DEVELOPMENT AND QUALITY EVALUATION OF MILLET FORTIFIED TUBER BASED EXTRUDED RTE PRODUCTS

by

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Development and quality evaluation of millet fortified tuber based extruded RTE 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 of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Seema B. R.

Dedicated to

My beloved parents

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Sri. Rudresh

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

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	:	Atta flour
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 centimeter per gram
D	:	Drumstick flour
d.b.	:	Dry basis

dia. : Diameter
e.g. : Example
etc. : Etcetera
Ey : Elephant yam flour
Fig. : Figure
g : Gram
G : Guar gum flour
g/100 g : Gram per 100 gram
g/cm^3 : Gram per centimeter cube
g/g : Gram per gram
g/kg : Gram per kilogram
g/l : Gram per liter
g/min : Gram per minute
g/ml : Gram per milliliter
g/s : Gram per second
h : Hour
H_2SO_4 : Sulphuric acid
HCL : Hydrochloric acid
hp : Horse power
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
kJ/100 g	Kilo Joule per 100 gram
kJ/kg	Kilo Joules per kilogram
L*	Lightness or darkness
Ltd.	Limited
m/s	Meter per second
mg	Milligram
mg/100 g	Milligram per 100 gram
mg/g	Milligram per gram
min	Minute
ml	Milliliter
mm	Millimeter
mM gallic acid/g	Mille mole gallic acid/gram
mM trolox equiv/g	Mille mole trolox equivalent/gram
mm/s	Millimeter per second
N	Newton
N/mm^2	Newton per millimeter square
No.	Number
p	Probability
P	Combinations
pH	Percentage of H+ ions
Ph	Phase
pps	Parts per second
Py	Purple yam flour

r : Correlation coefficient
R : Rice flour
R: B : Rice: banana
R: C: B : Rice: cassava: banana
R^2 : Reggration coefficient
Rg : Ragi flour
rpm : Revolution per minute
s : Second
S : Significant
Sl. : Serial
T : Temperature
tm : Residence time
tsp : Teaspoonful
V : Volts
viz : Namely
w.b. : Wet basis
w/w : Weight by weight
ΔE : Total colour change
µm : Micro metre
π : Pi
AACC : American association of cereal chemists
ANOVA : Analysis of variance
AOAC : Association of official analytical chemists
BD : Bulk density

BSG	:	Brewer’s spent grain
CBSG	:	Corn starch + brewer’s spent grain
CCP	:	Cast polypropylene
CCRD	:	Central composite rotatable design
CMC	:	Carboxymethyl cellulose
CO_2	:	Carbon dioxide
C.V.	:	Coefficient of variation
CRC	:	Corn starch + red cabbage
df	:	Degree of freedom
DSC	:	Differential scanning calorimeter
ER	:	Expansion ratio
F	:	F value
FCRD	:	Factorial completely randomised design
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
MPET	:	Metalized polyethylene terephthalate
PA	:	Phytic acid
PC	:	Protein content
PDHF	:	Partially defatted hazelnut flour
PDI	:	Protein dispersibility index

PE	Polyethylene
POR	Porosity
RH	Relative humidity
Rs	Rupees
RSM	Response surface methodology
RTC	Ready to cook
RTE	Ready-to-eat
SDS	Sodium dodecyl sulphate
SEI	Sectional expansion index
SME	Specific mechanical energy
SPI	Soy protein isolate
SSE	Single screw extruder
Std. Dev	Standard deviation
SWS	Sweet whey solids
TA	Texture analyzer
TAC	Total antioxidant capacity
TD	True density
TDF	Total dietary fibre
TPC	Total phenolic compound
TPC	Total plate count
TSE	Twin screw extruder
TVP	Textured vegetable protein
UTM	Universal testing machine
WAI	Water absorption index

WAR : Water absorption ratio

WBSG : Wheat flour + brewer’s spent grain

WHC : Water holding capacity

WPC : Whey protein concentrate

WRC : Wheat flour + red cabbage

WSI : Water solubility index

XRD : X-ray diffraction

Introduction

CHAPTER I

INTRODUCTION

Extrusion is the technique in which product is prepared by combination of high pressure, temperature and mechanical shear. High temperature short time (HTST) extrusion cooking technology has limitless applications in processing of cereal based products (Filli and Nkama 2007). Extrusion processing was introduced by Harper for the first time to food material (Mercier and Feillet 1975). It has become an important food process in the manufacture of snack foods, pasta, confectionery, ready-to-eat (RTE) cereals, textured vegetable protein (TVP) and pet foods (Singh *et al.*, 2010). Today, their processing functions include mixing, grinding, shearing, starch cooking, protein denaturation, texture alteration, enzyme inactivation, thermal cooking, shaping products, expansion and puffing. In the extruder, food is mixed mechanically, cooked to high temperature, pressure and is subjected to shear which is generated in the screw-barrel assembly. The cooked melt is then texturised and shaped in the die (Arhaliass *et al.*, 2003). 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). It offers several advantages such as less man power requirement, high productivity and product quality, versatile, low cost, preserves food for longer period, different product shapes and no effluents or waste.

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 the 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 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 ready to eat (RTE) puffed cereals and expanded snack foods.

Pasta, with its origin in Italy has gained wide popularity as a convenient and nutritionally palatable, low glycemic food. Consumers are increasingly interested in foods containing healthy ingredients. According to Marchylo *et al.* (2001) pasta has an excellent nutritional profile, being a good source of complex carbohydrates and a moderate source of protein and vitamins. Besides being easy to prepare and a very versatile food, pasta has a relatively long shelf life when it is stored appropriately. It is also considered an adequate vehicle for food supplementation with minerals, proteins, and many other valuable healthy components (Borneo and Aguirre 2008).

A nutritionally secure RTE food product 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 finger millet, rice, maize, elephant yam, purple yam, guar gum and drumstick were considered for preparation of extruded product in the present investigation.

