DEVELOPMENT AND QUALITY EVALUATION OF HOT EXTRUDED RTE PRODUCTS FROM SPECIALITY RICE

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TAVANUR - 679573, MALAPPURAM

KERALA, INDIA

2018

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PROJECT REPORT

Submitted in partial fulfilment of the requirement for the degree of

BACHELOR OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

Department of Food and Agricultural Process Engineering

Kelappaji College of Agricultural Engineering & Technology
Kerala Agricultural University
Tavanur, Malappuram – 679 573. Kerala, India

2018

DECLARATION

We hereby declare that this thesis entitled “**DEVELOPMENT AND QUALITY EVALUATION OF HOT EXTRUDED RTE PRODUCTS FROM SPECIALITY RICE”** is a bonafide record of research work done by us during the course of academic programme in the Kerala Agricultural University and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this project report entitled "**DEVELOPMENT AND QUALITY EVALUATION OF HOT EXTRUDED RTE PRODUCTS FROM SPECIALITY RICE"** is a record of project work done jointly by Mr. Akhil K G, Ms. Gopika P, Mr. Sonal Baiju under my guidance and supervision and that it has not previously formed the basis for any degree, diploma, fellowship or associateship or other similar title of another University or Society.

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ACKNOWLEDGEMENT

Any accomplishment requires the efforts of many people and this work is no different. We find great pleasure in expressing our deep sense of gratitude towards all those who have made it possible for us to complete this project with success.

First of all we would like to express our true and sincere gratitude to our mentor **Dr. Sudheer K.P.,** Professor and Head, Dept. of Agricultural Engineering, College of Horticulture, Vellanikkara, for his dynamic and valuable guidance, care, patience and keen interest in our project work. This project has been a result of combined efforts of our guide and us. He has been a strong and reassuring support to us throughout this project. We consider it as our greatest fortune to have him as the guide for our project work and our obligation to him lasts forever.

With deep sense of gratitude and due respect, we express our heartfelt thanks to **Dr. Santhi Mary Mathew**, Dean i/c, KCAET, Tavanur, for support that she offered while carrying out the project work.

We engrave our deep sense of gratitude to **Dr. Rajesh G.K.,** Assistant Professor, **Mrs. Sreeja R.,** Assistant Professor, **Dr. Anjineyulu Kothakota.,** Teaching Assistant, Department of Food and Agricultural Process Engineering, K.C.A.E.T, Tavanur.

With great pleasure we express our heartfelt special thanks to our beloved seniors **Er. Seema B.R, Er. Saranya S, Er. Pooja M.R,** for their care, help, encouragement and moral support which helped us get over all odds and tedious circumstances.

We express our profound sense of gratitude to **Mrs. Jojitha**, **Mrs Geetha**, **Er. Rooshi**, staff members of Department of Food and Agricultural Process Engineering, K.C.A.E.T, Tavanur and **Mr. Radhakrishnan M.V**, Lab Assistant for their immense help.

We express our thanks to all the **staff members of library**, K.C.A.E.T, Tavanur for their ever willing help and cooperation. We express our sincere thanks and gratitude to **Kerala Agricultural University** for providing this opportunity to do the project work.

We are greatly indebted to our **parents** for their love, blessings, and support which gave strength to complete the study.

Last but not the least, we bow our heads before **God Almighty** for the blessings bestowed upon us which made us to materialize this endeavour.

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SYMBOLS AND ABBREVIATIONS

et al.	:	And others
%	:	Per cent
&	:	And
/	:	Per
@	:	At the rate of
<	:	Less than
>	:	Greater than
±	:	Plus or minus sign
≤	:	Less than or equal to
≥	:	Greater than or equal to
◦	:	Degree
°C	:	Degree centigrade
µm	:	micrometer
a*	:	Greenness or redness
a_w	:	Water activity
b*	:	Blueness or yellowness
C	:	Corn flour
Cal/g	:	Calorie per gram
cm	:	Centimetre
cm^3/g	:	Cubic centimetre per gram
d.b.	:	Dry basis

dia.	:	Diameter
e.g.	:	Example
etc.	:	Etcetera
Fig.	:	Figure
g	:	Gram
g/100g	:	Gram per 100 gram
g/cm^3	:	Gram per centimetre cube
g/g	:	Gram per gram
g/kg	:	Gram per kilogram
g/ml	:	Gram per milliliter
g/s	:	Gram per second
h	:	Hour
hp	:	Horse power
K	:	Kumkumashali rice flour
kCal	:	Kilo Calories
kg	:	Kilogram
kg/cm^3	:	Kilogram per centimeter cube
kg/h	:	Kilogram per hour
kg/m^3	:	Kilogram per meter cube
kJ	:	Kilo Joule
L*	:	Lightness or darkness
Ltd.	:	Limited
m/s	:	Meter per second
mg	:	Milligram

mg/100g	:	Milligram per 100 gram
mg/g	:	Milligram per gram
min	:	Minute
ml	:	Milliliter
mm	:	Millimeter
mm/s	:	Millimeter per second
N	:	Newton
N/mm^2	:	Newton per millimetre square
No.	:	Number
P	:	Combinations
pH	:	Percentage of H+ ions
pps	:	Parts per second
R	:	Rakthashali rice flour
R^2	:	Reggration coefficient
rpm	:	Revolution per minute
s	:	Second
T	:	Temperature
tm	:	Residence time
tsp	:	Teaspoonful
V	:	Volts
viz	:	Namely
w.b.	:	Wet basis
w/w	:	Weight by weight
π	:	Pi

AOAC	:	Association of official analytical chemists
BD	:	Bulk density
BT	:	Barrel temperature
ER	:	Expansion ratio
FMC	:	Feed moisture content
HTST	:	High temperature-short time
ISS	:	Indian standard sieve
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
LDPE	:	Low density polyethylene
MAP	:	Modified atmospheric packaging
MC	:	Moisture content
PDHF	:	Partially defatted hazelnut flour
RSM	:	Response surface methodology
RTE	:	Ready-to-eat
SDS	:	Sodium dodecyl sulphate
SEI	:	Sectional expansion index
SME	:	Specific mechanical energy
SPI	:	Soy protein isolate
SS	:	Screw speed
SSE	:	Single screw extruder
SWS	:	Sweet whey solids
TA	:	Texture analyzer
TSE	:	Twin screw extruder
TVP	:	Textured vegetable protein

WAI : Water absorption index

WPC : Whey protein concentrate

WSI : Water solubility index

INTRODUCTION

CHAPTER I

INTRODUCTION

Extrusion cooking is a modern high-temperature short time (HTST) processing technology. Extrusion processing was introduced by Harper for the first time to food material (Mercier and Feillet 1975). It is a process by which a set of mixed ingredients are forced through an opening in a perforated plate or die with a design specific to the food, and is then cut to a specified size by blades. The machine which forces the mix through the die is an extruder, and the mix is known as the extrudate. The extruder consists of a large, rotating screw tightly fitting within a stationary barrel, at the end of which is the die. It offers several advantages over other types of cooking processes, such as faster processing times and significant reduction in energy consumed, which consequently results in lower prices for the final products. Extruders can be used for a wide range of traditional (conventional) food products, as well as in the production of numerous new products like cereal baby food, confectionary, breakfast cereals, snack foods, bakery products, flavors, pastas, pet food and meat products. An extruder represents a very complex bioreactor in which various types of raw food materials with different moisture contents and consistencies are treated under high temperatures, short residence times, high pressures and very strong shear forces. Extrusion technology is very useful from the standpoint of nutritional value as nutrient losses are lower compared to other thermal processing methods (Moscicki *et al.*, 2003).

Nowadays the production and consumption of expanded RTE products through extrusion cooking has notably increasing worldwide. Eating patterns are changing, snack foods play very important roles in the diet of the modern consumer. Many consumers do not have time to prepare traditional meals and increasingly even lack the knowledge of how to cook. They also want to relax in their comfort of their own home rather than to spend time at a full service restaurant. In India, several RTE products are available in the market. The RTE foods are prepared by extrusion cooking, puffing, popping, flaking, frying, toasting, etc. (Dias *et al.,* 2009).

Extrusion cooking has gained in popularity over the last two decades for a number of reasons:

- Versatility: a wide range of products, many of which cannot be produced easily by any other process, is possible by changing the ingredients, extruder operating conditions and dies.
- Cost: extrusion has lower processing costs and higher productivity than other cooking and forming processes.
- Productivity: extruders can operate continuously with high throughput.
- Product quality: extrusion cooking involves high temperatures applied for a short time, retaining many heat sensitive components of a food.
- Environmentally-friendly: as a low-moisture process, extrusion cooking does not produce significant process effluents, reducing water treatment costs and levels of environmental pollution.

Extrusion is classified into two types based on temperature (hot and cold extrusion). If the food is heated below 100°C the process is known as cold extrusion. Typical food products include pasta, pet food etc. If the food is heated above 100°C the process is known as hot extrusion (or extrusion cooking). Typical products include a wide variety of low density, expanded snack foods and ready to eat (RTE) puffed cereals.

A nutritionally secure RTE food products has immense importance in this era. In Ayurveda, the proposed ingredients are conventionally advised to women to cater to their health requirements, especially during late stages of the reproductive cycle. Considering the benefits of extrusion cooking technology different raw materials namely speciality rice (Rakthashali and Kumkumashali) and corn were considered for preparation of extruded product in the present investigation.

Rice (*Oryzasativa*) belongs to a family *Poaceae.* It is one of the most important foods in the world, supplying as much as half of the daily calories for half of the world's population. It is low in fat, low in cholesterol, high in starch and has a high nutritional content.

Rice is also an excellent source of energy. It is comprised of 77.5% carbohydrate. Hundred gram of rice contain 1,527 kJ (365 kCal) energy, 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. In addition to being a rich source of dietary energy, rice is a good source of vitamins as riboflavin 0.0149 mg, niacin 1.62 mg, thiamine 0.27 mg (Chandrashekaran *et al.*, 2008). Health benefits of rice includes its ability to provide fast and instant energy, stabilize blood sugar levels, while also providing an essential source of vitamin B1 to the human body. Other benefits include its ability to boost skin health, increase the metabolism, reduce high blood pressure, improve the immune system and provide protection against, cancer, and heart disease. Also ayurveda uses rice based diets in treating various imbalances in the body. A product out of this cereal will be a diet cum expanded snack for the consumers.

The Rakthashali is a rare and traditional red rice variety. It has high medicinal value. People believe that it can slow down the process of ageing. From vedic times onward, it is consider as a medicinal rice variant and an auspicious grain for vedic rites. The Ayurveda says this variety of rice, dating its use back to more than 3,000 years, is good for "dosha", such as "Vatha", "Pitha", and "Kafa". Modern studies say that it is rich in antioxidants, calcium, zinc, iron, & other minerals.Besides being a functional food for promoting lactation, "Rakthashali" have therapeutic value in the treatments of allergies & skin ailments, uterus related problems, gastro intestinal problems, liver, kidney, nerve disorders etc. Traditional rice varieties had unique nutritional and medicinal qualities. But due to the long duration for cultivation & low yield, they are an uneconomical choice for farmers. So the Rakthashali rice never been a popular one outside the coastal belt of south Karnataka where it is the native staple food. But now, due to the awareness about organic products and health, more people like to consume traditional red & brown rice variants like "Rakthashali".

