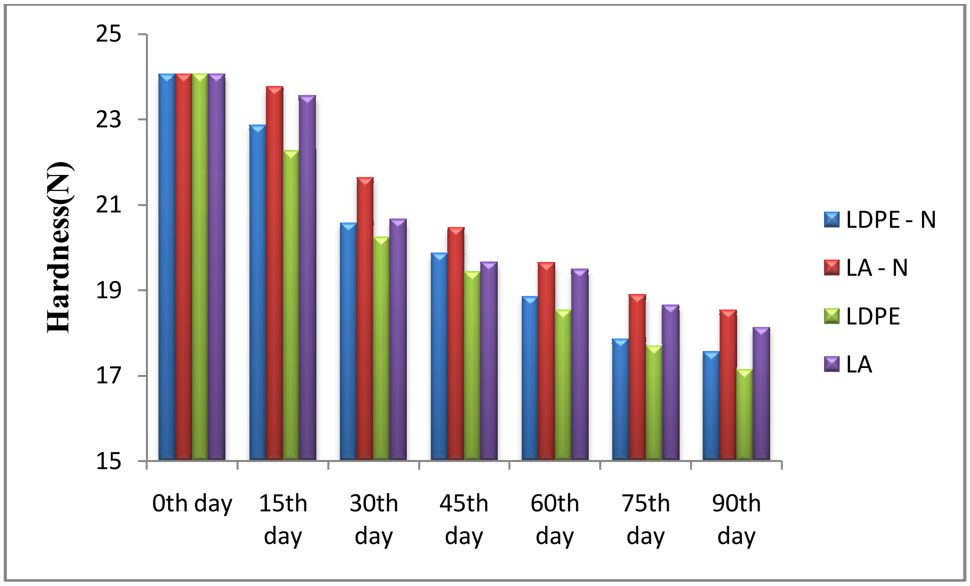


Fig.4.24. Variation in hardness during storage period

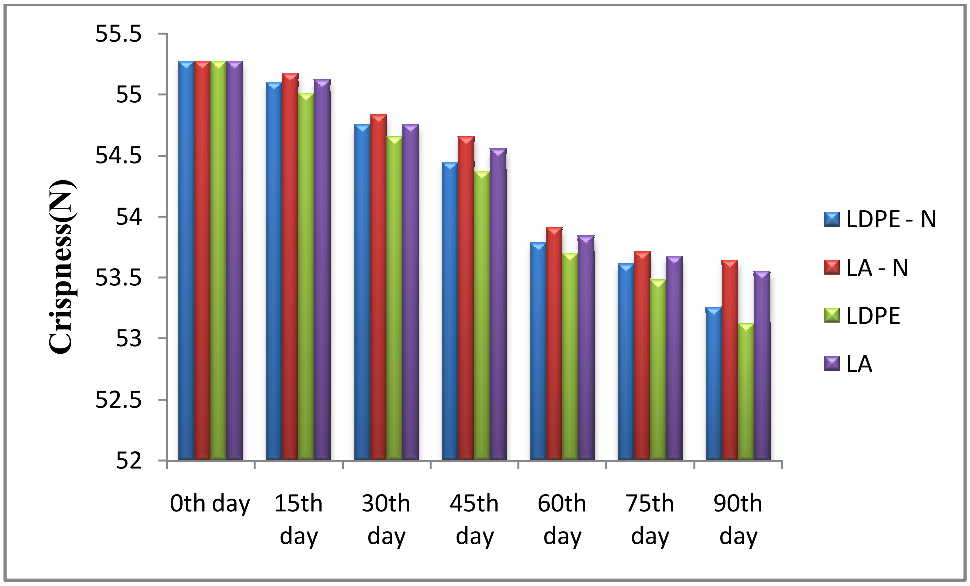


Fig.4.25. Variation in crispness during storage period

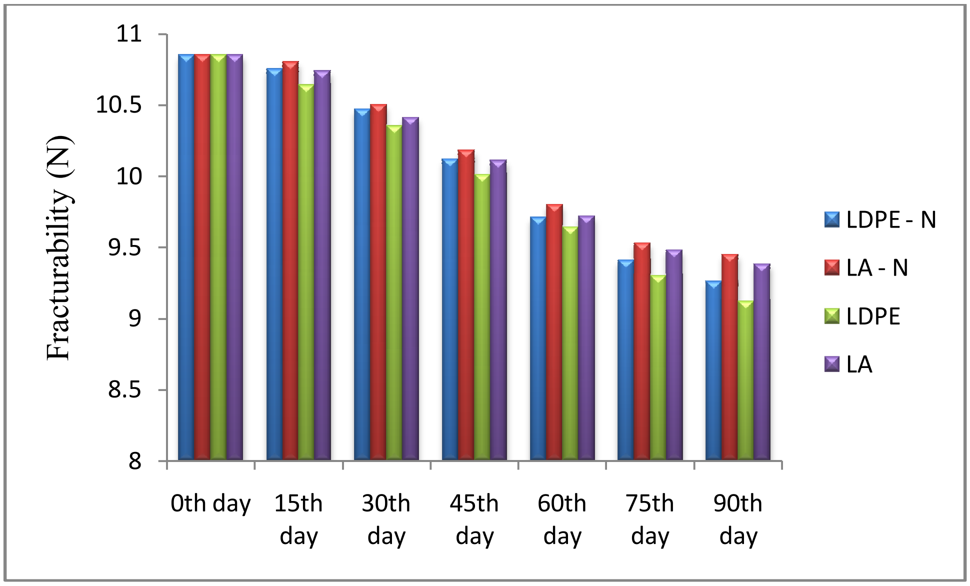


Fig.4.26. Variation in fracturability during storage period

4.7. MICROBAL ANALYSIS OF OPTIMALLY PRODUCED RTE EXTRUDED PRODUCT AFTER THREE MONTH STORAGE

The microbial analysis was carried out for all the samples after three month storage period. The microbial analysis showed that all the samples were found safe after the storage period of three months under study. Total plate count (TPC) of all the samples was found as 1× 10^3 cfu/g. The maximum permissible microbial limits of aerobic colony count for ready to eat food ranges from 10^4 to less than 10^6 cfu/g (Obaroakpo *et al.,* 2017). The results showed that there was no contamination in RTE products during storage period and the product was found to be microbially safe.

4.8. SENSORY ANALYSIS OF OPTIMALLY PRODUCED RTE EXTRUDED PRODUCT AFTER THREE MONTH STORAGE

The extruded samples stored in different packaging materials/technology were subjected to sensory analysis. Overall acceptability of RTE product varies from 7.0 to 8.8. All the samples had acceptable score, but the sample stored in laminated aluminum pouch with nitrogen flushing (active MAP) was mostly accepted by sensory panel (overall acceptability 8.8). Sensory score was given in Appendix D.