Finger millet (*Eleusine coracana*) also known as ragi in southern part of India. It is rich in carbohydrate, protein, calcium, dietary fibre, iron, minerals and low in fats. It is an important staple food for those peoples suffering from metabolic disorders like diabetes and obesity. It is considered to be one of the least allergic and most digestible grains available. Nutritionally, its importance is well recognized due to its high content of dietary fiber (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 (Patil and Sawant 2012). Health benefits associated with finger millet are nutritious food, easy to digest, promote healthy eating, promote natural weight loss, helps to maintain optimum sugar level in the blood and it acts as a good baby food due to rich in nutrient content. Regular consumption of finger millet having high dietary fiber and polyphenols contents is known to reduce the risk of diabetes mellitus and gastrointestinal tract disorders (Mathanghi and Sudha 2012).

Rice (*Oryza sativa*) belongs to a Gramminae or Grass family. 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. Hundred gram of rice contain 1,527 kJ (365 KCal) energy, 77.40 g carbohydrates, 0.12 g sugar, 1.30 g dietary fiber, 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.

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). 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.

Root and tubers are the third important food crops of mankind after cereals and grain legumes. Yams (*Dioscorea spp.*) have been grown in India since very ancient times. It is a rich source of carbohydrates, vitamins and has high calorific value. Fresh yams are difficult to store and are subject to deterioration during storage. Because yams are regarded as health foods and not staple foods in oriental countries, it is feasible to develop a stable form of yam products to fulfill the health food market. Since flours can be easily stored for long period of time and conveniently used in manufacturing formulated foods or capsules for consumption, dried yam flour is worth developing (Afoakwa and Sefa-Dedeh 2001).

Purple yams (*Dioscorea alata*) are cultivated throughout the tropical and subtropical regions of the world for their edible corms, which constitute a staple food for many people in many tropical countries in West Africa, South Asia and South America (Huang *et al.* 2007). The purple yams are rich in antioxidants and protects against disease caused by oxidant damage. It is rich in vitamin A, B, calcium and potassium which maintains skin, night vision, protection from lung and oral cavity cancer, controlling the heart rate and blood pressure.

Elephant foot yam (*Amorphophallus paeoniifolius*) is a highly potential tropical tuber crop of *Araceae* family. It is widely grown and consumed in south eastern countries. In India, it has gained the status of a cash crop due to its high production potential and market acceptability (Misra *et al,* 2002). According to Chattopadhyay *et al.* (2009) average nutritional profile contains mean energy value (236-566.70 kJ/100g), starch (11-28%), protein (0.8-2.60%), sugar (0.7-1.7%) and fat (0.07-0.40%). The most abundant macro mineral is potassium (327.83 mg/100 g), phosphorus (166.91 mg/100 g), calcium (161.08 mg/100 g), iron (3.43 mg/100 g) and the mean soluble oxalate content (13.53 mg/100 g) was safe from the viewpoint of accumulation of urinary oxalate leading to kidney stones. The tuberous roots of the plant posses blood purifier properties and have been used traditionally for the treatment of asthma, elephantiasis, tumors, inflammations, vomiting, cough, bronchitis, dyspepsia, colic, dysmenorrhoea, fatigue, anemia and general debility (Kirtikar and Basu 1989).

Guar gum (*Cyamopsis tetragonoloba*) is derived from the ground endosperm of the seed of the guar plant. The guar kernel is composed of many layers, namely husk (16-18%), endosperm (34-40%) and germ (43-46%). Gum is a white to yellowish white, nearly odourless, free-flowing powder with a bland taste. The commercial samples of guar gum contain approximately 4-12% moisture, 2-5% acid-soluble ash, 0.4-1.2% ash, and 2-6% protein. Guar seed is a rich source of mucilage or gum which forms a viscous gel in cold water and used as an emulsifier, stabilizer, thickener in a wide range of food and industrial application (Marina *et al.* 2007). It is also used for treating diabetes, diarrhea, obesity, irritable bowel syndrome (IBS), for reducing cholesterol and for preventing “hardening of the arteries” (atherosclerosis).

Drumstick (*Moringa olefeira*) belongs to *Moringaceae* family. It is cultivated almost all over the country and its fruits and leaves are used as vegetables. Almost all parts of the plant have been utilized in traditional medicine practices. Nutritionaly, drumstick pods and leaves are of great value as sources of protein, calcium, iron, phosphorus and Vitamins C which helps in maintaining skin integrity, vision, and immunity against infectious agent. Various parts of this plant such as the leaves, seed, roots, bark, flowers, fruit and immature pods act as cardiac and circulatory stimulants, possess antipyretic, antiepileptic, antispasmodic, antiulcer, diuretic, antihypertensive, antioxidant, anti-diabetic, antibacterial and antifungal activities, cholesterol lowering, hepatoprotective and are being employed for the treatment of different ailments in the indigenous system of medicine, particularly in South Asia (Mehta *et al.,* 2011).

So the product enriched with these raw materials *viz*. finger millet, rice, maize, elephant yam, purple yam, guar gum and drumstick will ensure a food which is safe to consume, nutritious and convenient.

In this back ground, a project entitled "Development and quality evaluation of millet fortified tuber based extruded RTE products" was under taken at Kelappaji College of Agricultural Engineering and Technology (KCAET), Tavanur, Kerala with the following objectives.

1. To standardise the composition of RTC (ready to cook) pasta from wheat flour, ragi flour, corn flour, elephant yam, purple yam and drum stick.
2. To standardise the composition of RTE food from ragi flour, corn flour, rice flour, elephant yam, purple yam and drum stick.
3. To standardise the extrusion process parameters for the production of RTE product.
4. To conduct the shelf life studies of extruded product under modified atmospheric packaging.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

This chapter reviews the research work carried out by various researches on development of pasta cold extruded products and application of high pressure extrusion processing to formulate extruded products. Literature related to cooking parameters of pasta, physical functional and textural properties of extruded RTE products are also discussed.