Maize (*Zea mays*) belongs to family *Poaceae*, also known as corn and it is the most important cereal grain in the world providing nutrients for humans and animals. Corn has become an attractive ingredient in the extrusion industry due to its attractive yellow colour and great expansion characteristic, which is one of the important parameters in the production of a cereal-based extruded snack food in terms of the functional properties of the final product (Tahnoven *et al*., 1998). Corn grits are widely used to elaborate expanded products by extrusion cooking. A lower degree of corn replacement is needed to increase the nutritional contribution of expanded snacks which in turn can help to keep consumer acceptance high (Robutti *et al.,* 2002). Corn flour contains small amounts of phosphorus, vitamin B12, magnesium, selenium, and vitamin B6. The major advantage with corn flour is that it is very low in fat so this RTE product can reduce the chances of heart disease and obesity.

In this back ground, a project entitled "Development and quality evaluation of hot extruded RTE product from speciality rice" was under taken at Kelappaji

College of Agricultural Engineering and Technology (KCAET), Tavanur, Kerala with the following objectives.

1. To standardise the extrusion process parameters.
2. To standardise the composition of RTE food from speciality rice flour (Rakthashali and Kumkumashali) and corn flour.
3. Shelf life studies and quality analysis of extruded RTE products.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

2.1 Raw materials

2.1.1 Rice (*Oryza sativa*)

Bryant *et al.* (2001) studied functional and digestive characteristics of extruded rice flour. Waxy (short grain), long grain, and parboiled (long grain) rice flours were extruded using three different temperatures and five different feed rates. The WAI and WSI of the extrudates was 0.67-5.86 and 86.45-10.03% respectively. Bulk density decreased with an increase in moisture and except waxy rice. The viscosity profiles of long grain and parboiled rice were similar. The main difference in the digestion profiles was due to temperature. The flours extruded at 100°C digested significantly slower than those extruded at 125°C and 150°C. The digestion rate for 11 and 25% added moisture was significantly less than that for 20%.

Charunuch *et al*. (2003) investigated the potential of brown rice as basic raw materials in the production of direct expansion extruded snack by twin screw extruder at varying screw speed (250, 300 and 350 rpm) and feed moisture (13, 15 and 17%). Results indicated that main factor (screw speed or feed moisture) had significant effect on physical properties of extrudates by showing that reducing feed moisture from 17 to 13% or increasing screw speed from 250 to 350 rpm provided more expandable extrudates with higher expansion ratio.

Ding *et al.* (2005) studied the effect of extrusion conditions, including feed moisture content (14-22%), feed rate (20-32%), barrel temperature (100-140°C) and screw speed (180-320 rpm) on the physico-chemical properties (expansion, density, WSI and WAI) and sensory characteristics (crispness and hardness) of an expanded rice snack. Increasing feed rate results in extrudates with a higher (expansion, hardness) and lower WSI. Increasing moisture content results in extrudates with a higher (density, hardness, WAI) and lower (expansion, crispness, and WSI). Higher barrel temperature increased the expansion, WSI (1.88 g/g) and crispness of extrudates but reduced density (0.5 g/cm^3). The result shows the optimum condition at 20% feed rate, 16% feed moisture and screw speed of 320 rpm.

Omwamba *et al.,* (2014) developed a Protein-Rich Ready-to-Eat extruded snack from a composite blend of Rice, Sorghum and Soyabean Flour. Extrusion cooking was carried out at barrel temperature of 110˚C - 150˚C, screw speed of 350 - 450 rpm, and feed moisture of 12% - 14% to investigate the effect of extrusion conditions on physical properties (expansion ratio and bulk density) of a rice, sorghum and soy flour blend. From response surface analysis, expansion ratio and bulk density were found to be significantly ($P < 0.05$) dependent on feed moisture and barrel temperature while the screw speed had a significant ($P > 0.05$) effect. Expansion ratio and bulk density ranged from 2.0 to 2.6 and 0.79 to 0.95 g/ml respectively. One hundred grams of the extruded product would supply 45% of the recommended daily allowance for protein in children aged up to 12 years. The mineral content in 100 g extrudates was found to be 52 mg calcium, 3.01 mg iron and 1.23 mg zinc. The retention of amino acids in the extruded products was 88% - 95% with lysine—a limiting amino acid in cereals having a loss of 9.1% after extrusion.

Rafe *et al.*, (2016) studied on the effect of extrusion processing on the physicochemical, nutritional, and functional properties of Tarom cultivar rice bran. However, the color of rice bran was improved by extrusion processing, but the protein content was reduced in the stabilized rice bran, which can be related to the denaturation of protein. Extrusion had also a reduction significant effect on the phytic acid as well as vitamin E in rice bran. However, the content of niacin, riboflavin, pantothenic acid, and folic acid remained unchanged, but the dietary fiber was enhanced which has beneficial health effect on human consumption. In comparison with unstabilized rice bran, water holding capacity was enhanced, but the oil absorption capacity was reduced. Foaming capacity and foaming stability of extruded rice bran was more than that of untreated rice bran, although they were less than that of rice bran protein concentrate/isolate. In general, the extrusion process improves some functional and nutritional properties of rice bran which are valuable to industrial applications and have potential as ingredient in food to improve consumer health.

2.1.2 Maize (*Zea mays*)

Extrusion cooking is a widely used process for elaborating different foods with a cereal base (Harper 1981,1989: Fast 1991, Kohlway *et al*. 1995), the majority of which contain corn and are manufactured with semolina and flours as raw materials (Katta *et al.* 1999).

Onwulata *et al.* (2001) by incorporating whey protein concentrate (WPC) and sweet whey solids (SWS) at concentrations of 500 and 250 g/kg to corn, potato or rice flour prepared snack product using high and low shear extrusion processing conditions and reported that, increased specific mechanical energy (SME) was desired for expanding products. But as a result of incorporating WPC and SWS, SME was reduced. Quality indices for expansion and decreased breaking strength ($P<0.05$) indicates poor textural effects. By adding reverse screw elements and reducing the moisture, SME was increased which increased breaking strength and product expansion. Extrudates with good quality were produced with up to 25% whey protein substitution for flour.

Palazuelos *et al*. (2006) studied the effects of extrusion feed moisture (16-30%) and barrel temperature (75-140°C) of third-generation expanded product by microwave heating. A blend of potato starch (50%), quality protein maize (35%) and soybean meal (15%) was used in the preparation of the snack food by single screw extruder with the help of central composite rotatable experimental design. The results indicated that when the barrel temperature was increased expansion ratio increased and bulk density decreased while feed moisture had no significant effect. Response surface methodology (RSM) showed the best expansion of extruded products at 28% feed moisture and 130°C barrel temperature. Hence, using extrusion technology it is possible to produce third-generation snacks that have a significant nutritional and nutraceutical value by using soybean meal and high-protein quality maize.

Yu *et al.,* (2013) prepared protein rich extruded products from corn flour blended with soy protein isolate (SPI), feed moisture (31.6-48.4 g/100 g) and process temperature (126.4-193.6°C). The results showed that the independent variables had significant effects on physical properties of extrudates. It has been observed that, a higher SPI (66.6 g protein/100 dry matter) and feed moisture content (48.4 g/100 g) increased the breaking stress (0.828 N/mm^2) and bulk density (0.864 g/ml), but decreased the expansion ratio (1.25), water solubility index (2.7 g/100 g), rehydration rate (49 g/100 g), colour L* (74.21) value, whereas higher feed moisture content increased color L* (87.37). However a higher temperature (193.6°C) increased breaking stress (0.828 N/mm^2), expansion ratio (1.77), rehydration rate (205 g/100 g) and L value (87.37), but decreased the bulk density (0.423 g/ml) and water solubility index (2.7g/100g).

Reddy *et al.,* (2014) developed the extruded Ready-To-Eat (RTE) snacks using corn,black gram, roots and tuber flour blends. Extrusion were carried out by mixing the flour blends in a proportion of 60–80: 20: 20 respectively and moisture was adjusted to 17–20 %. The roots and tubers flours were developed from potato (*Solanum tuberosum*), yam (*Dioscorea spp.*), sweet potato (*Ipomoea batatas L.*), taro (*Colocassia esculenta*) and beet root (*Beta vulgaris*). Different formulations were extruded at 80 ± 5°C (heater I) and 95–105 °C (heater II) temperature, 300–350 rpm screw speed, 100 ± 10°C die temperature and 15 ± 2 kg/h feed rate. The exit diameter of the circular die was 3 mm. Sensory acceptability, physical parameters and nutrient analysis along with storage stability of the products was conducted. The fiber and energy content of the RTE extruded snack improved in experimental samples prepared using root and tuber flours. A serving of 100 g of the snack can provide more than 400 kCal and 10 g of protein. The overall acceptability of RTE extruded products made with potato and taro were highly acceptable compared to yam and sweet potato.

Balfour *et al.,* (2014) studied on the Development and Quality Evaluation of Extruded Fortified Corn Snack. It was developed by single type screw extruder using Corn Meal, Oat Meal and Whey Protein Concentrate. The studies were conducted on incorporation of different ratios of CM, OM and WPC used and shelf life study was conducted for two months. Three different ratios of CM, OM and WPC were taken in the proportion of (90:7:3) for the first (80:16:4) second and (70:25:5) third treatment. Spinach and mint leaves were used for flavoring and seasoning. Physico-chemical and sensory analysis of the samples were evaluated. During storage it was observed that moisture content of the sample showed slight increase whereas there was a slight decrease in all the other proximate analysis. But it was observed that all the proximate parameters were increased from the control sample to the different treatments. Among the treatments the one with 80% and 70% CM were found nutritive. Depending upon the sensory attributes also the sample having 80% CM was found satisfactory for storage and is the most acceptable sample. Therefore the snack developed is a high fiber low calorie snack which can be recommended to the diabetic and obese people.

Topuz *et al.,* (2017) studied the Development of Extruded Shrimp-Corn Snack Using Response Surface Methodology**.** Dried shrimp muscle was ground and blended with corn flour at the level of 20% (w: w). The shrimp-corn flour mix was extruded through a co-rotating twin-screw extruder with a screw diameter of 24 mm. The effects of extrusion temperature (110-150°C), screw speed (200-500 rpm) and feed moisture (17-23 g/100 g) on physicochemical and sensory properties of shrimp-corn snack were investigated using response surface methodology. The extrusion temperature had a significant ($P \leq 0.05$) influence on hardness, omega-3 fatty acids content and sensory properties of shrimp-corn snack. Increasing extrusion temperature from 110°C to 150°C, resulted in a snack with higher hardness and lower omega-3 content. While higher overall acceptance scores were obtained at moderate temperature (130°C), higher omega-3 contents were obtained at lower temperatures combined with higher feed moistures. Predicted optimum condition for extruded shrimp-corn snack production was follows; extrusion temperature: 127.2°C, screw speed: 393.4 rpm, feed moisture: 21.6 g/100 g.