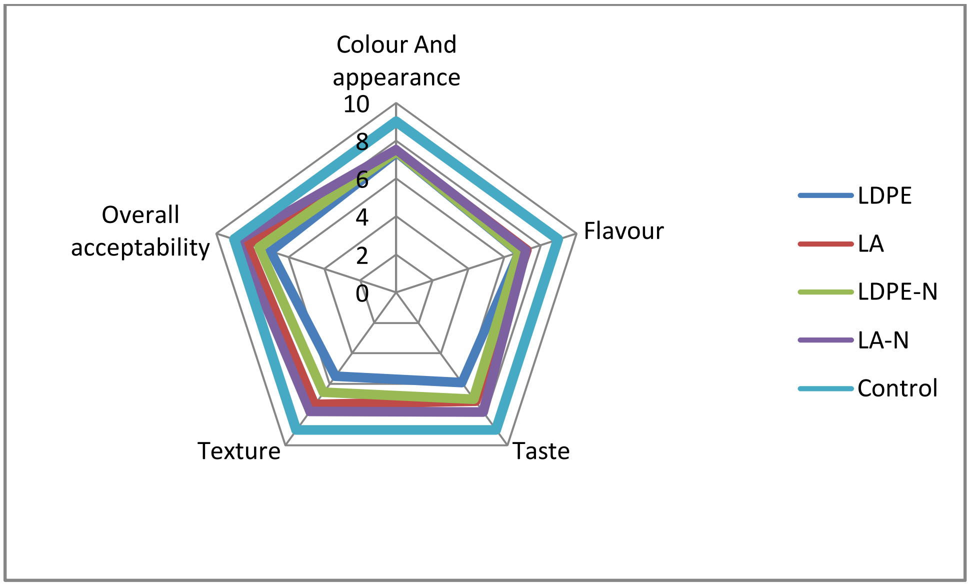


Fig.4.27. Sensory analysis of RTE extrudate

4.9. COMPARISON BETWEEN OPTIMALLY PRODUCED RTE EXTRUDATES AND COMMERCIALLY AVAILABLE EXPANDED SNACKS

The quality parameters of developed extrudates and few commercially available expanded snacks are presented in Table 4.5.

Table 4.5. Comparison between optimally produced extrudates and commercially available expanded snacks

	Optimally produced extrudates	Commercially available expanded snacks
Energy(kcal)	351	520-560
Protein (%)	14.31	5.5-7.0
Total carbohydrate (%)	68.60	55-62
Total fat (%)	2.20	27.5-34.5

The energy content, protein, carbohydrate and fat content of 100 g of developed extrudates and commercially available extrudates were 351 kcal, 14.31%, 68.60%, 2.2% and 520-560 kcal, 5.5-7.0%, 55-62%, 27.5-34.5%, respectively. From the table it is understood that the protein content of developed extrudates was higher compared to commercially available expanded snacks. Hence it can be recommended to all age groups.

4.10. COST ANALYSIS OF OPTIMALLY PRODUCED RTE EXTRUDED PRODUCT

The cost estimation for the production of optimised extruded products were conducted and the cost of production of 1kg of extruded product was Rs113.29/-. The benefit: cost ratio for optimised product packed under MAP in laminated aluminum pouch was 3.97. The detailed calculation is presented in Appendix E.

CHAPTER V

SUMMARY AND CONCLUSION

Malnutrition is directly related to the economic and social living standard of the people. It is the main reason for morbidity and mortality among the children, especially in the developing countries. Fortification or combination of two or more food ingredients can make a solution for this nutritional insufficiency to a certain extend. Cereal based food products are rich in carbohydrates and energy but they are insufficient in terms of protein. Food products with improved nutritional profile can be produced by blending legumes.

The rapid changing life style of the consumer demands convenience in terms of saving time and energy. Snacks are becoming more and more popular and have a strong relationship with nutritional status of the young population. Development of ready to eat snacks add convenience, saves labour and time, produce hygienic products of standard and uniform quality with improved shelf life. Extruded snacks have very less moisture content and water activity making them shelf stable. Shelf stable, nutrient rich products considered to be ideal to reduce malnutrition in the developing world. It is important to consider that these healthy snacks will provide sufficient macro and micronutrients especially to the nutritionally vulnerable segment of population. In this context extrusion is one of the commonly adopted processing techniques by food industries which employ mixing, forming, texturing and cooking to develop a novel food product. Thus using extrusion cooking, a nutritionally balanced RTE food product can be developed by fortifying both cereals and legumes.

Considering the above mentioned facts, development and evaluation of protein enriched RTE extruded food products was undertaken with the objectives- i) to standardise the composition of RTE food from ragi flour, rice flour, soybean flour, bengal gram flour and groundnut flour, ii) to optimise the extrusion process parameters *viz.,* moisture content of feed, screw speed and barrel temperature for the production of RTE extruded food iii)to conduct storage studies and quality analysis of RTE extruded food products.

The raw materials used for the development of RTE extruded foods were rice, ragi, Bengal gram, defatted soybean and defatted groundnut. Preliminary trails were conducted for standardizing the feed composition. Ten different feed compositions were made and they were extruded at 120°C temperature, 14% moisture content and 350 rpm screw speed. The expansion ratio and bulk density of the developed extrudates were analysed. Based on high expansion ratio and low bulk density one feed composition was standardised and which was used for further experiments. Physico chemical analysis of feed mix was conducted and recorded. Optimisation of extrusion process variables *viz.,* temperature (120, 130 and 140°C), moisture content (12, 14 and 16 % wb) and screw speed (300, 350 and 400 rpm) was conducted based on assessing the quality of extruded products in terms of physical, functional, engineering properties and proximate components by Box-Behnken design in RSM (Response Surface Methodology). The optimum operating parameters for the development of RTE extruded product was obtained based on the physico-chemical and functional properties of the extrudates. Quality analysis of optimally produced extrudates was conducted and recorded. Storage studies of optimally produced extrudate were conducted by using different packaging materials (LDPE and laminated aluminum pouch) and packaging technologies (Passive MAP, Active MAP with N_2 filling) and quality parameters were periodically analysed at 15 days intervals up to three months under ambient conditions. Microbial analysis and sensory evaluation of optimally produced samples after three month storage also conducted. Cost analysis of optimally produced RTE extruded food product was also performed.

From preliminary studies conducted for standardizing the feed composition, F7 (R_{60}:Rg_{10}:B_{10}:G_{10}:S_{10}) showed higher expansion ratio of 2.98 and lowest bulk density of 0.751 g/cm^3. So the feed composition F7 was selected for further experiments. The moisture content, water activity, bulk density, L*, a* and b* value `of feed mix was 8.95% wb, 0.562, 0.690 g/cm^3, 72.80, 3.71 and 17.22. The proximate components such as protein, carbohydrate, fat, dietary fibre and energy content of feed mix were 16.01%, 71.54%, 3.51%, 8.61% and 1594.41 kJ/100 g respectively.