2.1 Raw materials

2.1.1 Maize (*Zea mays*)

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 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, bulk density decreased and expansion ratio increased while feed moisture content 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 feasible to produce third-generation snacks that have a significant nutraceutical and nutritional 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), process temperature (126.4-193.6°C) and feed moisture (31.6-48.4 g/100 g). 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, but decreased the bulk density (0.423 g/ml) and water solubility index (2.7 g/100 g).

2.1.2 Finger millet (*Eleusine coracana*)

The effects of feed moisture (13-25%), screw speed (158-242 rpm), fructose, glucose, maltose and sucrose on extrusion of lactic acid fermented and dried maize finger millet blend investigated by Onyango *et al*. (2004) using single screw extruder. The barrel wall temperature at the feed, compression and heating sections were kept at 150, 180 and 180°C respectively. The results shows that fermentation caused a reduction in sectional expansion (0.01), bulk density (446.7 kg/m^3) and water absorption index (WAI) 3.69 g/g but increased specific volume (11.03 cm^3/g), water solubility index (WSI) 20.59%. Expansion ratio, specific volume and yellowness (10.60 to 15.04) decreased with increase in feed moisture. Increasing screw speed had a negative correlation with lightness (68.96 to 65.12).

Deshpande and Poshadri (2011) prepared composite flours of foxtail millet (50-70%) blend with rice (5-10%), amaranth seed flour (5%), Bengal gram (10-30%), and cow pea (5-10%) for production of RTE snack products using extrusion cooking. Extrusion cooking was carried out using a twin screw extruder at optimized extrusion parameters namely temperature for two different heating zones (115°C and 90°C), screw speed (400 rpm) and die diameter (3 mm). The results indicated that composite flour of foxtail millet, rice, amaranth, bengal gram and cow pea in the ratios of 60:05:05:20:10 shows high mass flow rate (3.30 g/s), expansion ratio (2.32), WSI (0.32%), WAI (5.2%), water holding capacity (WHC) 420%, low true density (0.4 kg/cm^3) and bulk density (0.1 kg/cm^3), oil absorption capacity (5%), overall acceptability (8.5) could be used to produce quality extrudates with acceptable sensory properties.

Sawant *et al.* (2013) conducted a study on physical and sensory characteristics of finger millet based RTE food using co-rotating twin screw extruder. Seven composite mixes were prepared using maize flour, finger millet flour, rice flour, bengal gram flour, full fat soy flour and skimmed milk powder in varying proportions using twin screw extruder at temperature (140°C), screw speed (300 rpm) and die diameter (3 mm). Physical properties of the extrudates like bulk density (0.1618 to 0.3946 g/cm^3), expansion ratio (2.42 and 3.50), WAI (3.96% to 6.87%) were analysed. The study revealed that the composite flour (Finger millet: Maize: Rice: Soy bean) in the ratio of 20:50:20:10 best suits to produce desirable qualities of the extrudates in terms of hardness (23.37 N), expansion ratio (3.5) and sensory characteristics (8.87).

2.1.3 Yam (*Dioscorea alata*)

Sebio *et al.* (2000) studied the effect of process parameters on physicochemical properties of yam flour based snacks using single screw extruder with various combinations of feed moisture content, barrel temperature and screw speed. The yam extrudate flour showed the greatest values of WSI at high feed moisture content (26%) and high barrel temperatures (150°C). The physical properties of the extruded product showed that at high temperature and low moisture content greater the expansion index. Hardness was influenced directly by feed moisture content and inversely by extrusion temperature.

Oke *et al.* (2012) investigated the effect of extrusion variables on extrudates properties of water yam flour, it was observed that changing the barrel temperature, screw speed and feed moisture content significantly affected the expansion ratio, mass flow rate, residence time, torque and SME. Increasing feed moisture content (18-28% d.b.) and the screw speed (80-180 rpm) resulted in a substantial decrease in residence time (27.5%), expansion ratio (46.6%) and SME (83.6%) whereas, mass flow rate (64.5%) of extrudates increased with increased screw speed .

Reddy *et al.* (2014) conducted a study on development of RTE extruded snack prepared from flour blends made with corn flour (60-80%), bengal gram flour (20%) and tuber flours (20%). Process conditions utilized were feed rate 15 ± 2 kg/h, moisture content 17-20%, barrel temperatures: 80 ± 5°C (heater I) and 95-105°C (heater II), screw speed 300-350 rpm, die temperature 100 ± 10°C and die diameter 3 mm. Shelf life studies showed after 2 months of storage, a slight increase in moisture content of the extruded products. However, combination of metalized polyethylene terephthalate (MPET) along with modified atmospheric packaging helps in retaining the texture and other sensory parameters of the extruded products for prolonged shelf life.

2.1.4 Wheat (*Triticum aestivum*)

Ding *et al.* (2006) studied the effect of extrusion conditions including feed moisture content (14-22%), feed rate (20-32 kg/h), barrel temperature (100-140°C) and screw speed (180-320 rpm) on the physical and functional properties of wheat based expanded snacks. The study reported that, increasing feed rate results in extrudates with a higher hardness and lower energy to puncture the samples. Increase in feed moisture content results in extrudates with high density, WSI, hardness and low expansion ratio. Increasing screw speed caused slight reduction in hardness and density of wheat extrudate. Higher barrel temperature reduced WAI, hardness and density, but increased the puncture energy of extrudate and WSI.

Stojceska *et al*. (2009) studied the effect of different feed moisture level (12 to 17%) during extrusion cooking, by using co-rotating twin screw extruder (TSE) on nutritional and physical properties of extruded products. Four different samples were prepared: wheat flour + brewer's spent grain (WBSG), wheat flour + red cabbage (WRC), corn starch + BSG (CBSG), and corn starch + red cabbage (CRC). Process conditions utilized were: screw speed 200 rpm, constant feed rate of 25 kg/h, and barrel temperature of 80 and 120°C. The results showed that increasing the water feed to 15% increased the level of total dietary fibre (TDF) in all the extrudates while extrusion processing increased the level of TDF in WBSG, CBSG and CRC but decreased in WRC products. All the samples showed a wide range of total antioxidant capacity (TAC) between 9.0 and 14.3 mM trolox equiv/g, total phenolic compound (TPC) 1.4 and 3.2 mM gallic acid/g, phytic acid (PA) 709.0 and 1187.3 mg/100 g, TDF (3.2 and 13.5%) and protein content (PC) 2.4 and 15.7%. In addition to water feed level affecting the TDF of the extrudates, also affected the bulk density, hardness, expansion ratio, WSI, SME and colour.