2.2 Conditioning and blending of raw materials

Garber *et al.* (1997) studied the effect of particle size (50-1,622 μm), screw speed (200-400 rpm) and feed moisture content (19-22%) on twin screw extrusion of corn meal and reported that product temperature, specific mechanical energy and torque generally showed no change within the particle size ranges from 100 to 1,000 μm, as the particle size increased >1,000 μm each value dropped significantly. Die pressure was influenced by the screw speed, particle size, and feed moisture content. The largest particle size (1,622 μm), highest moisture level (22%), and the lowest screw speeds (200 and 300 rpm) were the only conditions where starch was less than 97.5% of transformation (gelatinisation). hence, these two conditions also showed the hardest product and least expansion.

Singh *et al*. (2005) examined on the enhancement of process parameters of soy-sorghum blend with blend ratio (5, 10, 15, 20 and 25% of Soybean in blend), barrel temperature (80, 90 and 100°C) and feed moisture contents (15, 20 and 25%) in a single screw laboratory extruder for the preparation of ready to eat snack food. The effects of initial feed moisture content, barrel temperature and blend ratios on properties like bulk density, sectional expansion index (SEI) and crispness of extruded products were studied. RSM was used to optimize the process parameter for the development of best product. The analysis of data shows that all the process parameters had significant effect on physical properties.

Charunuch *et al.* (2008) conducted studies on rice snack with mulberry leaf indicating health benefits for higher potential in commercial scale. Mulberry leaf is dried and powdered and then mixed with rice, corn, soy, sugar, oil, vitamins and minerals. The operating conditions are then investigated with twin screw extruder at varying mulberry powder content (5, 7.5 and 10%), screw speed (300 and 350 rpm) and feed moisture (13, 15, and 17%). The functional properties and physical characteristics (bulk density, expansion ratio, texture measurement and organoleptic test) of the extrudates were examined. The result showed that at higher mulberry content (10%), the product was difficult to operate with irregular shape and less expansion while lower screw speed (300 rpm) and moderate moisture content (15%) gave suitable expansion of 8.3 and bulk density of 187 kg/m^3 with better preference in appearance.

Mesquita *et al.* (2013) studied the effects of processing on physical properties of extruded snacks with blends of sour cassava starch and flaxseed flour using a single screw extruder in a factorial central composite rotatable design with flaxseed flour percentage (0-20%), moisture (12-20%), extrusion temperature (90-130°C) and screw speed (190-270 rpm). The effect of extrusion variables was investigated in terms of expansion index, water absorption index, water solubility index, specific volume, hardness and color parameters (L*, a*, b*). The data analysis showed that variable extrusion process parameters and flaxseed flour affected physical properties of puffed snacks. Among the experimental conditions used in the study, expanded snack products with good physical properties were obtained under the conditions of flaxseed flour (10%), moisture (12%), temperature (90°C) and screw speed (230 rpm).

2.3 Extrusion

Extrusion is done with relatively dry materials to plasticise food mass, to reduce microbial load, denature enzymes, gelatinise starch, polymerise proteins and most importantly texturise the end product into a desirable form. Extrusion technologies have an important role in the food industry as efficient manufacturing processes. The importance of extrusion cooking over conventional cooking is mainly because of versatility, efficiency and economy of space and labour. There are two types of extrusion process: cold and hot extrusion.

Extrusion cooking is a multivariable unit operation which includes mixing, shearing, cooking, puffing and drying in one energy efficient, rapid continuous process. This process of high temperature short time (HTST) extrusion bring gelatinization of starch, denaturation of proteins, modification of lipids and inactivation of enzymes, microbes and many anti nutritional factors. The advantages of an extruded product would be the elimination of prolonged cooking by the consumer and less degradation of nutrients (Konstance *et al*. 1988).

Transport of material through extruders depends largely on friction at the barrel surface. 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) (Harper and Jansen, 1985).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 caused by the build-up of 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.

2.4 Optimisation and standardisation of extrusion process parameters

The process variables comprised of independent variables such as feed ingredients, composition, moisture content, particle size, extruder design, screw composition, die diameter, extruder operating condition, screw speed, feed rate and barrel temperature. Dependent variables includes extrudate properties such as bulk density, expansion ratio, texture, functional and sensory preferences and process data, material temperature, pressure, mixing profile, power consumption.

Yagci and Gogus (2008) used the RSM to investigate the effects of extrusion conditions including moisture content (12-18%), temperature (150-175°C), screw speed (200-280 rpm), and change in feed composition, durum clear flour (8-20%), partially defatted hazelnut flour (PDHF) (5-15%) and fruit waste (3-7%) contents on the physical and functional characteristics of the extruded snack food based on rice grit in combination with durum clear flour and partially defatted hazelnut flour. Response variables are bulk density, porosity, water absorption and water solubility indices and sensory properties of the extruded snacks. Changing process conditions affected the physical and functional properties of produced snacks. The results showed that the optimum operating extrusion process parameters were 168.8°C barrel temperature, screw speed of 280 rpm and feed moisture of 13.5%.

Jhoe *et al.* (2009) conducted study on soy-protein-fortified expanded extrudates using normal corn starch and showed that increasing screw speed resulted in higher specific mechanical energy (SME) and expansion, and lower mechanical strength. On the other hand, addition of 5-20% SPC (soy protein concentrate) led to lower SME and expansion, and higher mechanical strength. Water absorption index (WAI) increased and water solubility index (WSI) decreased with increase in screw speed and SPC level. Increasing screw speed resulted in a slight shift towards smaller molecular weight fractions of starch, as determined by gel permeation chromatography.

Nath *et al.* (2010) developed potato-soy RTE snacks using high temperature short time (HTST) air puffing process. The process parameters including puffing temperature (185-255°C) and puffing time (20-60 s) with constant air velocity of 3.99 m/s and initial moisture content of 36.74% for potato-soy blend with varying soy flour content from 5% to 25% were examined using RSM following central composite rotatable design (CCRD). The product in terms of minimum moisture content of 11.03% dry basis, maximum expansion ratio of 3.71, minimum hardness of 2,749.4 g, minimum ascorbic acid loss of 9.24% dry basis and maximum overall acceptability of 7.35 were obtained with 10.0% soy flour blend in potato flour at a process temperature of 231°C and a puffing time of 25.0 s.

Bisharat *et al*. (2013) studied the effect of addition of dehydrated broccoli or olive paste to corn flour for the generation of extrudates with increased value and quality. Extrudates were prepared using a twin-screw extruder, operating parameters including screw speed (150, 200 and 250 rpm) and extrusion temperature (140, 160 and 180°C). The moisture content of the raw mixture was managed in three levels (14, 16.5 and 19%), whereas the concentration of the added ingredient was adjusted to 4, 7 and 10% for broccoli and 4, 6 and 8% for olive paste. Structural properties and rehydration were examined with regard to process conditions and material characteristics. Products prepared with 140°C temperature, with 14% moisture content and 4% material concentration that were extruded at the highest screw speed of 250 rpm exhibited the highest degree of expansion.

2.5 Hot extruded products and their quality

2.5.1 Physical properties

2.5.1.1 Expansion ratio

The effect of process parameters on physicochemical properties of yam flour was done by Chang *et al.* (2001). Raw yam (*Dioscorea rotundata*) flour was cooked and extruded in a single-screw extruder. RSM using an incomplete factorial design was applied with various combinations of barrel temperature (100, 125, 150°C), feed moisture content (18, 22, 26%) and screw speed (100, 150, 200 rpm). The physical properties of the extruded product showed a greater expansion index at high temperature and low moisture content.

Gujral *et al.* (2001) studied the effect of extrusion temperature (100-150°C), screw speed (100-150 rpm) and feed moisture (16-24%) on the extrusion behaviour of flint and sweet corn grits. The extruder die pressure and extrudate properties, such as WSI and expansion were analyzed. Among extrusion temperature, feed moisture and screw speed, feed moisture showed more effect on die pressure, WSI and expansion. The regression models for WSI of extrudates from both corn types were significant and have high R^2 value (95.1 to 98.5). The particle size distribution indicates that flint corn grits had more fine and opaque particles and resulted in extrudates with lower WSI and expansion than sweet corn grits which had fewer fine particles.

Mezreb *et al*. (2003) investigated the effect of screw speed on the expansion, physico-chemical properties and structural properties of both wheat and corn extrudates. A digital image technique was used to determine the structural properties. An increase in screw speed resulted in products with higher longitudinal expansion, water solubility and smaller structure patterns.

Shannon *et al.* (2010) studied the effect of protein (6, 12 or 18% d.b.), moisture content (15, 18 or 21% w.b.) and barrel temperature (100, 120 or 140°C) on the physicochemical characteristics of pea flour extrudates and a leavening agent (0.5% sodium bicarbonate) was used. Extrusion of pea flour containing 6% of protein and 15% of moisture at a set temperature of 120°C resulted in expansion indices of 3.3 and 3.6 respectively in the absence or presence of the leavening agent. Expansion indices decreased and extrudate hardness, bulk and particle densities, increased with increase in protein or moisture content.

Oke *et al.* (2013) studied on the expansion ratio of extruded water yam (*Dioscorea alata*) starches using a single screw extruder. The objective of this study was to develop predictive models that relate extrusion process variables to expansion ratio of five varieties of water yam starch. This was accomplished by varying the feed moisture content (FMC) and extruder parameters which include barrel temperature (BT), screw speed (SS) and determine their effects on resulting expansion ratio using response surface methodology. A single screw extruder (DCE 330, NJ) was used in evaluating the extrudate's physical property, expansion ratio of the starches that were processed using standard wet milling procedure. The expansion ratios of all the extrudates considered in this study ranged from 1.05 to 1.93. It was observed that changing the feed moisture content, barrel temperature and screw speed significantly ($P<0.05$) linear, quadratic and interaction influences on the expansion ratio.

Korkerd *et al*. (2015) studied the expansion properties of extruded snacks enriched with nutrition sources from food processing-by products. Rich sources of protein and dietary fiber from food processing by-products, defatted soybean meal, germinated brown rice meal, and mango peel fiber, were added to corn grit at 20% (*w*/*w*) to produce fortified extruded snacks. Increase of total dietary fiber from 4.82% (wb) to 5.92–17.80% (wb) and protein from 5.03% (wb) to 5.46–13.34% were observed. The product indicated high expansion and good acceptance tested by sensory panels. There were 22.33–33.53 and 5.30–11.53 fold increase in the phenolics and antioxidant activity in the enriched snack products. The effects of feed moisture content, screw speed, and barrel temperature on expansion and nutritional properties of the extruded products were investigated by using response surface methodology. Regression equations describing the effect of each variable on the product responses were obtained. The snacks extruded with feed moisture 13–15% (wb) and extrusion temperature at 160–180°C indicated the products with high preference in terms of expansion ratio between insoluble dietary fiber and soluble dietary fiber balance. The results showed that the by-products could be successfully used for nutritional supplemented expanded snacks.

2.5.1.2 Density

Thymi *et al*. (2005) reported the effect of varied feed rate (1.16-6.44 kg/h), product temperature (100-260°C), feed moisture content (12-25 kg/100 kg w.b.)

and screw speed (150-250 rpm) on structural properties of extruded corn starch. As the residence time increased for all temperature and moisture contents there was a slight increase in apparent density, while the expansion ratio and the porosity of extruded products decreased with the residence time. The radial expansion ratio of the extrudates decreased with high feed moisture contents which results in higher apparent density and lower porosity values. The increase in temperature resulted in a significant density decrease and higher porosity.