Box-Behnken experimental design was used for the selection of best combination of process parameters in extusion processes and RTE expanded snacks are developed by extrusion process with different combination of temperature, feed moisture content and screw speed. The physical, engineering, functional properties and proximate components of the developed extrudate were determined and optimisation was done by using RSM. The optimum operating condition for the development of RTE extrudate was obtained as temperature of 140°C, moisture content of 12.20% and screw speed of 383.96 (384) rpm. The extrusion was performed at optimised condition and the quality parameters of the optimally produced extrudates were recorded. The moisture content, water activity, L* value, a* value, b* value, hardness, crispness and fracturability of optimally produced extrudates were 4.39%, 0.430, 63.94, 5.31, 18.59, 24.05 N, 55.27 N and 10.85 N, respectively. The proximate components such as protein, carbohydrate, fat, dietary fibre and energy content of optimally produced extrudate were 14.31%, 68.60%, 2.20%, 9.49% and 1467.54 kJ/100 g, respectively. The total ash content was 1.68% and selected minerals iron 8.94 mg/100 g, calcium 55.0 mg/100 g and potassium 372.5 mg/100 g.

Storage studies of optimally produced extrudates were conducted and quality parameters such as moisture content, water activity colour parameters and textural properties were analysed. The packaging materials were found to be significantly affects the quality parameters of the extrudates. The initial moisture content was 4.39% and after three month storage the moisture content was increased and the respective moisture content of the sample stored in LDPE and laminated aluminum pouch with and without nitrogen filling were 6.78, 6.35 and 6.89, 6.65% (wb) respectively. Water activity also increased from 0.430 and the water activity of the sample stored in LDPE and laminated aluminum pouch with and without nitrogen filling were 0.654, 0.632 and 0.665, 0.645 respectively. The packaging materials were doesn't significantly affect the colour parameters even though a slight decrease in L* value and a slight increase in a* and b* value were observed. The initial hardness, crispness and fracturablity of optimally produced RTE extrudate were 24.05, 55.27 and 10.85 N and these values were reduced during storage. After 90 days storage period the hardness of the sample in LDPE and laminated aluminum pouch with and without nitrogen filling were 17.55, 18.52 and 17.13, 18.12 N, respectively and crispness of the sample in LDPE and laminated aluminum pouch with and without nitrogen filling were 53. 25, 53.64 and 53.12, 53.55 N, respectively and the fracturablity of the sample in LDPE and laminated aluminum pouch with and without nitrogen filling were 9.26, 9.45 and 9.12, 9.38 N, respectively.

Microbial analysis was conducted after three month storage and the microbial load was within the permissible limit. The overall acceptability varied from 7.0 to 8.8 and the highest value obtained for samples packed in laminated aluminum pouch with nitrogen flushing.

The total production cost of 1kg of extruded RTE product was found to be Rs. 113.29/-. The benefit cost ratio of the production was found to be 3.97:1.

CHAPTER VI

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APPENDIX A

Table A1 Effect of process parameters on physical properties of the extruded products

Run	**Temperature (°C)**	**Moisture content (%)**	**Screw speed (rpm)**	**MC (%)**	**Water activity**	**Expansion ratio**
1	130	14	350	5.41	0.475	2.77
2	140	14	300	4.85	0.443	3.06
3	120	12	350	5.25	0.501	2.61
4	140	14	400	4.75	0.441	3.10
5	130	16	400	6.23	0.492	2.69
6	140	16	350	5.15	0.451	2.98
7	140	12	350	**4.47**	**0.423**	**3.21**
8	130	14	350	5.58	0.476	2.78
9	130	12	300	5.26	0.465	2.72
10	130	14	350	5.56	0.477	2.79
11	130	12	400	5.20	0.463	2.82
12	120	14	400	5.79	0.521	2.59
13	130	14	350	5.55	0.478	2.78
14	130	14	350	5.49	0.479	2.79
15	120	14	300	5.83	0.522	2.52
16	130	14	350	5.52	0.474	2.87
17	120	16	350	**6.31**	**0.538**	**2.42**
18	130	16	300	6.10	0.493	2.60

Table A.2 Effect of process parameters on engineering properties of the extruded products

Run	**Temperature (°C)**	**Moisture content (%)**	**Screw speed (rpm)**	**Bulk density (g/cm^3)**	**True density (g/cm^3)**	**Porosity (%)**
1	130	14	350	0.775	1.45	57.75
2	140	14	300	0.681	1.37	58.29
3	120	12	350	0.821	1.72	57.58
4	140	14	400	0.673	1.27	58.38
5	130	16	400	0.752	1.50	57.60
6	140	16	350	0.663	1.20	58.12
7	140	12	350	**0.652**	**1.15**	**58.57**
8	130	14	350	0.776	1.41	57.78
9	130	12	300	0.762	1.55	57.90
10	130	14	350	0.769	1.42	57.76
11	130	12	400	0.745	1.49	57.98
12	120	14	400	0.835	1.79	57.49
13	130	14	350	0.765	1.39	57.77
14	130	14	350	0.764	1.47	57.78
15	120	14	300	0.841	1.86	57.40
16	130	14	350	0.765	1.44	57.81
17	120	16	350	**0.858**	**1.92**	**57.38**
18	130	16	300	0.783	1.64	57.65

Table A.3.Effect of process parameters on colour parameters of the extruded products

Run	Temperature (°C)	Moisture content (%)	Screw speed (rpm)	L* value	a* value	b* value
1	130	14	350	67.12	4.83	17.83
2	140	14	300	**63.99**	5.23	18.43
3	120	12	350	67.54	4.52	17.66
4	140	14	400	64.98	5.20	18.40
5	130	16	400	67.54	4.69	17.70
6	140	16	350	64.72	5.15	18.21
7	140	12	350	64.20	**5.32**	**18.62**
8	130	14	350	66.95	4.85	17.84
9	130	12	300	65.82	4.98	17.99
10	130	14	350	67.23	4.86	17.85
11	130	12	400	66.81	4.90	17.91
12	120	14	400	**69.92**	4.30	17.50
13	130	14	350	67.00	4.87	17.88
14	130	14	350	67.80	4.88	17.89
15	120	14	300	69.02	4.39	17.58
16	130	14	350	67.50	4.84	17.86
17	120	16	350	68.36	**4.21**	**17.43**
18	130	16	300	66.86	4.77	17.79

Table A.4.Effect of process parameters on textural properties of the extruded products

Run	**Temperature (°C)**	**Moisture content (%)**	**Screw speed (rpm)**	**Hardness (N)**	**Crispness (N)**	**Fracturability (N)**
1	130	14	350	26.57	54.12	13.52
2	140	14	300	25.15	53.17	12.77
3	120	12	350	30.16	48.51	17.08
4	140	14	400	24.77	54.82	11.82
5	130	16	400	28.15	51.95	15.00
6	140	16	350	24.31	54.22	11.24
7	140	12	350	**23.52**	**55.72**	**10.30**
8	130	14	350	27.85	53.18	14.82
9	130	12	300	28.45	51.13	15.98
10	130	14	350	27.52	53.42	14.53
11	130	12	400	27.12	52.48	14.12
12	120	14	400	31.20	47.45	18.62
13	130	14	350	27.32	53.67	14.31
14	130	14	350	27.41	53.53	14.44
15	120	14	300	32.99	46.37	19.43
16	130	14	350	26.44	54.29	13.41
17	120	16	350	**33.86**	**45.23**	**20.54**
18	130	16	300	29.12	50.18	16.41

Table A.5.Effect of process parameters on functional properties of the extruded products