2.1.5 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% w.b.). 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.

2.1.6 Guar gum (*Cyamopsis tetragonoloba*)

Thakur and Saxena (2000) prepared extruded snack from composite flour of corn flour, green gram flour blended with xanthan, guar gum, arabic gum and carboxymethyl cellulose (CMC). The system of sensory score and expansion ratio of extruded snack food can be effectively optimized using RSM and with a minimum number of experiments run at 160°C with a feed rate of 70 g/min. Responses were affected by changes in corn flour, green gram flour, and guar gum levels and to a lesser extent by xanthan, gum arabic and CMC levels. The maximum sensory score of 21.4 and expansion ratio of 13.2 were identified at corn flour 692 g/kg, green gram flour 307 g/kg, xanthan 0.302 g/kg, guar gum 0.216 g/kg, gum arabic 0.196 g/kg and CMC levels 0.262 g/kg.

Parada *et al.* (2011) investigated on the effect of guar gum (0-10%) on some physical and nutritional properties of extruded products blended with flour (maize, potato, rice and wheat) prior to extrusion on the microstructure, physical properties (expansion, density, texture and pasting) and nutritional properties (starch digestibility). The inclusion of guar gum did not decrease starch digestibility rather at guar gum (10%) rapidly digestible starch increased by maize (24%), potato (15%), rice (25%) and wheat (43%). In general, increase in starch digestibility appear to be related to the larger matrix surface area, weaker microstructure (*i.e.,* lower textural hardness) and lower viscosity of extrudates containing guar gum. These results recommend that micro structural changes affect the starch digestibility of extrudates; in spite of that, probably other factors such as during digestion particle size may also play an important role.

2.1.7 Drumstick (*Moringa oleifera*)

Oduro *et al.* (2008) studied on the nutritional potential in *Moringa oleifera* leaves and sweet potato (*Ipomoea batatas*) leaves and reported that *M. oleifera* leaves contains crude protein of 27.51%, crude fibre of 19.25%, crude fat of 2.23%, ash content of 7.13%, moisture content of 76.53%, carbohydrate content of 43.88% and calorific value of 305.62 Cal/g. Calcium and iron content were 2,009.00 and 28.29 in mg/100 g (dry matter) respectively. These results reveal that the leaves contain an appreciable amount of nutrients and can be included in diets to supplement our daily nutrient needs.

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.

Oluwole and Olapade (2011) studied the effect of extrusion cooking of white yam and bambara-nut blend on some selected extrudate parameters like residence time, throughput and moisture content were investigated in this study. Extrusion was carried out following a three variable response surface methodology using a Box Behnken design. Blend of yam meal and Bambara nut meal in the ratio of (80:20) respectively was conditioned into 12.5, 15.0 and 17.5% moisture content on dry basis and allowed to equilibrate for 4 hour. Extrusion was carried out on a single screw extruder at screw speed (50, 60 and 70 rpm) and barrel temperatures (130°C, 140°C and 150°C). The study revealed that the extrusion time varied between 13.1 and 29.7 sec, product moisture from 11.1 to 16.8% dry basis and throughput varied from 13.3 to 34.4 kg/h. The result indicates that the second order poly-nomial was adequate to model the dependence of the extrudate parameters of residence time, throughput and moisture content on extrusion variables of barrel temperature, feed moisture content and screw speed.

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* and 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 technologies have an important role in the food industry as efficient manufacturing processes. There are two types of extrusion process: cold and hot extrusion.

In cold extrusion process, the product is extruded without cooking or distortion of food. The extruder has a deep-flighted screw, which operates at a low speed in a smooth barrel, to knead and extrude the material with little friction. Typical food products include pastry dough, individual pieces of candy or confections, pasta pieces and some types of confectionery (Fellows, 2000).

In hot extrusion (also called extrusion cooking) extruder consists of a high tolerance screw rotating in a barrel. The food materials of proper moisture content is fed into the extruder, inside which cooking takes place mainly by viscous shear heat generated and they are conveyed to the die. This process results in an elevation of temperature and pressure. As the dough exits the die, it puffs largely due to flashing of moisture vapour (Smith, 1971).

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 brings 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.

The extrusion cooking is being used increasingly for the manufacture of snack foods. In extrusion processes, cereals are cooked at high temperature for a very short time. Starch is gelatinized and proteins may be inactivated, microorganisms are largely destroyed and the product's shelf life is there by extended. The products are easily fortified with additives (Sowbhagya and Ali, 2001).

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, 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.

Guha and Ali (2006) studied the effect of amylose content (5.0-28.6%) of rice and barrel temperature (80-120°C) on extrusion system parameters; torque and net SME and extrudate characteristics; expansion ratio (ER), extrudate bulk density (BD), WSI, and shear stress were studied using a twin-screw extruder. The feed rate (15 kg/h), moisture content (20.0 ± 0.2) of feed and the screw speed (400 rpm) were kept constant. BD and ER of the product with a barrel temperature of 120°C were desirable for extrudate rice product from low-amylose rice. Experimental data on system parameters and extrudate characteristics fit to second-degree polynomial regression equations ($r \geq 0.904$, $p \leq 0.01$) with the amylose content of rice and barrel temperature of the extruder.

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%.