Bhattacharyya *et al*. (2005) studied the physico-chemical characteristics of extruded snacks prepared from rice, corn and taro by twin screw extrusion. Sodiumdodecyl sulphate and phosphate buffer (pH 6.9) were found to extract more protein than plain buffer solution. Loss of carbohydrate was documented in extruded snacks. And also, the extrusion process parameter markedly affect the texture, starch digestible characteristics and surface methodology of taro, rice and corn starch blend extrudates. The result showed a trend towards increasing expansion, decreasing density and lowest value for the breaking force of extrudates (13.03 N ± 0.88) was found with barrel temperature141-159ºC.

Pansawat *et al.* (2008) used feed formulation containing rice flour, fish powder, menhaden oil and vitamin E for extrusion at a feed rate of (10 kg/h) using a co-rotating twin-screw extruder. Primary extrusion variables were feed moisture (19-23 g/100 g d.b.), screw speed (150-300 rpm) and temperature (125-145°C). The highest SME was observed at high screw speed, medium barrel temperature and low feed moisture. Increased screw speed and/or decreased feed moisture decreased mean residence time (tm). The products with high expansion ratio and low product density, which generally are good characteristics of extruded snack, were produced at high screw speed, medium extrusion temperature and low feed moisture.

Menis *et al*. (2013) investigated the effects of the moisture content (12, 18 and 20%) of the raw material, extrusion temperature (150, 157 and 164°C) and screw speed (165, 170 and 175 rpm) on the structural parameters, volatile compound retention and sensory acceptability of corn grit extrudates. Higher moisture content increased ethyl butyrate retention (0.62 mg/g), while higher temperature results in more expanded (3.7) extrudates with lower density (0.13 g/cm^3) and cutting force. The most acceptable extrudates were those obtained with low moisture content (12%) under conditions of high extrusion temperature (164°C) and high screw speed (175 rpm).

2.5.1.3 Moisture content & water activity

Linko *et al,* (1982) studied the extrusion cooking and bioconversations of cereals and reported that at typical high temperatures and pressure prevailing in HTST extrusion cooking, a water activity (a_w approximately 1) may be reached even at well below 20% moisture, explaining the high degree of cooking obtainable during extrusion cooking of cereal based materials at very low moisture levels.

Onwulata *et al,* (2006) studied on the physical properties of extruded products as affected by cheese whey and reported that evaporation of water is a main cause of product expansion. Product expansion increased directly with decrease moisture at high shear, for whey substituted products.

Marzec *et al.* (2007) studied the influence of water activity on acoustic emission of flat extruded wheat bread and rye bread subjected to three-point breaking test. It was found that breaking of flat extruded bread generated vibrations in whole audible spectrum. Acoustic emission signal energy expressed in arbitrary units was more dependent on water activity in low frequencies region. The slope was doubled in the water activity range (0-0.5) and at higher water activities it increased sharply with increasing wetness of the material. Majority of acoustic emission events lasted 68.11 s, and their energy statistically was not dependent on water activity. However, number of acoustic emission events depended on water activity and decreased almost 20 fold in the a_w range from (0.03 to 0.75).

Meng *et al.* (2010) conducted a study on the effects of extrusion conditions on system parameters and physical properties of a chickpea flour-based snack food. RSM was used to study the effects of feed moisture content (16-18%), barrel temperature (150-170°C) and screw speed (250-320 rpm) on extruder system parameters and physical properties of a chickpea flour-based snack food. Product temperature and die pressure were affected by all three process variables, while SME and motor torque were only influenced by screw speed and barrel temperature. All three variables affected the product properties significantly, the products are characterized by high expansion ratio (4.99) and low bulk density and hardness, were obtained at low feed moisture (16%), high screw speed (320 rpm) and medium to high barrel temperature (160°C). The results showed that screw speed and barrel temperature had positive linear effects ($p<0.01$) on expansion while, feed moisture content had a negative linear effect.

2.6 Colour and texture

Bhattacharyya *et al.* (2006) examined the physico-chemical characteristics of extruded snacks prepared from rice, corn and taro by twin-screw extrusion at temperature 141, 150 and 159°C, respectively. Sodium dodecyl sulphate (SDS) and phosphate buffer (pH 6.9) were found to extract more protein than plain buffer solution from extrudates. The extractable protein decreased in all solvents after extrusion (0.127 to 0.039%). Loss of carbohydrate (maltose) was documented in extruded snacks. The results showed an increase in maltose content (1.92 to 4.16%) and decreasing breaking force (13.03 to 20.49 N) with increase in barrel temperatures from 141-159°C.

Anton and Luciano (2007) studied the instrumental texture evaluation of extruded snack foods. Texture evaluation of extruded snacks is a complex subject, where the combination of the techniques involves sensory, instrumental and microstructure analysis. From a practical perspective, empirical methods are suggested as alternative to fundamental techniques, especially to food scientists and food manufacturers interested in predicting consumer perception of texture.

Altan *et al.* (2008) examined the processability of barley flour with the combination of tomato pomace for the production of snack food in a twin-screw extruder. The effect of the variables such as tomato pomace content (2-10%), extrusion die temperature (140-160°C) and screw speed (150-200 rpm) on system parameters and physical properties of extrudates were assessed by using RSM. The system parameters and product responses were most affected by changes in pomace level (2% and 10%), temperature (160°C) and to a lesser extent by screw speed (200 rpm) and had higher preference levels for parameters of texture, colour, taste and overall acceptability.

The tri-stimulus colour values (L*, a* and b*) of small millets based *kurkure* products stored for a month in LDPE and PP film packages were reported by Sudha Devi, (2012). The lightness factor L* values slightly decreased after storage in both the packages. For e.g., in case of foxtail millet *kurkure*, the initial L* value of 73.54 decreased to 70.46 and 70.52 respectively for the products stored in LDPE and PP packages. However, the chromaticity coordinate values a* and b* almost did not change from initial values of respective products. The foxtail, little, proso and barnyard millets based *kurkure* products had high initial

L* values indicating that they are brightly coloured products and the kodo millet *kurkure* was relatively a dull product.

Aneeshya *et al*. (2013) studied textural properties and economic feasibility of an extruded RTE snack from starch based food products. The raw materials were mixed in 2 different combinations namely, rice: banana (R:B) and rice: cassava: banana (R:C:B) in different proportions *viz*. R_{60}:B_{40}, R_{70}:B_{30}, R_{80}:B_{20}, R_{90}:B_{10}, R_{70}:C_{20}:B_{10}, R_{50}:C_{40}:B_{10}, R_{30}:C_{60}:B_{10} and R_{10}:C_{80}:B_{10}. These mixes were extruded under various extrusion process parameters of die temperatures (170, 180, 190 and 200°C), screw speed (80, 100, 120 rpm), feed rate (1.4 to 2.28 kg/h) and feed moisture content (16%). The textural properties of the extrudates were determined. The crispness of the extrudates from these combinations ranged from 3.2 to 8.1. Extrudates with R_{10}:C_{80}:B_{10} combination gave good crispness at elevated temperature.

Seema and Sudheer (2017) studied on the development and quality evaluation of millet fortified tuber based extruded RTE products. The raw materials were mixed in seven different combinations namely: corn, corn : rice, corn : ragi, corn : elephant yam : purple yam : drumstick, ragi : elephant yam : purple yam : drumstick, ragi : corn : rice : elephant yam : purple yam : drumstick and rice : elephant yam : purple yam : drumstick in different proportions *viz.* C_{100}, C_{50}:R_{50}, C_{50}:Rg_{50}, C_{60}:Ey_{15}:Py_{20}:D_5, Rg_{60}:Ey_{15}:Py_{20}:D_5, Rg_{20}:C_{25}:R_{25}:Ey_{10}:Py_{15}:D_5 and R_{60}:Ey_{15}:Py_{20}:$D_{5.}$ These mixes were extruded under various extrusion process parameters of die temperatures (100, 110 and 120°C), screw speed (350 rpm) and moisture content (17.5%). Kurkure was selected as the control and was taken as the 22nd treatment in order to compare the quality of the snacks. Organoleptic and quality parameters of these processed snacks were done using standard engineering properties including physical, functional, colour and textural assessments.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the methodologies used to perform the preparation of samples, blending of prepared flours and experiments on extrusion of ingredients blended in different proportions under different process parameters. The chapter also describes the standardised methods to carry out the physical and engineering properties of the developed extrudates and storage characteristics of best extrudates.

3.1 Raw materials

The main raw materials used for the development of extruded products were rice varieties (Rakthashali and Kumkumashali) and corn. The raw materials were procured from local market.

3.1.1 Preparation of samples for extrusion

The rice flour and corn flour were sieved manually using ISS 85 mesh in order to obtain uniform particle size.

3.2 Development of hot extruded RTE products from speciality rice

Ready to eat (RTE) crispy products were prepared from rice varieties, and corn by hot extrusion technology using a Laboratory model Twin screw extruder.

3.2.1 Laboratory model Twin screw extruder

Ready to eat (RTE) crispy products were prepared by hot extrusion technology using a Laboratory Model Twin screw extruder. The laboratory model Twin screw extruder (make: Basic Technologies, Kolkatta; model: L-TSE) is a compact but sturdy food processing equipment that can be used for scientific small scale extrusion product development. The main component of the extruder is twin stainless steel screws of uniform diameter rotating in opposite direction inside a sturdy stainless steel barrel. The main drive (10 hp motor; 440 V, 3 Ph) is axially coupled to a reduction gear box. The out-put shaft of worm reduction gear of the gear box is provided with a *torque limiter coupling*. This device consists of a *torque limiter* and a *roller chain type coupling*.

The torque limiter is a protective device having spring loaded friction surface. When there is any overload, the friction surfaces slip and smoke may come out if there is any oil contamination. The barrel of the extruder receives the feed from a co-rotating, variable speed, feeder placed just above the main extruder. The feeding rate of the feeder is controlled by a knob on the feeder controller. The barrel is provided with two electric band-heaters and water cooling jackets. There are two temperature sensors, one fitted on the front die plate and the other sensor is fitted near the feed hoper (feed zone) and both are connected to temperature controllers placed on the main panel board. At the end of the barrel (and screw), the die-plate of the die is fixed with the help of a screw-nut, tightened by a special hook type wrench. An automatic cutting knife is fixed on a rotating shaft of knife cutter powered by a DC motor. The cutter is actually driven by a variable speed controller which is controlled by a knob placed on the panel board.

The automatic knife cutter assembly is covered using a hinged safety guard. While operating, this safety guard must be kept in place and a limiting switch ensures that the cutter will not operate if the safety guard is not in place. Most of the controls of the extruder can be done using a panel board. There is an emergency switch, conveniently placed at the centre of the extruder, to immediately stop the machine in case of emergencies.