Run	**Temperature (°C)**	**Moisture content (%)**	**Screw speed (rpm)**	**WSI (%)**	**WAI (g/g)**
1	130	14	350	23.12	4.32
2	140	14	300	27.67	5.52
3	120	12	350	20.38	3.75
4	140	14	400	29.14	5.37
5	130	16	400	25.43	4.12
6	140	16	350	28.02	5.40
7	140	12	350	**30.25**	**5.61**
8	130	14	350	23.22	4.22
9	130	12	300	24.15	4.85
10	130	14	350	23.24	4.25
11	130	12	400	26.75	4.58
12	120	14	400	19.52	**3.40**
13	130	14	350	22.35	4.39
14	130	14	350	22.24	4.36
15	120	14	300	18.30	3.58
16	130	14	350	22.21	4.20
17	120	16	350	**15.68**	3.62
18	130	16	300	21.52	4.70

Table A.6.Effect of process parameters on proximate components of the extruded products

Run	**Temperature (°C)**	**Moisture content (%)**	**Screw speed (rpm)**	**Carbohydrate (%)**	**Protein (%)**	**Fat (%)**	**Dietary fiber (%)**
1	130	14	350	69.48	14.79	2.58	9.25
2	140	14	300	**67.90**	**13.95**	**1.90**	**9.67**
3	120	12	350	70.31	15.69	2.92	8.82
4	140	14	400	68.61	14.40	2.25	9.42
5	130	16	400	69.84	15.24	2.75	9.15
6	140	16	350	68.35	14.35	2.12	9.50
7	140	12	350	68.31	14.10	1.95	9.51
8	130	14	350	69.33	14.83	2.59	9.24
9	130	12	300	68.90	14.52	2.31	9.30
10	130	14	350	69.47	14.84	2.49	9.22
11	130	12	400	69.80	14.92	2.65	9.10
12	120	14	400	**70.82**	**15.91**	**3.23**	**8.75**
13	130	14	350	69.42	14.85	2.55	8.23
14	130	14	350	69.41	14.86	2.56	9.26
15	120	14	300	70.12	15.45	2.80	8.90
16	130	14	350	69.44	14.87	2.57	9.21
17	120	16	350	70.33	15.81	3.15	8.80
18	130	16	300	68.95	14.65	2.45	9.32

APPENDIX B

Table B.1.Analysis of variance (ANOVA) for moisture content of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	4.08	9	0.45	154.14	< 0.0001	significant
A-Temperature	1.96	1	1.96	667.07	< 0.0001	
B-Moisture content	1.63	1	1.63	554.36	< 0.0001	
C-Screw speed	6.125E-004	1	6.125E-004	0.21	0.6601	
AB	0.036	1	0.036	12.29	0.0080	
AC	9.000E-004	1	9.000E-004	0.31	0.5951	
BC	9.025E-003	1	9.025E-003	3.07	0.1178	
A^2	0.39	1	0.39	133.28	< 0.0001	
B^2	0.038	1	0.038	12.82	0.0072	
C^2	0.046	1	0.046	15.73	0.0041	
Residual	0.024	8	2.939E-003			
Lack of Fit	8.425E-003	3	2.808E-003	0.93	0.4907	not significant
Pure Error	0.015	5	3.017E-003			
Cor Total	4.10	17				

Std. Dev.	0.054	R-Squared	0.9943
Mean	5.46	Adj R-Squared	0.9878
C.V. %	0.99	Pred R-Squared	0.9618
PRESS	0.16	Adeq Precision	46.839

Table B.2.Analysis of variance (ANOVA) for water activity of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.015	9	1.675E-003	446.65	< 0.0001	significant
A-Temperature	0.013	1	0.013	3499.20	< 0.0001	
B-Moisture content	1.860E-003	1	1.860E-003	496.13	< 0.0001	
C-Screw speed	4.500E-006	1	4.500E-006	1.20	0.3052	
AB	2025E-005	1	2.025E-005	5.40	0.0486	
AC	2.500E-007	1	2.500E-007	0.067	0.8028	
BC	2.500E-007	1	2.500E-007	0.067	0.8028	
A^2	3.007E-005	1	3.007E-005	8.02	0.0221	
B^2	3.341E-006	1	3.341E-006	0.89	0.3729	
C^2	3.007E-005	1	3.007E-005	8.02	0.0221	
Residual	3.000E-005	8	3.750E-006			
Lack of Fit	1.250E-005	3	4.167E-006	1.19	0.4022	not significant
Pure Error	1.750E-005	5	3.500E-006			
Cor Total	0.015	17				

Std. Dev.	1.936E-003	R-Squared	0.9980
Mean	0.48	Adj R-Squared	0.9958
C.V. %	0.40	Pred R-Squared	0.9851
PRESS	2.252E-004	Adeq Precision	77.249

Table B.3.Analysis of variance (ANOVA) for expansion ratio of the extuded products

Source	Sum of Squares		Mean df	F Square	p-value Value	Prob > F
Model	0.72	9	0.080	49.03	< 0.0001	significant
A-Temperature	0.62	1	0.62	379.81	< 0.0001	
B-Moisture content	0.057	1	0.057	35.08	0.0004	
C-Screw speed	0.012	1	0.012	7.50	0.0255	
AB	3.422E-004	1	3.422E-004	0.21	0.6583	
AC	2.250E-004	1	2.250E-004	0.14	0.7194	
BC	2.500E-005	1	2.500E-005	0.015	0.9043	
A^2	0.016	1	0.016	9.74	0.0142	
B^2	0.011	1	0.011	6.66	0.0325	
C^2	5.827E-003	1	5.827E-003	3.59	0.0948	
Residual	0.013	8	1.623E-003			
Lack of Fit	6.984E-003	3	2.328E-003	1.94	0.2416	not significant
Pure Error	6.003E-003	5	1.201E-003			
Cor Total	0.73	17				

Std. Dev.	0.040	R-Squared	0.9822
Mean	2.78	Adj R-Squared	0.9622
C.V. %	1.45	Pred R-Squared	0.8349
PRESS	0.12	Adeq Precision	24.108

Table B.4.Analysis of variance (ANOVA) for bulk density of the extuded products

	Sum of		Mean	F	p-value	
Source	Squares		df	Square	Value	Prob > F
Model	0.061	9	6.810E-003	97.80	< 0.0001	significant
A-Temperature	0.059	1	0.059	844.88	< 0.0001	
B-Moisture content	7.220E-004	1	7.220E-004	10.37	0.0122	
C-Screw speed	4.805E-004	1	4.805E-004	6.90	0.0303	
AB	1.690E-004	1	1.690E-004	2.43	0.1579	
AC	1.000E-006	1	1.000E-006	0.014	0.9076	
BC	4.900E-005	1	4.900E-005	0.70	0.4259	
A^2	6.025E-004	1	6.025E-004	8.65	0.0187	
B^2	3.341E-004	1	3.341E-004	4.80	0.0599	
C^2	2.727E-007	1	2.727E-007	3.917E-003	0.9516	
Residual	5.570E-004	8	6.963E-005			
Lack of Fit	4.150E-004	3	1.383E-004	4.87	0.0604	not significant
Pure Error	1.420E-004	5	2.840E-005			
Cor Total	0.062	17				