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 231.0°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 Cold extruded products and their quality

Pagani *et al.* (1989) studied the influence of the extrusion process on characteristics and structure of pasta using blend of wheat flour, three types of spaghetti were produced using the following three kneading and forming processes: A) kneading with a continuous press and forming by pressure-extrusion B) kneading and forming by sheeting-rolls C) kneading by hand and forming with sheeting-rolls. The results of the investigation, demonstrate that the kneading and forming of pasta dough with a continuous press induces a decrease in spaghetti quality in comparison with roll-sheeting or hand-working processes.

Marti *et al.* (2010) extracted starches from parboiled rice flour and produced pasta samples by cold extrusion processes at 50°C and hot extrusion at 115°C. The products were evaluated by differential scanning calorimeter (DSC) and size exclusion chromatography. The molecular changes induced by both pasta making and cooking process in boiling water were also investigated using iodine absorption property of samples.

Ranganna *et al.* (2012) used a sophisticated Brabender single screw extruder (SSE) to develop small millets based extruded pasta by blending cassava flour.

2.6 Physical properties

Gimenez *et al.* (2013) prepared corn-broad bean spaghetti type pasta with a corn/broad bean flour blend in a 70:30 ratio through an extrusion-cooking process. The effect of temperature (80, 90 and 100°C) and moisture (28, 31 and 34%) on the extrusion responses (SME and pressure) and the quality of pasta product (expansion, firmness, cooking-related losses, water absorption and stickiness) was evaluated. The structural changes of starch were studied by means of DSC and X-ray diffraction (XRD). The operating conditions at moisture content (28%) and temperature (100°C) was best to obtain corn-broad bean spaghetti-type pasta with high protein and dietary fibre content.

Kumari *et al.* (2013) studied the effect of feed compositions and processing parameters on the physical and nutritional properties of extruded product. Pasta formulation was substituted with multi cereal composite mix at three different levels of 50, 70 and 90% (w/w) to enhance the nutritional profile. All the samples were assessed for physical properties (bulk density, swelling power, water holding capacity, amino acid profile, morphological properties, foam capacity and foam stability) and nutritional properties (protein, ash, crude fibre, fat, carbohydrate and calorific value). Extrusion cooking was carried out using a single screw extruder at 400 rpm screw speed in different ratios and put for the sensory evaluation. The findings of the study indicates that multi cereal substitute with 50% showed better result in terms nutrition and physical properties ($p<0.05$) which would be further utilized in development of therapeutic products.

Sudha devi *et al.* (2015) studied the use of little millet for production of pasta using cold extrusion technology. The objective of the study was standardization of composition of millet flour for millet pasta, process optimization and quality evaluation of millet pasta. The composite flours were prepared using little millet flour and other flour fractions namely maida, soy flour and cow pea flour. The extrudate physical properties namely bulk density, tapping density, expansion ratio, water holding capacity (WHC), WAI and moisture retention were also analyzed. The result of the composite millet powder and maida indicated that up to 50% inclusion of millet flour with maida yielded good results and indicated that mass flow rate 1.91 ± 0.12 g/s, tap density 0.73 ± 0.01 g/cm^3, bulk density 0.57 ± 0 g/cm^3, water soluble index 0.36%, moisture retention 35.67 ± 0.4, expansion ratio 1.45 ± 0.31, water absorbing index 3.14 ± 0.03% and water holding capacity 384.2 ± 0.07.

A study was undertaken to develop millet fortified cold extruded pasta products and to study the quality attributes of the developed products by Chanu and Jena (2015). Four pasta samples with different ratios of wheat flour to millet flour (1:0, 8:1, 4:1 and 2:1) were prepared using a single screw pasta extruder. The average moisture content of fresh and dried pasta was found to be 31.73 ± 1.01% and 11.84 ± 1.01% wet basis respectively. Average specific length of the developed millet fortified pasta products was found to be 27.70 ± 0.99 mm and average sectional expansion ratio was 0.91 ± 0.006. The bulk density of developed pasta varied between 281.71 ± 3.42 and 301.88 ± 16.17 kg/m^3. The result indicates a decreasing trend in desirable b* values (yellowness) were observed with increase in millet flour content. Highest value of 1.16 ± 0.09 of water absorption ratio was found for sample with 2:1 ratio of wheat to millet flour and lowest value of 0.81 ± 0.07 was obtained for the sample with ratio 1:0.

2.7 Cooking properties

The effect of experimental parameters (temperature, shearing and hydration) on the pasta making process and on quality characteristics of spaghetti was studied by Abecassis *et al.* (1994). The screw speed determines the flow rate of the extruder and the average specific mechanical energy (70 kJ/kg) transferred to the product for pasta extrusion but it may vary in the ratio of 5:1 according to the extrusion condition especially temperature and dough hydration which determines the dough viscosity also had a great effect on pressure in the barrel and at the die. Cooking quality increased by increasing the amount of hydration of semolina and screw speed. The result shows that excessive increase in temperature during extrusion appeared to be the major factor in the degradation of cooking quality. Therefore control of temperature at the die was proposed as the easiest method to guarantee the quality of finished products.

Devaraju *et al.* (2003) reported development of finger millet based pasta products with good cooking quality, storage stability, acceptability and higher nutritive values using composite finger millet flour (50%), refine wheat flour (40%), defatted soy/WPC (10%) and hot water (75°C). The mean protein, energy, calcium and iron in the experimental pasta ranged from 14-18 g, 365-372 kCal, 102-148 mg and 3-5 mg, respectively.

2.8 Colour and Texture

Edwards *et al.* (1993) prepared extruded noodles from durum wheat semolina of variable protein content to provide a series of sample with a range of cooking quality. Firmness of cooked noodles was measured using an Universal Testing Machine (UTM) and compared with the storage modulus and dynamic viscosity obtained by dynamic rheometry. A correlation (r^2 at least 0.87) was found between the Instron values and the rheometer measurements at both optimum and over cooking times. The Instron peak force measurement was found to be a more precise indicator of noodle firmness than peak energy. Even though moisture content was shown to have a major influence on the texture of cooked noodles, the differences in moisture between samples were not sufficient to produce the differences measured by either the Instron or by dynamic rheometry.