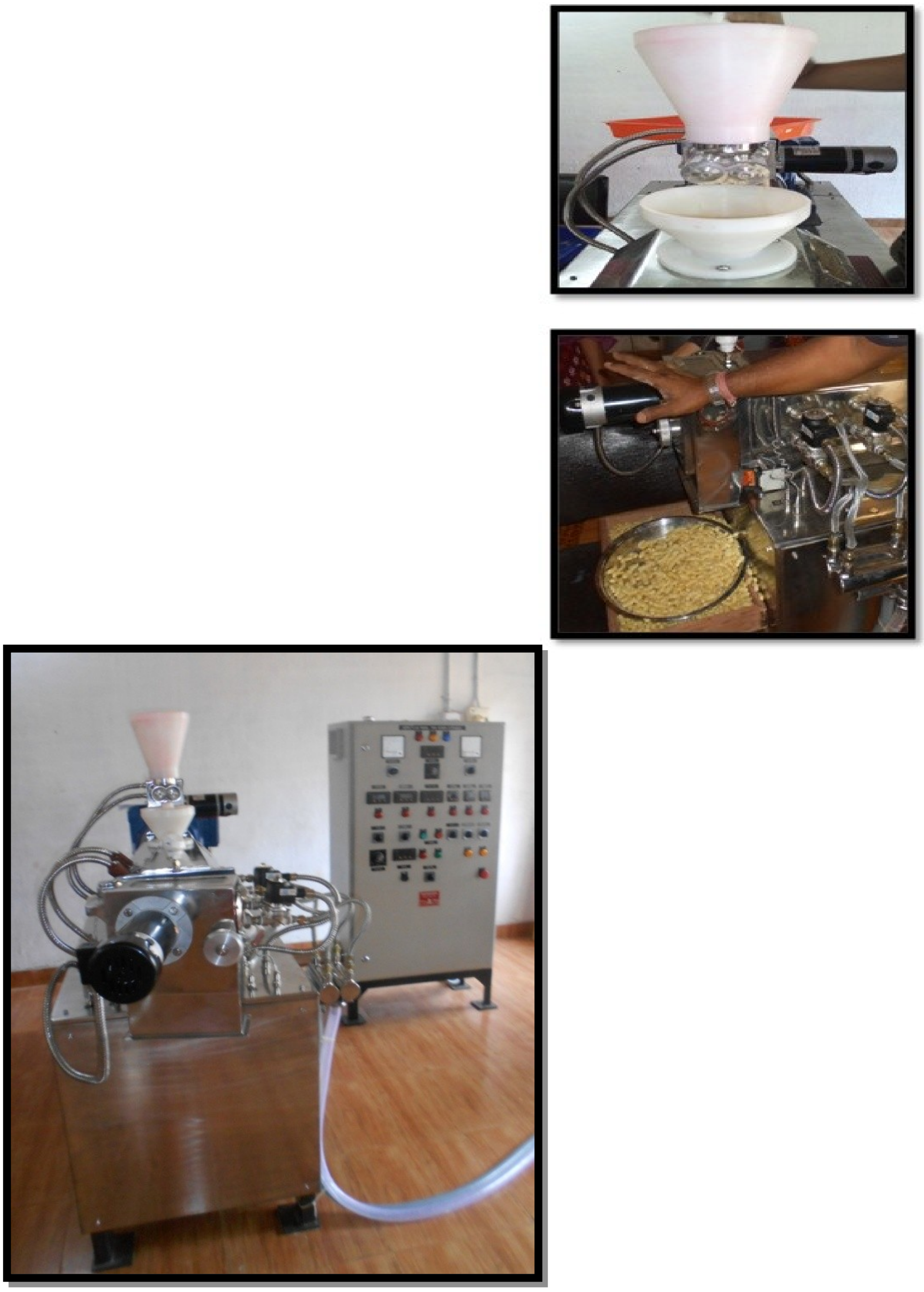

Plate 3.1 Twin Screw Extruder

3.2.2 Working of Twin screw extruder

The heater control switches were put on after setting the temperature of barrel at the “die” and feed ends using the temperature controllers on the panel board. The extruder barrel was initially heated to attain desired temperatures and the valve of cooling water line to solenoid valve is opened to maintain barrel temperature. Then the machine was started and allowed to run empty for five minutes. During this time, the screw speed was adjusted to desired level using the controller switch of the variable speed motor. Initially, the “start up flour” of high moisture content (30% w.b.) was fed to the barrel. This was continued until a regular flow of extrudate was obtained from the extruder. Then the conditioned flour/grit mix of desired moisture content (17.5%) was fed continuously without any interruption in feeding. The cutter switch was put on and the cut extrudates were collected at die end. When cutter switch is in off position, a continuous extrudate could be obtained.

3.2.3 Optimization of Twin screw extruder operating parameters

The operating parameters of the twin screw extruder mainly, the feed moisture content and the screw speed, were optimized based on the previous study. The selected Screw speed was 350 rpm and feed moisture content was 17.5%.

3.2.4 Preparation of samples

The raw materials (corn, rakthashali and kumkumashali) were blended in six different combinations. The various proportions used under each combination are described below. The combinations were selected in the ratio of R_{100}, C_{50}:R_{50}, C_{40}:R_{60}, C_{25}:R_{75}, C_{50}:K_{50} and C_{40}:K_{60}. The amount of raw materials used to produce various flour blends constituted 500 g each are indicated in Table 3.1.

Table 3.1 Raw material used to prepare the six blends

Blends (%)	**Quantity of raw materials**
R_{100}	R_{500g}
C_{50}:R_{50}	C_{250g}:R_{250g}
C_{40}:R_{60}	C_{200g}:R_{300g}
C_{25}:R_{75}	C_{125g}:R_{375g}
C_{50}:K_{50}	C_{250g}:K_{250g}
C_{40}:K_{60}	C_{200g}:K_{300g}

3.2.5 Experimental method

The blends in six different combinations of $R_{500g,}$ C_{250g}:R_{250g}, C_{200g}:R_{300g}, C_{125g}:R_{375g}, C_{250g}:K_{250g}, C_{200g}:K_{300g} were extruded at temperatures of 100 and 110ºC at constant speed of 350 rpm and 17.5% moisture content. Organoleptic and quality parameters of these processed snacks were done using standard engineering properties including physical, colour and textural assessments. The second stage of the work includes the storage studies which were done with selected extrudates.

3.2.6 Extrusion of RTE products

The extruder was primed before actual operation and 3 mm circular “die” was fixed at the barrel end. The Heater #1 was set at (100 and 110ºC) and Heater #2 was set at 60ºC and both were switched on for barrel heating. Cooling water line to solenoid valve is shut till required temperature was reached. The other operational settings namely, screw speed (350 rpm), feeder speed (35% of max) and cutter (30% of max) were set in the main control panel. When the required temperature was reached, the water line is opened for automatic barrel temperature control. Then the extruder (screws), feeder and cutter were switched on and initially higher moisture (30%) feed was fed to the barrel to lubricate the barrel and screws. When, the product just started coming out of die, the experimental feed was fed using the auto feeder. The uniformly cut, RTE product was collected just below the cutter assembly using trays. The products were transferred within few minutes to the aluminium pouches, sealed and stored for further analyses.

3.3 Physical parameters of RTE expanded products

The following physical parameters are to be studied for the hot extruded RTE product.

3.3.1 Expansion ratio

The degree of expansion of extrudates was expressed as the ratio of diameter of extrudate to the diameter of “die” (Fan *et al.,* 1996). Ten pieces of extrudates were randomly selected and their diameter was measured with a vernier calliper. The mean of those ten measurements will give the diameter of the extruded product. The extrudates expansion ratio was then calculated as:

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

3.3.2 Bulk density

The bulk density (BD) was calculated by measuring the actual dimensions of the extrudates (Chinnaswamy and Bhattacharya, 1986). Ten pieces of extrudate were randomly selected and their diameter and length was measured using digital vernier calliper with least count of 0.1mm. The average of these ten measurements will give the diameter and length of the extrudate (Ding *et al.*, 2005). The weight per unit length of extrudate was determined by weighing measured lengths (1 cm). The experiments were repeated thrice and the bulk density was calculated by using the following equation assuming cylindrical shape of extrudate (Launay *et al.*, 1983):

$$\text{Bulk density}\left(\text{g/cm}^3\right)=\frac{4\text{m}}{\pi d^2 L}$$

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

3.3.3 Water activity (a_w)

Aqua lab water activity meter was used for the measurement of water activity. 2 g of ground sample was taken in sample cup which was provided with water activity meter. The reading displayed on the water activity meter was taken as water activity of the ground extrudate (Murphy *et al.*, 2003).

Plate 3.2 Aqualab Water Activity Meter

3.4 Engineering properties of hot extruded products

3.4.1 Colour characteristics

The overall objective of colour to the food is to make it appealing and recognizable. Colour is important to consumer as a means of identification, as a method of judging quality and for its basic aesthetic value and Colour of the extruded RTE products was measured using Hunter lab colour flex meter (made by: Hunter Associates Laboratory, Reston, Virginia, USA).

The colour was measured by using CIELAB scale at 10° observer at D_{65} illuminant. It works on the principle of focusing the light and measuring the energy reflected from the sample across the entire visible spectrum. The colour meter has filters that relay on "standard observation curves" which defined the amount of red yellow and blue colours. It provides reading in terms of L*, a* and b*. The luminance (L*) forms the vertical axis, which indicates light - dark spectrum with a range from 0 (black) to 100 (white). In the same way, a* indicates the green - red spectrum with a range of - 60 (green) to + 60 (red) and b* indicates the blue - yellow spectrum with a range from - 60 (blue) to + 60 (yellow) dimensions respectively (Ali *et al*. 2008).

A cylindrical glass sample cup (6.35 cm dia. x 4 cm deep) was placed at the light port (3.175 cm dia.). The instrument was initially calibrated with a black as well as with standard white plate.

Plate 3.3 Hunter Lab Colour Flex Meter

3.4.2 Texture analysis

Textural properties of hot extruded ready-to-eat expanded (*kurkure* type) products were studied using a Texture Analyzer (TA.XT texture analyser, Stable micro systems Ltd.).

The texture analyzer measures force, distance and time, thus providing three dimensional product analyses. Force may be measured against set distance and distance may be measured to achieve set of forces. Results may be read directly from the keyboard or transmitted to a printer or computer. The probe carrier contains a sensitive cell. The load cell has mechanical overload and under load protection and an electronic monitoring system that stops the motor drive when an overload condition is detected. Distance and speed control is achieved using a step motor attached to a fine lead screw that winds the probe carrier up and down.

For RTE extruded products the experiments were carried out by different tests that generated as plot of force (N) vs. time (s), from which texture values for extruded product were obtained. Three replications of each combination were taken for analysis. During the testing, the samples were held manually against the base plate and the different tests were conducted according to TA settings. The textural properties such as hardness were measured by using penetration test (Stable Micro Systems).

The probe used here is HDP/BSK blade with knife. The extrudate was cut with this probe and a curve with the force over time was generated. The value of force was taken as a measurement for hardness.

TA settings

Mode: Measure Force in Compression
Option: Return to Start
Pre Text speed: 1.50mm/s
Test speed: 2 mm/s
Post Test speed: 10 mm/s
Distance (compression): 20 mm
Data Acquisition Rate: 400 pps

3.5 Sensory evaluation of RTE expanded products after storage

Since the extrudates from the twin screw extruder were bland in taste, they were first “prepared” like the commercial *kurkure* product before serving to sensory panel. The hot extruded RTE products were “prepared” by coating with commercial *masala*. The RTE products were toasted with 3 tsp of sunflower oil (per 100 g) and 2 tsp of *chat masala* as a flavouring agent. The prepared products were evaluated for sensory characteristics by a panel of 10 judges along with the commercially available product as a control.