Std. Dev.	8.344E-003	R-Squared	0.9910
Mean	0.76	Adj R-Squared	0.9809
C.V. %	1.10	Pred R-Squared	0.8893
PRESS	6.844E-003	Adeq Precision	30.670

Table B.5.Analysis of variance (ANOVA) for true density of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.76	9	0.084	39.89	< 0.0001	significant
A-Temperature	0.66	1	0.66	312.56	< 0.0001	
B-Moisture content	0.015	1	0.015	7.24	0.0275	
C-Screw speed	0.017	1	0.017	8.09	0.0217	
AB	5.625E-003	1	5.625E-003	2.66	0.1416	
AC	2.250E-004	1	2.250E-004	0.11	0.7527	
BC	1.600E-003	1	1.600E-003	0.76	0.4098	
A^2	9.845E-003	1	9.845E-003	4.65	0.0631	
B^2	1.745E-003	1	1.745E-003	0.83	0.3903	
C^2	0.039	1	0.039	18.61	0.0026	
Residual	0.017	8	2.116E-003			
Lack of Fit	0.013	3	4.242E-003	5.05	0.0567	not significant
Pure Error	4.200E-003	5	8.400E-004			
Cor Total	0.78	17				

Std. Dev.	0.046	R-Squared	0.9782
Mean	1.50	Adj R-Squared	0.9537
C.V. %	3.06	Pred R-Squared	0.7300
PRESS	0.21	Adeq Precision	20.272

Table B.6.Analysis of variance (ANOVA) for porosity of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.84	9	0.20	306.95	< 0.0001	significant
A-Temperature	1.54	1	1.54	2313.63	< 0.0001	
B-Moisture content	0.20	1	0.20	307.68	< 0.0001	
C-Screw speed	5.513E-003	1	5.513E-003	8.28	0.0206	
AB	0.016	1	0.016	23.47	0.0013	
AC	0.000	1	0.000	0.000	1.0000	
BC	4.225E-003	1	4.225E-003	6.35	0.0358	
A^2	0.065	1	0.065	98.38	< 0.0001	
B^2	9.818E-004	1	9.818E-004	1.48	0.2592	
C^2	2.455E-004	1	2.455E-004	0.37	0.5605	
Residual	5.325E-003	8	6.656E-004			
Lack of Fit	3.175E-003	3	1.058E-003	2.46	0.1777	not significant
Pure Error	2.150E-003	5	4.300E-004			
Cor Total	1.84	17				

Std. Dev.	0.026	R-Squared	0.9971
Mean	57.83	Adj R-Squared	0.9939
C.V. %	0.045	Pred R-Squared	0.9708
PRESS	0.054	Adeq Precision	62.273

Table B.7.Analysis of variance (ANOVA) for L* value of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	41.56	9	4.62	21.99	0.0001	significant
A-Temperature	35.91	1	35.91	171.03	< 0.0001	
B-Moisture content	1.21	1	1.21	5.76	0.0432	
C-Screw speed	1.58	1	1.58	7.54	0.0252	
AB	0.022	1	0.022	0.11	0.7518	
AC	2.025E-003	1	2.025E-003	9.644E-003	0.9242	
BC	0.024	1	0.024	0.11	0.7439	
A^2	0.77	1	0.77	3.68	0.0913	
B^2	1.79	1	1.79	8.53	0.0193	
C^2	0.076	1	0.076	0.36	0.5650	
Residual	1.68	8	0.21			
Lack of Fit	1.15	3	0.38	3.58	0.1016	not significant
Pure Error	0.53	5	0.11			
Cor Total	43.24	17				

Std. Dev.	0.46	R-Squared	0.9612
Mean	66.85	Adj R-Squared	0.9174
C.V. %	0.69	Pred R-Squared	0.5579
PRESS	19.11	Adeq Precision	16.824

Table B.8.Analysis of variance (ANOVA) for a* value of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.69	9	0.19	594.91	< 0.0001	significant
A-Temperature	1.56	1	1.56	4935.01	< 0.0001	
B-Moisture content	0.10	1	0.10	320.79	< 0.0001	
C-Screw speed	0.014	1	0.014	43.13	0.0002	
AB	4.900E-003	1	4.900E-003	15.52	0.0043	
AC	2.500E-005	1	2.500E-005	0.079	0.7855	
BC	0.000	1	0.000	0.000	1.0000	
A^2	0.010	1	0.010	32.86	0.0004	
B^2	1.705E-004	1	1.705E-004	0.54	0.4834	
C^2	8.250E-004	1	8.250E-004	2.61	0.1446	
Residual	2.525E-003	8	3.156E-004			
Lack of Fit	7.750E-004	3	2.583E-004	0.74	0.5730	not significant
Pure Error	1.750E-003	5	3.500E-004			
Cor Total	1.69	17				

Std. Dev.	0.018	R-Squared	0.9985
Mean	4.82	Adj R-Squared	0.9968
C.V. %	0.37	Pred R-Squared	0.9912
PRESS	0.015	Adeq Precision	83.636

Table B.9.Analysis of variance (ANOVA) for b* value of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.75	9	0.19	159.26	< 0.0001	significant
A-Temperature	1.52	1	1.52	1248.17	< 0.0001	
B-Moisture content	0.14	1	0.14	112.98	< 0.0001	
C-Screw speed	9.800E-003	1	9.800E-003	8.03	0.0220	
AB	8.100E-003	1	8.100E-003	6.64	0.0328	
AC	6.250E-004	1	6.250E-004	0.51	0.4945	
BC	2.500E-005	1	2.500E-005	0.020	0.8897	
A^2	0.069	1	0.069	56.64	< 0.0001	
B^2	7.576E-005	1	7.576E-005	0.062	0.8095	
C^2	1.939E-004	1	1.939E-004	0.16	0.7005	
Residual	9.758E-003	8	1.220E-003			
Lack of Fit	7.075E-003	3	2.358E-003	4.39	0.0724	not significant
Pure Error	2.683E-003	5	5.367E-004			
Cor Total	1.76	17				

Std. Dev.	0.035	R-Squared	0.9944
Mean	17.91	Adj R-Squared	0.9882
C.V. %	0.20	Pred R-Squared	0.9334
PRESS	0.12	Adeq Precision	43.600

Table B.10.Analysis of variance (ANOVA) for hardness of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	132.97	9	14.77	40.13	< 0.0001	significant
A-Temperature	119.04	1	119.04	323.32	< 0.0001	
B-Moisture content	4.19	1	4.19	11.38	0.0097	
C-Screw speed	2.50	1	2.50	6.78	0.0314	
AB	1.58	1	1.58	4.28	0.0724	
AC	0.50	1	0.50	1.35	0.2788	
BC	0.032	1	0.032	0.088	0.7743	
A^2	1.56	1	1.56	4.23	0.0737	
B^2	0.34	1	0.34	0.93	0.3633	
C^2	2.42	1	2.42	6.58	0.0334	
Residual	2.95	8	0.37			
Lack of Fit	1.39	3	0.46	1.49	0.3250	not significant
Pure Error	1.56	5	0.31			
Cor Total	135.91	17				