Marti *et al.* (2011) evaluated various properties of commercial pasta made from a mixture of durum wheat semolina and buckwheat flour. The characterization of products, belonging to different producers, focused on the assessment of chemical and physical properties such as mechanical properties before and after cooking, water uptake and surface characteristics. Sensory analysis was conducted to evaluate firmness, resistance to breaking and overall acceptability. The texture analysis showed a lowest Young modulus value (0.48 N/mm^2). The results highlighted high heterogeneity of the mechanical properties, solid loss and water absorption among the samples.

A study was conducted by Fiorda *et al*. (2013) to evaluate the quality of gluten-free pasta formulated with the combined use of a pre-gelatinized flour made from cassava starch and dehydrated cassava bagasse (10%), amaranth flour (30%), and cassava starch (60%) allowed for the improvement of a product with adequate texture, color and nutritional value and compared with commercial wheat pasta products, obtaining pasta that was not very sticky (3.2 N), fiber rich (9.37 g/100g) and protein (10.41 g/100g) and with adequate firmness (43.6 N), as well as presenting a light yellowish color.

2.9 Sensory and storage studies

Good storage quality of processed food is an essential characteristic to extend their utilization. Various factors like quality of raw foods, composition of food, packaging material and extent of heat application influence the storage quality. The storage quality of processed foods was evaluated by several investigators in terms of sensory characters.

Sowbhagya and Ali (2000) prepared maize vermicelli with and without antioxidant and packed in cast polypropylene (CCP) and a laminate of metalized polyester with low density polyethylene (MPET/ PE). The packs were stored at 38ºC, 92% RH (accelerated storage) for 100-140 days. Firmness and elasticity of product remained good up to 100 days.

Zardetto (2004) reported that under conditions of optimal storage (41ºC) and in MAP with CO_2 concentrations above 30%, the colony is visible after 60 days, and that a small increase in the storage temperature resulted in decrease in the shelf life of the product. This result suggested that the 30% of CO_2 concentration in MAP was not sufficient to stop the spoilage of pasta by *P. Aurantiogriseum*, when the product was subjected to an abuse temperature for a short time during its storage.

The effect of incorporation of finger millet in pasta products was investigated by Shanthi *et al.* (2005). Refined wheat flour, soya flour and whole wheat flour were blended with finger millet in different proportions with wheat and refined wheat flour as the main ingredient. The results of sensory evaluation revealed that incorporation of finger millet up to 30% and soya flour up to 10% was in the acceptable range for pasta fortification.

Devaraju *et al.* (2008) prepared pasta by using finger millet composite flour, defatted soy flour being the protein source and WPC. Fortification of the protein content was made from 13.12% in control to 17.78% in pasta made from finger millet composite flour. Sensory evaluation scores indicate that non-significant difference among the control and experimental products for texture. Fortification with WPC and defatted soy flour helped in improving protein content as well as the sensory profile.

Sudha devi *et al.* (2013) conducted a study to improve the shelf-life of proso millet based pasta, prepared with different combinations by packaging interventions. Results revealed that there was a remarkable decrease in moisture, protein, fat and carbohydrates at different rates in all the samples packaged in different packaging materials. However, there was no much variation in ash and crude fibre during storage with different packaging materials. The product packaged in PP was found to keep good only for 30 days and the main cause of quality loss was more permeability to environment agents. Packaging in LDPE provided a shelf-life of three months with an acceptable quality at the end of storage period. Hence, it was concluded that LDPE packed proso millet based pasta (Proso millet + wheat flour @50% each) could be stored at room temperature for three months without appreciable quality deterioration.

2.10 Hot extruded products and their quality

2.10.1 Physical properties

2.10.1.1 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 using a single-screw extruder. RSM using an incomplete factorial design was applied with various combinations of feed moisture content (18, 22, 26%), barrel temperature (100, 125, 150°C) and screw speed (100, 150, 200 rpm). The physical properties of the extruded product showed a greater expansion index at high temperature and low feed moisture content.

Gujral *et al.* (2001) studied the effect of temperature (100-150°C), screw speed (100-150 rpm) and feed moisture (16-24% w.b.) on the extrusion behaviour of flint and sweet corn grits. The extruder die pressure, WSI and expansion ratio 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 expansion, water solubility index and smaller structure patterns.

Shannon *et al.* (2010) studied the effect of protein (6, 12 or 18%), 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 0.5% sodium bicarbonate was used as a leavening agent. Extrusion of pea flour containing protein (6%) and feed moisture content (15%) 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.

2.10.1.2 Density and porosity

Thymi *et al*. (2005) reported the effect of varied feed moisture content (12-25 kg/100 kg w.b.), product temperature (100-260°C), screw speed (150-250 rpm) and feed rate (1.16-6.44 kg/h) on structural properties of extruded corn starch. As the residence time increased for all temperature and feed moisture content 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 corn, rice 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. Extrusion operating parameters were feed moisture (19-23 g/100 g d.b.), screw speed (150-300 rpm) and temperature (125-145°C). The highest specific mechanical energy was observed at low feed moisture, medium barrel temperature and high screw speed. Also with increased screw speed and/or decreased feed moisture results in decreased mean residence time (tm). The products with high expansion ratio and low product density, which generally are good characteristics of extruded RTE 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 of the raw materials (12, 18 and 20%), 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 results in increased ethyl butyrate retention (0.62 mg/g), while higher temperature results in more expanded (3.7) extrudates with lower bulk 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).

2.10.1.3 Moisture content & water activity

Sacchetti *et al.* (2004) prepared snack products by using chestnut-rice flour. The effects of extrusion temperature and chestnut flour content on physical (density, moisture content and colour) and functional (WSI, WAI and WHC) properties of the extrudates were studied. Since chestnuts are rich in sugars, the flour content restricted the starch gelatinization and the expansion of the product, also the combined effect of flour content and temperature enhanced the browning reactions. Chestnut flour of 30% processed at temperature of 120°C was found to be suitable for producing a snack-like product if properly mixed with rice flour by extrusion-cooking process.