3.6 Selection of the best hot extruded RTE, expanded products

Among the seven combinations, screening was done, primarily based on sensory characteristics. Sensory analysis was done based on nine point Hedonic scale. The best judged product was the one which was of good taste, and overall acceptability.

RESULTS AND DISCUSSION

CHAPTER IV
RESULTS AND DISCUSSION

This chapter deals with the results and discussion of the experiments conducted on extrusion with the corn and rice varieties (Rakthasali and Kumkumasali) blended in different proportions for developing hot extruded (RTE) products. The second phase of investigation includes the storage studies and quality analysis of the selected extrudates with objective and subjective parameters.

4.1 Hot extrusion (RTE)

Optimization of feed moisture content, screw speed and final treatments were carried out based on previous study. The results obtained are presented and discussed in details under the sessions as given below.

4.2 Development of hot extruded RTE product

Based on earlier studies conducted by Seema *et al.,* (2016), a screw speed of 350 rpm and feed moisture content of 17.5% were selected. The temperatures considered are 100 and 110°C.

Table 4.1 The selected hot extruded RTE products

Combinations	Composition (%)	Temperature (°C)
P_1T_1	P_1 (R_{100})	T_1 (100)
P_2T_1	P_2 (C_{50}:R_{50})	T_1 (100)
P_3T_1	P_3 (C_{40}:R_{60})	T_1 (100)
P_4T_1	P_4 (C_{25}:$R_{75)}$	T_1 (100)
P_5T_2	P_5(C_{40}:R_{60})	T_2 (110)
P_6T_2	P_6 (C_{50}:K_{50})	T_2 (110)
P_7T_2	P_7 (C_{40}:K_{60})	T_2 (110)

4.3 Quality parameters of hot extruded RTE products

The quality parameters *viz*. physical and engineering properties of the hot extrudates were determined by standard laboratory procedures as mentioned in chapter III and their results are discussed.

4.3.1 Quality of the hot extrudates based on physical properties

Physical properties of the seven extrudates in terms of expansion ratio, bulk density, and water activity are discussed under the following headings.

4.3.1.1 Expansion ratio

Expansion is an important physical property of the developed snack food. Starch is the main component in cereals which plays a major role during expansion process (Kokini *et al*., 1992). The expansion ratio of the hot extruded RTE products varied from 3.198 to 4.069 is given in Appendix A1. The maximum expansion ratio (4.069) was observed for P2T1 combination *i.e.,* 100°C temperature whereas, minimum expansion ratio (3.198) was observed for treatment P1T1 *i.e.,* 100°C temperature (Fig 4.1 (a)). Significant variation ($p<0.0001$) was noticed as regards expansion ratio for the seven combinations under consideration.

The results showed that expansion increased with increasing corn content, this can be explained by the fact that when feed material with high percent corn (having more starch) results in increasing in starch gelatinization during extrusion thereby increases extrudate volume. This observation coincides with that of extruded product prepared using hard-to-cook beans and quality protein maize (Ruiz *et al.*, 2008).

4.3.1.2 Bulk density

Density is a major physical property of the extrudate product. Bulk density, which considers expansion in all direction ranged from 0.694 to 0.880 g/cm^3 which is presented in Appendix A1. It was observed that the minimum bulk density (0.694 g/cm^3) was observed for P5T2 and maximum bulk density (0.880 g/cm^3) was observed for P1T1 (Fig 4.1 (b)). Significant difference ($p<0.0001$) was noticed as regards bulk density and for the combinations under concern.

The results showed that as temperature increases bulk density decreases. This is because at high temperatures (110°C), extrudates exiting the die lose more moisture and become lighter in weight (Koksel *et al*., 2004). High temperature resulted in the larger extent of starch gelatinization thus the volume of the extrudate increased and the bulk density decreased (Case *et al.,* 1992).

4.3.1.3 Water activity (a_w)

The water activities of the extrudates were determined by methodologies explained in 3.3.3. This property was used as a critical control point to correlate whether the products made were in safe level. The water activities of all combinations ranged from 0.338 to 0.486 (Appendix A1). The maximum a_w (0.486) was observed for P2T1 combination *i.e.,* 100°C temperature whereas, minimum a_w (0.338) was observed for P5T2 combination *i.e.,* 110°C temperature (Fig 4.1 (c)). Significant variations were noted with respect to a_w of each combinations ($p<0.05$) taken for the study.

The results showed that water activities of all treatments were safe for storage of RTE products.

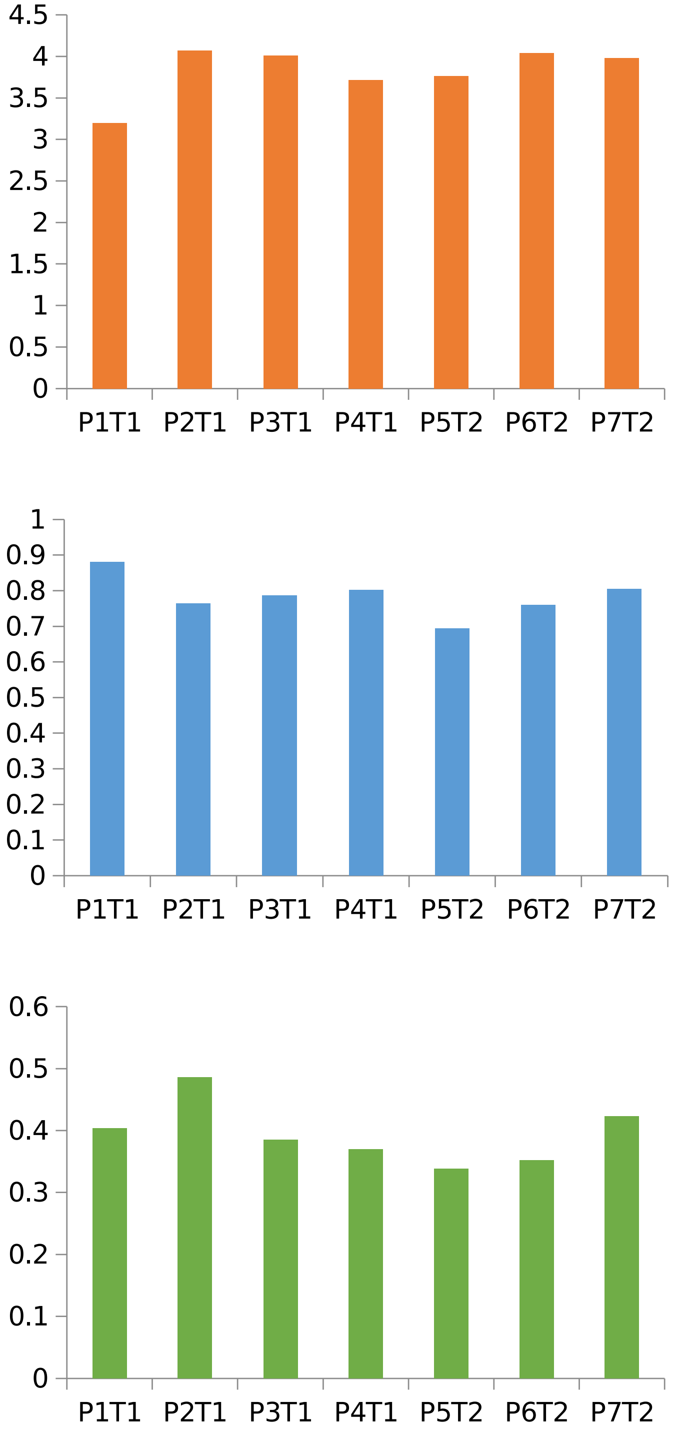

Fig. 4.1 Physical properties of hot extruded RTE products

4.4 Quality of the hot extrudates based on colour properties

The tri-stimulus colour values were calculated as per the methodologies discussed under 3.4.1. Significant variation ($p<0.0001$) was noticed as regard to L*, a* and b* values for the various combinations under concern.

4.4.1 Colour (L* value)

Colour is one of the most vital physical attributes of extrudate product and directly related to the acceptability of food product. The maximum value for lightness is 100 indicating whiteness. Therefore, decrease in L***** value indicates a decrease in whiteness. Colour of various combinations of extrudates varied from 61.10 to 75.030. The maximum colour L* (75.030) was observed for combination P6T2 *i.e.,* 110°C temperature whereas, minimum colour L* (61.10) was observed for combination P4T1 *i.e.,* 100°C temperature (Appendix A2).

The results suggested that there was an increase in L* value with temperature. The increase in temperature increased the degree of superheating of water in the extruder, leading to slightly greater expansion which in turn led to lighter colored product.

4.4.2 Colour (a* value)

The *a** value for various combinations of extrudates varied from 3.660 to 8.36. The maximum colour a* (8.36) was observed for combination P4T1 *i.e.,* 100°C temperature whereas, minimum colour a* (3.660) was observed for combination P6T2 *i.e.,* 110°C temperature (Appendix A2). It appeared that with increase in temperature, a* value of the extrudate decreased due to the loss of colour pigments at high temperature.

4.4.3 Colour (b* value)

The b* value for various combinations of extrudates varied from 16.44 to 27.530. The maximum colour b* (27.530) was observed for combination P7T2 *i.e.,* 110°C temperature whereas, minimum colour b* (16.44) was observed for combination P1T1 *i.e.,* 100°C temperature (Appendix A2). As temperature increases(110°C) the b* values also increased because at high temperatures degradation of pigments were accelerated. An increasing addition of corn flour resulted in extrudate becoming more yellow, as recorded by increase in b* values.

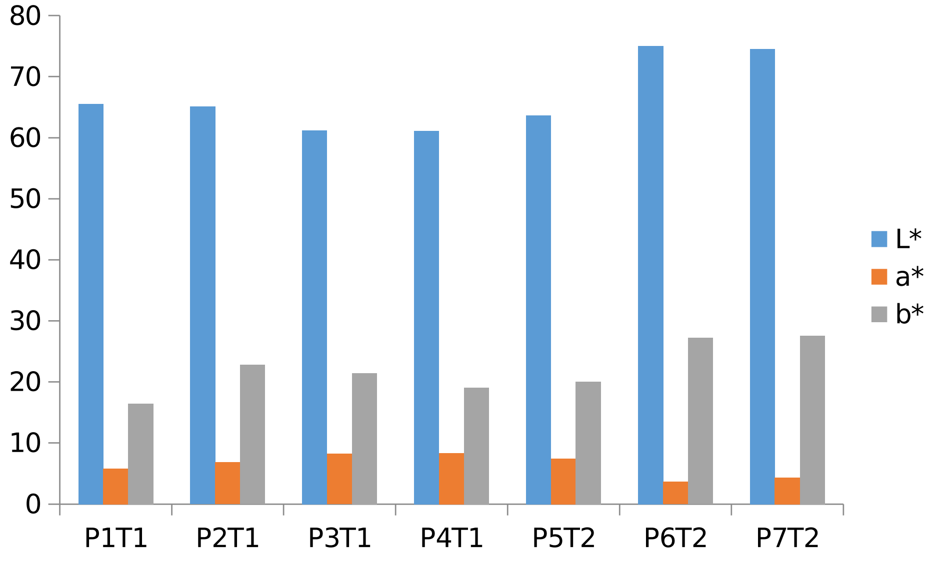

Fig. 4.2 Colour value for extruded RTE product

4.5 Storage studies of hot extruded RTE products

The extruded products were stored in a 400 gauge aluminium pouches in replicated kits and the MAP was created using nitrogen flushing. The quality parameters (water activity, colour and textural properties) of developed RTE extruded products were analysed upto three months.