Std. Dev.	0.61	R-Squared	0.9783
Mean	27.91	Adj R-Squared	0.9539
C.V. %	2.17	Pred R-Squared	0.8200
PRESS	24.46	Adeq Precision	20.314

Table B.11.Analysis of variance (ANOVA) for fracturability of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	124.41	9	13.82	27.78	< 0.0001	significant
A-Temperature	109.08	1	109.08	219.18	< 0.0001	
B-Moisture content	4.08	1	4.08	8.19	0.0211	
C-Screw speed	3.16	1	3.16	6.36	0.0358	
AB	1.59	1	1.59	3.19	0.1119	
AC	4.900E-003	1	4.900E-003	9.846E-003	0.9234	
BC	0.051	1	0.051	0.10	0.7579	
A^2	0.89	1	0.89	1.78	0.2190	
B^2	0.12	1	0.12	0.25	0.6324	
C^2	4.70	1	4.70	9.45	0.0153	
Residual	3.98	8	0.50			
Lack of Fit	2.34	3	0.78	2.37	0.1873	not significant
Pure Error	1.64	5	0.33			
Cor Total	128.39	17				

Std. Dev.	0.71	R-Squared	0.9690
Mean	14.91	Adj R-Squared	0.9341
C.V. %	4.73	Pred R-Squared	0.6904
PRESS	39.75	Adeq Precision	16.988

Table B.12.Analysis of variance (ANOVA) for crispness of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	158.03	9	17.56	49.74	< 0.0001	significant
A-Temperature	115.29	1	115.29	326.57	< 0.0001	
B-Moisture content	4.90	1	4.90	13.88	0.0058	
C-Screw speed	4.28	1	4.28	12.12	0.0083	
AB	0.79	1	0.79	2.24	0.1725	
AC	0.081	1	0.081	0.23	0.6443	
BC	0.044	1	0.044	0.12	0.7329	
A^2	15.50	1	15.50	43.90	0.0002	
B^2	3.55	1	3.55	10.06	0.0132	
C^2	8.19	1	8.19	23.18	0.0013	
Residual	2.82	8	0.35			
Lack of Fit	1.90	3	0.63	3.40	0.1104	not significant
Pure Error	0.93	5	0.19			
Cor Total	160.85	17				

Std. Dev.	0.59	R-Squared	0.9824
Mean	51.86	Adj R-Squared	0.9627
C.V. %	1.15	Pred R-Squared	0.8032
PRESS	31.66	Adeq Precision	20.833

Table B.13.Analysis of variance (ANOVA) for WSI of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	246.91	9	27.43	39.64	< 0.0001	significant
A-Temperature	212.18	1	212.18	306.54	< 0.0001	
B-Moisture content	14.80	1	14.80	21.38	0.0017	
C-Screw speed	10.58	1	10.58	15.29	0.0045	
AB	1.53	1	1.53	2.20	0.1760	
AC	0.016	1	0.016	0.023	0.8843	
BC	0.43	1	0.43	0.62	0.4538	
A^2	2.461E-003	1	2.461E-003	3.556E-003	0.9539	
B^2	3.00	1	3.00	4.33	0.0710	
C^2	3.56	1	3.56	5.15	0.0530	
Residual	5.54	8	0.69			
Lack of Fit	4.23	3	1.41	5.39	0.0503	not significant
Pure Error	1.31	5	0.26			
Cor Total	252.45	17				

Std. Dev.	0.83	R-Squared	0.9781
Mean	23.51	Adj R-Squared	0.9534
C.V. %	3.54	Pred R-Squared	0.7244
PRESS	69.56	Adeq Precision	21.875

Table B.14.Analysis of variance (ANOVA) for WAI of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	7.73	9	0.86	83.32	< 0.0001	significant
A-Temperature	7.13	1	7.13	691.57	< 0.0001	
B-Moisture content	0.11	1	0.11	10.95	0.0107	
C-Screw speed	0.17	1	0.17	16.89	0.0034	
AB	1.600E-003	1	1.600E-003	0.16	0.7038	
AC	2.250E-004	1	2.250E-004	0.022	0.8862	
BC	0.024	1	0.024	2.33	0.1653	
A^2	0.048	1	0.048	4.67	0.0627	
B^2	0.17	1	0.17	16.94	0.0034	
C^2	0.023	1	0.023	2.23	0.1740	
Residual	0.082	8	0.010			
Lack of Fit	0.052	3	0.017	2.85	0.1442	not significant
Pure Error	0.030	5	6.080E-003			
Cor Total	7.81	17				

Std. Dev.	0.10	R-Squared	0.9894
Mean	4.46	Adj R-Squared	0.9776
C.V. %	2.28	Pred R-Squared	0.8878
PRESS	0.88	Adeq Precision	30.516

Table B.15.Analysis of variance (ANOVA) for Carbohydrate content of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	10.15	9	1.13	155.48	< 0.0001	significant
A-Temperature	8.84	1	8.84	1218.92	< 0.0001	
B-Moisture content	2.812E-003	1	2.812E-003	0.39	0.5508	
C-Screw speed	1.28	1	1.28	176.48	< 0.0001	
AB	1.000E-004	1	1.000E-004	0.014	0.9094	
AC	2.500E-005	1	2.500E-005	3.447E-003	0.9546	
BC	2.500E-005	1	2.500E-005	3.447E-003	0.9546	
A^2	0.013	1	0.013	1.82	0.2143	
B^2	8.836E-003	1	8.836E-003	1.22	0.3018	
C^2	2.455E-004	1	2.455E-004	0.034	0.8586	
Residual	0.058	8	7.253E-003			
Lack of Fit	0.043	3	0.014	4.98	0.0581	not significant
Pure Error	0.015	5	2.910E-003			
Cor Total	10.21	17				

Std. Dev.	0.085	R-Squared	0.9943
Mean	69.38	Adj R-Squared	0.9879
C.V. %	0.12	Pred R-Squared	0.9298
PRESS	0.72	Adeq Precision	45.724

Table B.16.Analysis of variance (ANOVA) for Protein content of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5.18	9	0.58	868.73	< 0.0001	significant
A-Temperature	4.56	1	4.56	6883.32	< 0.0001	
B-Moisture content	0.088	1	0.088	133.13	< 0.0001	
C-Screw speed	0.45	1	0.45	681.13	< 0.0001	
AB	3.025E-003	1	3.025E-003	4.57	0.0651	
AC	2.500E-005	1	2.500E-005	0.038	0.8508	
BC	9.025E-003	1	9.025E-003	13.62	0.0061	
A^2	0.062	1	0.062	92.88	< 0.0001	
B^2	2.461E-003	1	2.461E-003	3.72	0.0901	
C^2	4.261E-003	1	4.261E-003	6.43	0.0349	
Residual	5.300E-003	8	6.625E-004			
Lack of Fit	1.300E-003	3	4.333E-004	0.54	0.6745	not significant
Pure Error	4.000E-003	5	8.000E-004			
Cor Total	5.19	17				