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 68.11s, 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 water activity ranges from 0.03 to 0.75.

Meng *et al.* (2010) conducted a study on the effects of extrusion conditions on the 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. Die pressure and the product temperature 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 hardness and bulk density, 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.

2.11 Functional properties

WAI and WSI of extruded food products were determined by Anderson *et al*. (1982). The extruded puff was milled to mean particle size of 200-250 µm. A 2.5 g sample was dispersed in 25 ml distilled water, using a glass rod to break up any lumps and then stirred for 30 min. The dispersions were rinsed into a tarred centrifuge tube, made up to 32.5 g and centrifuged at 4000 rpm for 15 min. The supernatant was decanted for of its solid content and sediment was weighed to find WAI.

Balandran-Quintan *et al.* (1998) investigated the functional and nutritional properties of extruded whole pinto bean meal. Pinto bean meals with 18, 20 and 22% feed moisture were extruded at 140, 160 and 180°C barrel temperature using screw speeds of 150, 200 and 250 rpm in a single-screw extruder. Expansion ratio, bulk density, water solubility and absorption indices, *in vitro* protein digestibility and trypsin inhibitor activity in extrudates were measured. Feed moisture content and temperature influenced expansion index, bulk density, water absorption index and *in vitro* protein digestibility. Best product was produced with 160°C barrel temperature and 22% feed moisture content.

Screw speed had most significant effect on WAI and WSI of extrudates. The effect of increased screw speeds produced lower overall WAI and higher overall WSI. On further increase of screw speed, overall WAI increased and overall WSI decreased (Badrie and Mellows, 1991). But according to Anderson *et al*. (1969), Tang and Ding (1994) and Lo *et al*. (1998), an increase in screw speed resulted in reduction of WAI and increase in WSI.

Kharat (2013) standardized the process technology for foxtail millet based nutri-rich extruded product. The composite flour was prepared by mixing foxtail millet (45%), broken rice (45%), chickpea (5%) and rice bran (5%). The extruded product was prepared by varying the extrusion conditions such as barrel temperature (100, 110 and 120°C), feed moisture (12.50, 15.00 and 17.5%) and screw speed (300, 350 and 400 rpm). The best operating condition of barrel temperature of 120°C, screw speed of 400 rpm and feed moisture of 15%, recorded the maximum expansion ratio (3.52), mass flow rate (3.87 g/s), bulk density (0.12 g/cm^3), moisture retention (36.73%), WAI (2.82 g/g), WSI (0.15 g/g), WHC (419.72%), SME (29.54 kJ/kg), colour value such as, L* (62.97), a* (1.01) and b* (15.20), fat (2.36%), dietary fiber (7.44%), carbohydrates (68.93%), protein (6.38%), phenolic content (1.9%) and total ash (1.03%), with an overall acceptability of 7.82.

2.12 Colour and texture

Bhattacharyya *et al.* (2006) examined the physico-chemical characteristics of extruded snacks prepared from corn, rice and taro by using twin-screw extruder at barrel temperature of 141, 150 and 159°C respectively. Phosphate buffer (pH 6.9) and sodium dodecyl sulphate (SDS) 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 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.

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%), screw speed (150-200 rpm) and extrusion die temperature (140-160°C) on system parameters and physical properties of extrudates were assessed by using RSM. The system parameters and product responses were mostly 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.

2.13 Sensory and storage studies

The effect of extrusion cooking conditions on the nutritional value, sensory characteristics and storage stability of maize-based snack food was examined by Lasekan *et al.* (1996). Samples were analysed for lysine loss, protein dispersibility index (PDI), lipid oxidation (changes in total carbonyls) and sensory characteristics during storage (25, 30 and 40°C). When extrusion temperature increased extruded samples were decreased in lysine (3.0 to 2.70) content and PDI (69.3 to 32.30). Storage at moisture contents above the monolayer region reduced the total carbonyls (0.66 to 0.53) in samples. However, total carbonyls of products were found to be increase with increase in storage temperature (0.50 to 0.75). In addition, storage at high temperature *i.e.,* at 40°C significantly reduced the sensory acceptance of the maize-based snack (7.70 to 6.20).

Boonyasirikool and Charunuch (2000) produced a nutritious soy fortified snack with good texture and good protein quality with 2% soybean oil and fortified with a mixture of minerals, vitamins and amino acids. Mixed ingredients were adjusted to 16.5% moisture content and fed at 365 g/min to extrusion process at 165 to 167°C temperature and screw speed at 300 rpm by using twin screw extruder. The obtained snack had an expansion ratio (3.9), bulk density (58 g/l) and compression force (60.17 N). Sensory evaluation of the product was done for preference and acceptance together with control samples and popular market snacks.

Vijayarani *et al.* (2012) developed value added extruded products from corn flour (5%), refined wheat flour (80-90%) and with different proportions of spirulina (5-15%), replacing water with whey water. The sensory evaluation of the developed value added extruded product using spirulina showed that 5% of spirulina incorporated product got the maximum mean score (4.96) compared to 10% (4.68) and 15% (4.55) due to intensification of colour and odour. The storage studies for the control (100% refined wheat flour) 5, 10 and 15% spirulina incorporated samples were carried out for a period of one month. The total bacterial and fungal counts were enumerated using plated count. Nutrient Bengal agar medium was used for the determination of fungi count. No contamination was found for the period of one month and the product is found to be microbially safe till the observed period.

Hazarika *et al.* (2013) studied the effect of extrusion cooking parameters on the properties of extruded product prepared from rice, sweet potato and yam using a single screw extruder. Optimization was done by RSM using Central Composite Design. Using screw speed (132 to 468 rpm), barrel temperature (103°C to 137°C) and feed composition as the three independent variables, the three responses taken were expansion index, bulk density and breaking strength. The products were analyzed for their proximate, physical, antioxidant and sensory characteristics. There was a significant colour change in all the three samples as indicated by total colour change (ΔE). Texture analysis of the extrudate samples showed hardness values ranging from 28.68 N to 47.57 N. Considering the results of sensory evaluation, rice flour incorporated with sweet potato was judged as the best combination.