4.5.1 Water activity

The water activity of the developed hot extruded RTE products before and after storage for three months is presented in Fig. 4.3. It was observed that after three months of storage, the water activity of products increased slightly in all the samples. For a given storage period, the water activity was maximum in P5T2 (0.338 to 0.526) and minimum in P7T2 (0.423 to 0.432). The slight increase in water activity during storage was probably due to change in humidity conditions of the surroundings. Manthey *et al.* (2008) observed a progressive increase in water activity of cereal bran enriched breads during storage.

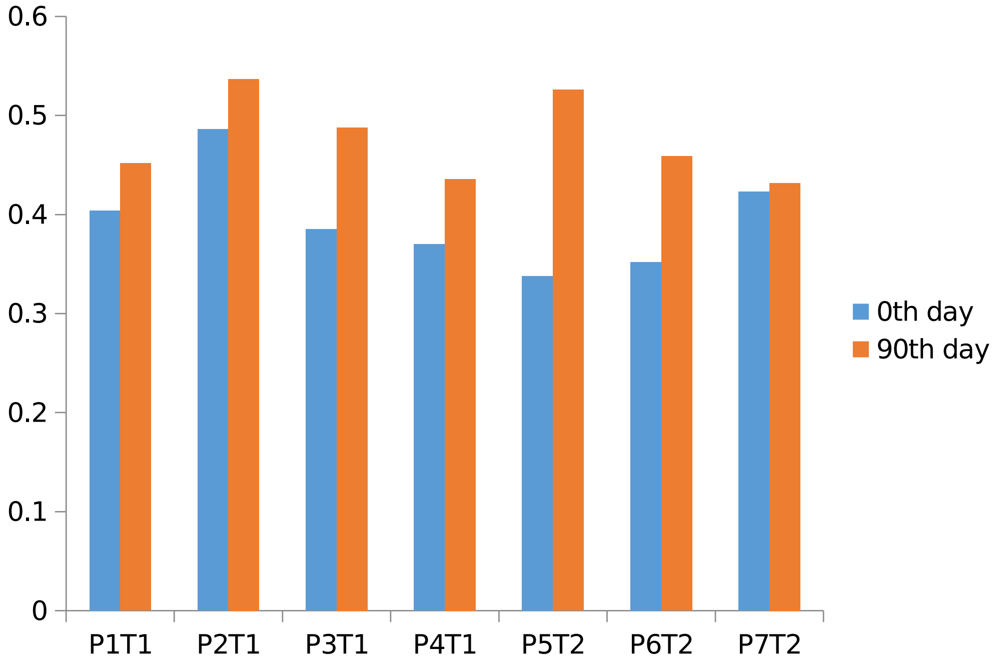

Fig. 4.3 Effect of storage period on water activity of hot extruded RTE product

4.5.2 Colour of hot extruded RTE products during storage

Colour is the important physical characteristic of extrudate product and is directly related to the acceptability of food product. The influence of colour values (L*, a* and b*) of different hot extruded RTE products during three months storage is presented in Appendix A4.

Colour values were measured for hot extruded RTE samples. From Fig. 4.4 (a), it was inferred that after three months of storage there was a decrease in L* value in all the combinations. For a given storage period maximum colour L* (61.22 to 43.12) was observed for combination P3T1 whereas, minimum colour L* (65.54 to 54.47) was observed for combination P1T1.

Throughout the storage period maximum value of a* was observed in P3T1 (8.21 to 5.71) whereas, minimum colour a* (5.82 to 5.36) was observed for P1T1 combination are shown in Fig. 4.4(b). The results suggested that, during storage a* value showed a decreasing trend.

From Fig. 4.4 (c), it was inferred that that after three months of storage there was an decrease in b* value in all combinations. The maximum colour b* was observed in P6T2 (21.43 to 12.88) and minimum colour b* (16.44 to 13.88) in P1T1 combination.

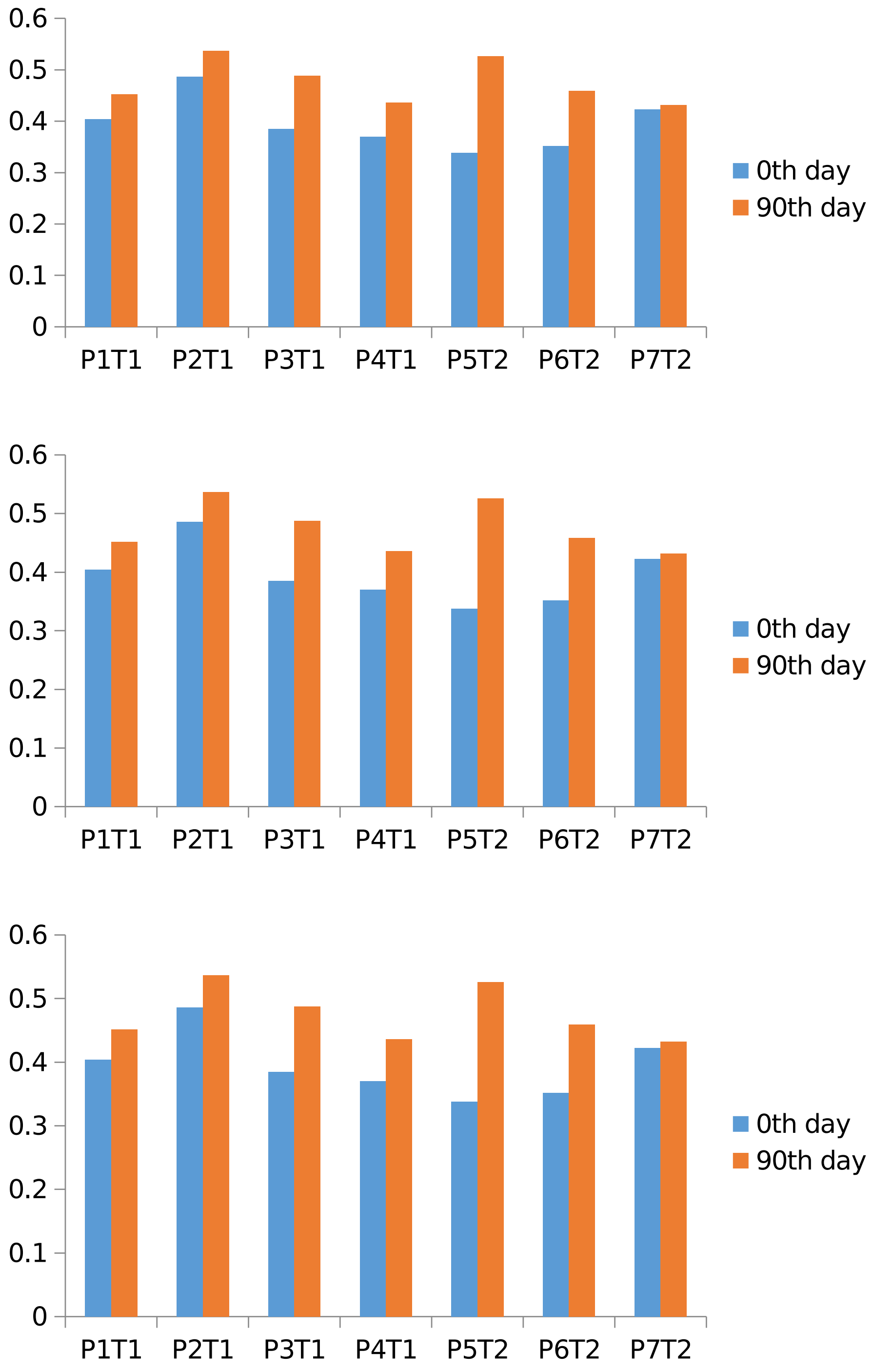

Fig. 4.4 Effect of storage period on colour values of hot extruded RTE products

4.6 Textural properties of hot extruded RTE products during storage

The textural properties of the extrudates were determined by the methodology described as per 3.4.2 and their variation after three months are discussed. Textural properties are discussed in terms of hardness.

4.6.1 Hardness (N)

The hardness of expanded extrudate is a perception of the human being and is associated with the expansion and cell structure of the product. Hardness of the extrudate varied from 0.354 to 1.701 N. The minimum hardness (0.354 N) was observed for combination P5T2 *i.e.,* 110°C temperature whereas, maximum hardness (1.701 N) was observed for combination P1T1 *i.e.,* 100°C temperature (Appendix A5). Various combinations were found to have significant effect on extrudate hardness.

It was seen that, increase in temperature resulted in decreased hardness (Fig. 4.5). An increase in temperature increased the degree of superheating of water in the extruder, encouraging bubble formation and also decreased melt viscosity, leading to reduced density and hardness of extrudate (Mercier and Feillet, 1975). It was noted that progressive increase in temperature resulted in pore formation of air cells and the surface appeared flaky and porous and hence decreased hardness (Bhattacharya and Choudhary, 1994). Therefore, a crispy texture was obtained with increasing temperature due to decrease in hardness. Similar behavior was observed by Chaiyakul *et al.* (2009) for high-protein, glutinous rice-based snack. Increasing finger millet flour level resulted in increased hardness of extrudates (Sawant *et al.,* 2013).

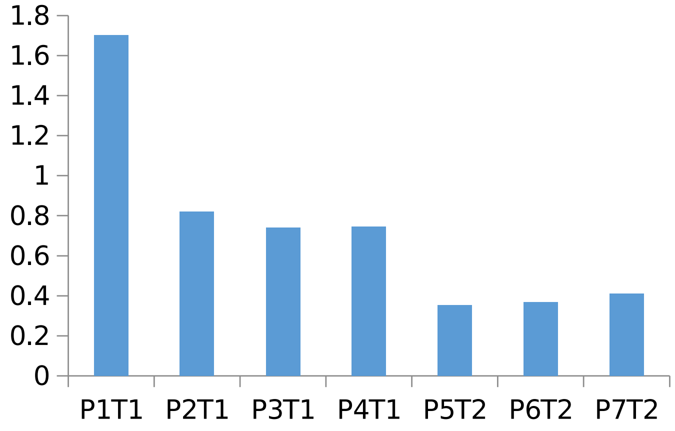

Fig 4.5 Textural properties of hot extruded RTE products

These values of hardness were compared with the hardness values of earlier studies done by Seema *et al.,* (2016). In that study the raw materials were mixed in seven different combinations namely: corn, corn : rice, corn : ragi, corn : elephant yam : purple yam : drumstick, ragi : elephant yam : purple yam : drumstick, ragi : corn : rice : elephant yam : purple yam : drumstick and rice : elephant yam : purple yam : drumstick in different proportions *viz.* C_{100}, C_{50}:R_{50}, C_{50}:Rg_{50}, C_{60}:Ey_{15}:Py_{20}:D_5, Rg_{60}:Ey_{15}:Py_{20}:D_5, Rg_{20}:C_{25}:R_{25}:Ey_{10}:Py_{15}:D_5 and R_{60}:Ey_{15}:Py_{20}:$D_{5.}$ These mixes were extruded under various extrusion process parameters of die temperatures (100, 110 and 120°C), screw speed (350 rpm) and moisture content (17.5%).