Std. Dev.	0.026	R-Squared	0.9990
Mean	14.89	Adj R-Squared	0.9978
C.V. %	0.17	Pred R-Squared	0.9949
PRESS	0.027	Adeq Precision	103.467

Table B.17.Analysis of variance (ANOVA) for Fat content of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	2.19	9	0.24	141.19	< 0.0001	significant
A-Temperature	1.88	1	1.88	1092.22	< 0.0001	
B-Moisture content	0.051	1	0.051	29.72	0.0006	
C-Screw speed	0.25	1	0.25	146.29	< 0.0001	
AB	9.000E-004	1	9.000E-004	0.52	0.4904	
AC	1.600E-003	1	1.600E-003	0.93	0.3634	
BC	4.000E-004	1	4.000E-004	0.23	0.6428	
A^2	3.030E-004	1	3.030E-004	0.18	0.6860	
B^2	7.758E-004	1	7.758E-004	0.45	0.5211	
C^2	4.848E-005	1	4.848E-005	0.028	0.8709	
Residual	0.014	8	1.723E-003			
Lack of Fit	7.450E-003	3	2.483E-003	1.96	0.2384	not significant
Pure Error	6.333E-003	5	1.267E-003			
Cor Total	2.20	17				

Std. Dev.	0.042	R-Squared	0.9937
Mean	2.55	Adj R-Squared	0.9867
C.V. %	1.63	Pred R-Squared	0.9418
PRESS	0.13	Adeq Precision	42.827

Table B.18.Analysis of variance (ANOVA) for Dietary fiber content of the extuded products

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.09	9	0.12	284.12	< 0.0001	significant
A-Temperature	1.00	1	1.00	2338.36	< 0.0001	
B-Moisture content	2.000E-004	1	2.000E-004	0.47	0.5136	
C-Screw speed	0.074	1	0.074	173.11	< 0.0001	
AB	2.500E-005	1	2.500E-005	0.058	0.8151	
AC	2.500E-003	1	2.500E-003	5.84	0.0421	
BC	2.250E-004	1	2.250E-004	0.53	0.4891	
A^2	0.013	1	0.013	30.83	0.0005	
B^2	2.209E-003	1	2.209E-003	5.16	0.0528	
C^2	1.091E-004	1	1.091E-004	0.25	0.6273	
Residual	3.425E-003	8	4.281E-004			
Lack of Fit	1.675E-003	3	5.583E-004	1.60	0.3019	not significant
Pure Error	1.750E-003	5	3.500E-004			
Cor Total	1.10	17				

Std. Dev.	0.021	R-Squared	0.9969
Mean	9.20	Adj R-Squared	0.9934
C.V. %	0.22	Pred R-Squared	0.9733
PRESS	0.029	Adeq Precision	58.357

APPENDIX C

Table C.1. Moisture content of extruded product during storage period

No. of days	Active MAP		Passive MAP	
	LDPE	LA	LDPE	LA
0	4.39	4.39	4.39	4.39
15	4.60	4.52	4.72	4.65
30	4.98	4.78	5.12	4.92
45	5.57	5.23	5.77	5.59
60	6.03	5.58	6.18	5.63
75	6.56	6.11	6.64	6.29
90	6.78	6.35	6.89	6.65

Table C.2. Water activity of extruded product during storage period

No. of days	Active MAP		Passive MAP	
	LDPE	LA	LDPE	LA
0	0.430	0.430	0.430	0.430
15	0.478	0.462	0.498	0.471
30	0.523	0.492	0.543	0.511
45	0.561	0.544	0.571	0.545
60	0.583	0.568	0.598	0.584
75	0.628	0.618	0.642	0.623
90	0.654	0.632	0.665	0.645

Table C.3. L* value of extruded product during storage period

No. of days	Active MAP		Passive MAP	
	LDPE	LA	LDPE	LA
0	63.94	63.94	63.94	63.94
15	63.92	63.93	63.92	63.93
30	63.65	63.64	63.63	63.65
45	63.21	63.24	63.20	63.25
60	62.91	62.94	62.90	62.95
75	62.82	62.84	62.81	62.84
90	62.74	62.75	62.73	62.75

Table C.4. a* value of extruded product during storage period

No. of days	Active MAP		Passive MAP	
	LDPE	LA	LDPE	LA
0	5.31	5.31	5.31	5.31
15	5.33	5.32	5.34	5.33
30	5.45	5.42	5.46	5.43
45	5.78	5.76	5.78	5.78
60	5.95	5.94	5.96	5.94
75	6.12	6.11	6.12	6.11
90	6.23	6.21	6.24	6.21

Table C.5. b* value of extruded product during storage period

No. of days	Active MAP		Passive MAP	
	LDPE	LA	LDPE	LA
0	18.59	18.59	18.59	18.59
15	18.61	18.60	18.61	18.60
30	18.72	18.72	18.73	18.72
45	18.94	18.93	18.94	18.93
60	19.22	19.21	19.23	19.21
75	19.34	19.33	19.35	19.33
90	19.52	19.51	19.52	19.51

Table C.6. Hardness of extruded product during storage period

No. of days	Active MAP		Passive MAP	
	LDPE	LA	LDPE	LA
0	24.05	24.05	24.05	24.05
15	22.85	23.75	22.25	23.54
30	20.56	21.63	20.23	20.66
45	19.86	20.46	19.42	19.65
60	18.84	19.63	18.52	19.49
75	17.85	18.88	17.68	18.65
90	17.55	18.52	17.13	18.12

Table C.7. Crispness of extruded product during storage period

No. of days	Active MAP		Passive MAP	
	LDPE	LA	LDPE	LA
0	55.27	55.27	55.27	55.27
15	55.10	55.17	55.01	55.12
30	54.75	54.83	54.65	54.75
45	54.44	54.65	54.37	54.55
60	53.78	53.91	53.70	53.84
75	53.61	53.71	53.48	53.67
90	53.25	53.64	53.12	53.55

Table C.8. Fracturability of extruded product during storage period

No. of days	Active MAP		Passive MAP	
	LDPE	LA	LDPE	LA
0	10.85	10.85	10.85	10.85
15	10.75	10.80	10.64	10.74
30	10.47	10.50	10.35	10.41
45	10.12	10.18	10.01	10.11
60	9.71	9.80	9.64	9.72
75	9.41	9.53	9.30	9.48
90	9.26	9.45	9.12	9.38

Table C.9. Analysis of variance for effect of packaging materials (with passive and active MAP) on moisture content during storage period

	Sum of squares	df	Mean square	F	Sig
Between Groups	0.490	3	0.163	1.633E3	0.000
With in Groups	0.001	8	0.000		
Total	0.491	11			

Table C.10. Analysis of variance for effect of packaging materials (with passive and active MAP) on water activity during storage period

	Sum of squares	df	Mean square	F	Sig
Between Groups	0.002	3	0.001	586.000	0.000
With in Groups	0.000	8	0.000		
Total	0.002	11			

Table C.11. Analysis of variance for effect of packaging materials (with passive and active MAP) on L* during storage period

	Sum of squares	df	Mean square	F	Sig
Between Groups	0.001	3	0.000	2.750	0.112
With in Groups	0.001	8	0.000		
Total	0.002	11			

Table C.12. Analysis of variance for effect of packaging materials (with passive and active MAP) on a* during storage period

	Sum of squares	df	Mean square	F	Sig
Between Groups	0.002	3	0.001	0.134	0.937
With in Groups	0.040	8	0.005		
Total	0.042	11			

Table C.13. Analysis of variance for effect of packaging materials (with passive and active MAP) on b* during storage period

	Sum of squares	df	Mean square	F	Sig
Between Groups	0.000	3	0.000	1.000	0.441
With in Groups	0.001	8	0.000		
Total	0.001	11			

Table C.14. Analysis of variance for effect of packaging materials (with passive and active MAP) on hardness during storage period

	Sum of squares	df	Mean square	F	Sig
Between Groups	3.386	3	1.129	1.129E4	0.000
With in Groups	0.001	8	0.000		
Total	3.387	11			

Table C.15. Analysis of variance for effect of packaging materials (with passive and active MAP) on crispness during storage period

	Sum of squares	df	Mean square	F	Sig
Between Groups	0.542	3	0.181	1.806E3	0.000
With in Groups	0.001	8	0.000		
Total	0.543	11			

Table C.16. Analysis of variance for effect of packaging materials (with passive and active MAP) on fracturability during storage period

	Sum of squares	df	Mean square	F	Sig
Between Groups	0.189	3	0.063	628.750	0.000
With in Groups	0.001	8	0.000		
Total	0.189	11			

APPENDIX D

Table D.1. Sensory score of extruded sample after three month storage

	LDPA	**LA**	**LDPE-N**	**LA-N**	**Control**
Colour And appearance	7.36	7.44	7.43	7.52	9
Flavour	6.8	7.23	6.83	7.22	9
Taste	5.9	7.1	6.99	7.82	9
Texture	5.5	7.32	6.54	7.76	9
Overall acceptability	7.0	8.25	7.61	8.8	9

APPENDIX E

Cost analysis

Cost of machineries	
Cost of twin screw extruder + coating machine	Rs 17,00,000/-
Cost of drier	Rs 2,50,000/-
Cost of hammer mill	Rs 1,10,000/-
Cost of packaging machine	Rs 1,00,000/-
Cost of mini mill	Rs 35,000/-
Miscellaneous item	Rs 50,000/-
Total cost	Rs 22,45,000 /-
25% subsidy therefore, total cost (C)	16,83,750/-

Assumption

Life span (L) = 10 years

Annual working hours (H) = 275 days (per day 8 hours) = 2200 hours

Salvage value (S) = 10% of initial cost

Interest on initial cost (i) = 15% annually

Repair and maintenance = 5% of initial cost

Insurance and taxes = 2% of initial cost

Electricity charge = Rs 7/unit

Labour wages = Rs 400/day

1. Total fixed cost of extrusion

i. Depreciation $= \frac{\text{C-S}}{\text{L}\times\text{H}} = \frac{1683750-168375}{10\times2200}$ = Rs 68.88/h

ii. Interest $= \frac{\text{C+S}}{2}\times\frac{\text{i}}{\text{H}} = \frac{1683750+168375}{2}\times\frac{15}{100\times2200}$ = Rs 36.15/h

iii. Insurance and taxes = 2% of initial cost

$\frac{2}{100\times2200}\times 1683750$ = 15.30/h

Total fixed cost = i + ii+ iii = Rs 147.32

2. Total variable cost of extrusion

i. Repair and maintenance = 5% of initial cost

$= \frac{5}{100\times2200}\times 1683750$ = Rs 38.26/h

ii. Electricity cost

a) Energy consumed by the extruder = 7.5kW/h

Cost of energy consumption/h = Power × duration × cost of 1 unit

7.5×8×7 = Rs 420/ day

b) Energy consumed by drier, mini mill and hammer mill = 2 kW/h

Cost of energy consumption/h = Power × duration × cost of 1 unit
=2×8×7 = Rs 112/day

iii. Energy requirement for MAP = 2 kW/h
2×8×7 = Rs 112/day

iv. Labour cost = Rs 400/day

Packaging cost = Rs 2000/day

v. Cost of raw material for preparation of 100 kg of extruded product

Sl No	Raw materials	Quantity (kg)	Unit rate (per kg)	Total amount (Rs)
1	Rice	60	40	2400
2	Ragi	10	50	500
3	Bengal gram	10	95	950
4	Ground nut	10	240	2400
5	Soybean	10	110	1100
6	Salt + masala	15	50	750
Total cost of raw materials			Rs 8100/-	

Therefore variable/operating cost = i + ii + iii + iv + v

= Rs 11,182.26 /-

Therefore total cost of production of 100 kg of extruded product

= Fixed cost + Variable cost

= 147.32 + 11,182.26

= 11329.58/100 kg of RTE product

= Rs 113.29/kg of RTE product

The market selling price of 1kg of extruded product = Rs 450/kg

Benefit – cost ratio = 450/113.29 = 3.97

Therefore the total production cost of 1kg of extruded RTE product was found to be Rs. 113.29/-. The benefit cost ratio of the production was found to be 3.97:1.

DEVELOPMENT AND EVALUATION OF PROTEIN ENRICHED RTE EXTRUDED FOOD PRODUCTS

By

ATHIRA K

(2017-18-001)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree
Master of Technology
In
Agricultural Engineering
(Agricultural Processing and Food Engineering)
Faculty of Agricultural Engineering and Technology
Kerala Agricultural University

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ABSTRACT

Malnutrition causes major health problems due to qualitative and quantitative insufficiency of dietary protein and calories intake. Protein energy malnutrition is a serious threat especially in children in developing countries. Fortification or combination of two or more food ingredients can make a solution for this nutritional insufficiency to a certain extend. Food products with improved nutritional profile can be produced by blending legumes. Ready to eat food products are plays a major role in modern consumer's diets. Extrusion cooking is a novel technology adopted by food industries as it is a rapid, continuous and cost-effective process. Therefore, an investigation has been taken up to develop a protein enriched ready to eat food products from rice, ragi, Bengal gram, ground nut and soybean using extrusion cooking. The feed composition selected for the extrusion were 60% rice, 10% ragi, 10% Bengal gram, 10% soybean and 10% groundnut flour and the physico chemical analysis of the feed mix was conducted and recorded. The process variables used in the study were temperature (120,130 and 140°C), moisture content (12, 14 and 16%) and screw speed (300, 350 and 400 rpm). The optimisation of process parameters was analysed using RSM based on the quality characteristics of the extrudates. The optimum operating conditions of extrusion process namely, barrel temperature, moisture content and screw speed was found to be 140°C, 12.20% and 383.96 (384) rpm respectively. The storage studies of optimally produced extrudates were conducted by using different packaging materials (LDPE and laminated aluminum) and packaging technologies (Active and passive MAP). The extrudates packed in laminated aluminum with active MAP had good overall acceptability after three months of storage and they were microbiologically safe. The total production cost of 1kg of extruded RTE product was found to be Rs. 113.29/-.