4.7 Sensory evaluation of hot extruded RTE products

Sensory evaluation indicates the acceptability of a product. The acceptability of extrudate was judged on a nine-point Hedonic scale. The sensory evaluation was carried out on the basis of colour and appearance, flavour, taste, crispiness and overall acceptability of the developed product. The sensory evaluation of the extruded product revealed that there were significant differences among the treatments for the organoleptic qualities. Considering the results of sensory evaluation, the best product was selected. The selected product was the one which was of good taste and overall acceptability. Based on sensory evaluation, Corn (50%) : Kumkumashali (50%), i.e., (P6T2) RTE product was selected as the best combination out of all combinations under concern.

Table 4.2 Mean sensory score card for hot extruded RTE products

Treatment	Colour & appearance	Flavour	Taste	Crispiness	Overall acceptability
P1T1	7.7	6.16	6.16	8	7.33
P2T1	7.5	6.6	7.31	7.9	7.45
P3T1	7.7	7	7.08	7.58	7.42
P4T1	7	6.9	7.1	7.2	7.12
P5T2	7.08	6.91	6.3	7.1	7.25
P6T2	8.9	8	7.41	8.08	8.16
P7T2	9	7.41	7	7.58	7.3

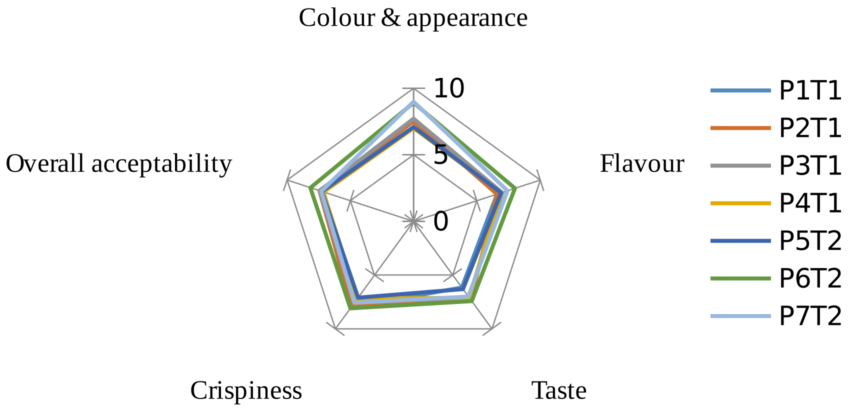

Fig 4.6 Sensory evaluation of extruded RTE products after storage

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

Extrusion processing has become an important food process in the manufacture of pasta, ready-to-eat cereals, snacks, pet foods, and textured vegetable protein (TVP). The fast changing life style of the consumer demands convenience in terms of saving time and energy. Development of ready to eat snacks add convenience, serves labour and time, provides hygienic products of standard and uniform quality with enhanced shelf life. The extruder is a high temperature short time process which minimises losses in vitamins and amino acids. Colour, flavour and product shape and texture are also affected by the extrusion process. Extrusion has been widely applied in the production of nutritious food. The production and consumption of expanded ready-to-eat (RTE) products through extrusion cooking is notably increasing worldwide. So by keeping these points in view the research work entitled "Development and quality evaluation of hot extruded RTE products with speciality rice" was undertaken in Department of Food And Agricultural Process Engineering, KCAET, Tavanur, Kerala.

Ready to eat (RTE) extruded product were developed by using rice flour (Rakthashali and Kumkumashali) and corn flour in different combinations and proportions namely P1 (R_{100}), P2 (C_{50}:R_{50}), P3 (C_{40}:R_{60}), P4 (C_{25}:R_{75}), P5 (C_{50}:K_{50}) and P6 (C_{40}:K_{60}) under same operating conditions of the twin screw extruder (i.e., screw speed- 350 rpm and feed moisture content-17.5% with two different temperature (i.e., T1-100 and T2-110°C). From these combinations and temperatures seven combinations (P1T1, P2T1, P3T1, P4T1, P5T2, P6T2, P7T2) were selected for shelf life study.

The quality parameters *viz,* physical properties (expansion ratio, bulk density and water activity), colour and textural properties for various RTE extruded products were determined. The extruded products were stored in a 400 gauge aluminium pouches in replicated kits and MAP was done along with nitrogen flushing. The quality parameters (water activity, colour and textural properties) of developed RTE extruded products were analysed upto 3 months.

The expansion ratio of the seven combinations of extruded RTE products ranged from 3.198 to 4.069. Maximum expansion ratio (4.069) was observed for P2T1 and minimum (3.198) for P1T1 combination. The expansion increased with increasing corn content, this can be explained by the fact that when feed material with high percent corn (having more starch) results in increasing in starch gelatinization during extrusion thereby increases extrudate volume. . Bulk density, which considers expansion in all direction ranged from 0.694 to 0.880 g/cm^3. It was observed that the minimum bulk density (0.694 g/cm^3) was observed for P5T2 and maximum bulk density (0.880 g/cm^3) was observed for P1T1. The results showed that as temperature increases bulk density decreases. The water activities of all combinations ranged from 0.338 to 0.486. The results indicated that at elevated temperatures have low a_w, which signifies the safe range of the products for consumption.

Extrusion process significantly affected the colour. L* values of various combinations of extrudates varied from 61.10 to 75.030. The maximum colour L* (75.030) was observed for combination P6T2 whereas, minimum colour L* (61.10) was observed for combination P4T1. An increase in L* value was observed with temperature. The *a** value varied from 3.660 to 8.36. The maximum colour a* (8.36) was observed for combination P4T1 whereas, minimum colour a* (3.660) was observed for combination P6T2. It appeared that with increase in temperature, a* value of the extrudate decreased. The b* value varied from 16.44 to 27.530. The maximum colour b* (27.530) was observed for combination P7T2 whereas, minimum colour b* (16.44) was observed for combination P1T1. An increasing addition of corn flour resulted in extrudate becoming more yellow, as recorded by increase in b* values.

The water activity of the developed RTE products after storage for three months increased slightly in all the samples. For a given storage period, the water activity was maximum in P5T2 (0.338 to 0.526) and minimum in P1T2 (0.404 to 0.452).

For a given storage period there was a decrease in L* value in all the treatment combinations. Maximum colour L* (61.22 to 43.12) was observed for combination P3T1 whereas, minimum colour L* (65.54 to 54.47) was observed for combination P1T1. The a* value showed decreasing trend during storage. Maximum value of a* was observed in P3T1 (8.21 to 5.71) whereas, minimum colour a* (5.82 to 5.36) was observed for P1T combination. The maximum colour b* was observed in P6T2 (21.43 to 12.88) and minimum colour b* (16.44 to 13.88) in P1T1 combination.

. Hardness of the extrudate varied from 0.354 to 1.701 N. The minimum hardness (0.354 N) was observed for combination P5T2 *i.e.,* 110°C temperature whereas, maximum hardness (1.701 N) was observed for combination P1T1. These values varied significantly with the values from earlier study done by Seema *et al.,* (2016). It was seen that, increase in temperature resulted in decreased hardness.

Based on sensory evaluation, P6T2 i.e., Corn (50) : Kumkumashali (50) was selected as the best comination out of all combinations under concern. The selection was based on maximum expansion, minimum bulk density and hardness and maximum colour value and crispiness.

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CHAPTER VI

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APPENDICES

APPENDIX A1

Table A1 Physical properties of hot extruded RTE products

Combinations	**ER**	**BD (g/cm^3)**	**a_w**
P1T1	3.198	0.880	0.404
P2T1	4.069	0.764	0.486
P3T1	4.010	0.786	0.385
P4T1	3.714	0.802	0.370
P5T2	3.762	0.694	0.338
P6T2	4.040	0.760	0.352
P7T2	3.980	0.805	0.423

ER: Expansion Ratio; BD: Bulk density; a_w: Water activity; T: Temperature, °C (T1-100°C, T2-110°C)

APPENDIX A2

Table A2 Colour of hot extruded RTE products

Combinations	**Colour**		
	L*	**a***	**b***
P1T1	65.54	5.82	16.44
P2T1	65.07	6.85	22.81
P3T1	61.22	8.2	21.43
P4T1	61.10	8.36	19.05
P5T2	63.65	7.45	20.04
P6T2	75.030	3.660	27.190
P7T2	74.560	4.320	27.530

APPENDIX A3

Table A3 Effect of storage period on water activity of extruded RTE products

Storage period (days)	P1T1	P2T1	P3T1	P4T1	P5T2	P6T2	P7T2
0	0.404	0.486	0.385	0.370	0.338	0.352	0.423
90	0.452	0.537	0.488	0.436	0.526	0.459	0.432

APPENDIX A4

Table A4 Effect of storage period on colour values of extruded RTE products

Storage period (days)	P1T1	P2T1	P3T1	P4T1	P5T2	P6T2	P7T2
L*							
0	65.54	65.07	61.22	61.10	63.65	75.030	74.560
90	54.47	48.27	43.12	59.24	5.42	59.87	57.92
a*							
0	5.82	6.85	8.21	8.36	7.45	3.660	4.320
90	5.36	5.43	5.7	7.45	6.53	2.39	3.52
b*							
0	16.44	22.81	21.43	19.05	20.04	27.190	27.530
90	13.88	14.26	12.88	14.83	15.07	17.29	19.06

APPENDIX A5

Table A5 Effect of storage period on hardness values of extruded RTE products

Combinations	Hardness
P1T1	1.701
P2T1	0.821
P3T1	0.739
P4T1	0.745
P5T2	0.354
P6T2	0.369
P7T2	0.412

DEVELOPMENT AND QUALITY EVALUATION OF HOT EXTRUDED RTE PRODUCTS FROM SPECIALITY RICE

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ABSTRACT OF THE THESIS
Submitted in partial fulfilment of the requirement for the degree of

BACHELOR OF TECHNOLOGY
IN
AGRICULTURAL ENGINEERING
Faculty of Agricultural Engineering and Technology
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2018

ABSTRACT

As the eating patterns are changing day by day, snack foods play very important role in the diet of the modern consumer. Consumer appeal for ready-to-eat (RTE) products is forecast to grow rapidly as consumers demand convenient snacks with exciting sensory and textural properties. Extrusion technology has been used extensively in the production of cereal RTE snacks due to its ease of operation and ability to produce a variety of textures and shapes which appeal to consumers. So the present study was undertaken to develop ready to eat (RTE) expanded products from rice varieties (Rakthashali and Kumkumashali) and corn. The blends of six different combinations were extruded at temperature of 100 and 110°C at a screw speed of 350 rpm and 17.5% feed moisture content. From these seven extruded product was evaluated for physical, colour and textural properties. The extruded products were stored in aluminium pouches and with nitrogen flushing. The quality parameters (expansion ratio, water activity, colour and textural properties) of stored RTE products were analysed upto three months. Based on sensory evaluation, a combination with Corn and Kumkumashali rice in 50 : 50 ratio was selected as the best combination out of all combinations under concern for the production of RTE product.