Manjula and Visvanathan (2014) studied the effect of extrusion on the physical, functional and textural properties of broken rice blended with maize flour and finger millet. The density of blends ranged from 0.11 to 0.44 g/cm^3, expansion ratio (1.54-2.46), true density (78.91-477.84 kg/m^3), porosity (28.13-37.95%), WAI (5.0-8.05 g/g) and hardness (1.35-10.09 N). It was noted that the increase in feed moisture content resulted in extrudates with a lower expansion ratio and WAI, higher WSI, density and hardness. Among the various combinations tried, the blend with finger millet (60%), broken rice (30%) and maize (10%), at 16% feed moisture content, 110°C barrel temperature and 290 rpm screw speed yielded good sensory results. The results obtained from the experiments were significantly different at ($p \leq 0.01$) of all combinations.

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, functional, structural and engineering properties of the developed extrudates and storage characteristics of the best extrudates based on objective and subjective evaluation.

3.1 Raw materials

The raw materials selected for the development of extruded products were corn, ragi, rice, atta, elephant foot yam, purple yam and drumstick. Corn, ragi, rice and atta were procured from nearby local market and the elephant foot yam, purple yam, drumstick were collected from progressive farmers of Tavanur area, Malappuram district, Kerala.

3.1.1 Preparation of samples for extrusion

Freshly harvested elephant foot and purple yam were procured from local market, cleaned with water to remove the surface dirt. Both the yams were cleaned, peeled, sliced using a slicer (Plate 3.1) and blanched with hot water (100ºC for 3 minutes). However the drumstick pulp was taken and blanched for 9 minutes at 100ºC in hot water and all these were dried in a cabinet dryer at 70ºC for 4h. The above said raw materials were milled in a hammer mill (Plate 3.2) to obtain flours. The flours / grits were further sieved manually using ISS 35 mesh in the case of flours and ISS 85 mesh in the case of grits in order to obtain flour / grits of uniform particle size. The flours were mainly used for developing cold extruded (RTC) products and the grits were used for the developing hot extruded RTE expanded products.

Plate 3.1 Slicer **Plate 3.2 Hammer mill**

Experiment I

3.2 Development of millet fortified tuber based cold extruded pasta products

Cold extruded pasta mainly consists of flour mix containing tuber, wheat and millet flours and a binding agent like guar gum. The blended flour mixes at appropriate moisture content were extruded in a pasta making machine (make: La Monferrina, Italy) into desired shaped products.

3.2.1 Description of pasta machine (cold extruder)

The laboratory model Pasta Machine (make: La Monferrina, Italy; model: Dolly) was used for preparing cold extruded products (Plate 3.3). The unit was basically a single screw extruder (SSE) with a short stainless steel screw of uniform pitch powered by a 3 hp electrical motor through a speed reduction system. The main screw could be easily dismantled, for cleaning the end “die” was removed. Different types of “die” could be attached to produce pasta of various shapes as per the requirement. The dough to be extruded was prepared just prior to extrusion in the same pasta machine using the kneading facility. The flours and other ingredients were put in to the feeding trough and the kneader (paddle type) switch was first selected to blend the ingredients thoroughly. Later, required quantity of water (1 kg flour = 300 ml of water) was added and the flours were worked for a while to get optimum dough characteristics suitable for cold extrusion. Once the dough of required consistency was ready, extrusion switch was selected to produce pasta of desired shape. A pasta cutter blade, optionally attached at the outlet of the “die” could cut the extruded pasta to the desired size.

a) Extruder

b) Different dies

Plate 3.3 Laboratory model pasta making machine (Cold extruder)

3.2.2 Standardisation of combination of raw materials

The raw materials used were blended in different combinations and proportions. Various combination used for cold extruded pasta are described below in Table 3.1

Table 3.1 Raw material used to prepare six blends of cold extrudate

Combinations	**Raw materials (%)**
P1	A_{100}
P2	A_{98}:G_2
P3	Rg_{60}:Ey_{15}:Py_{20}:D_3:G_2
P4	C_{60}:Ey_{15}:Py_{20}:D_3:G_2
P5	A_{60}:Ey_{15}:Py_{20}:D_3:G_2
P6	Rg_{25}:C_{20}:A_{25}:Ey_{10}:Py_{15}:D_3:G_2

A=Atta flour, Rg=Ragi flour, C=Corn flour, Ey=Elephant yam flour, Py=Purple yam flour, D=Drumstick pulp power, G=Gaur gum.

3.2.3 Pasta product manufacture

The pasta products were manufactured by following the procedure advocated by the pasta machine manufacturer. The sieved flours were first blended (in the machine itself) for 5 min and then kneaded for about 10 min after adding optimum quantity of water. The quantity of water was decided based on manufacturer recommendations (for 1 kg flour = 300 ml of water). When the dough characteristic was optimum, it was extruded using appropriate “dies” (available shapes which are a *ribbed tube, shanku, twisted ribbons*). The cutter speed was set to optimum level (3 to 12 rpm) depending upon the shape of the final product. The extruded pasta were collected in trays and then dried in cabinet dryer to obtain translucent pasta. The products were then packed in 400 gauge LDPE bags, thermally sealed and stored at ambient conditions (Temperature : 28-30ºC, Relative humidity : 60-65% RH).

3.3 Sensory evaluation of cooked pasta products

The millet fortified pasta products were prepared with the same process protocol as that of commercially available pasta and were evaluated for sensory characteristics. The recipe for preparation of pasta as given in Appendix A. Whole wheat pasta as control was prepared in similar way and presented for sensory evaluation along with the experimental samples. The judges scored the cooked pasta for colour, texture, taste, flavour and overall acceptability on a 9 point hedonic scale (Appendix B).

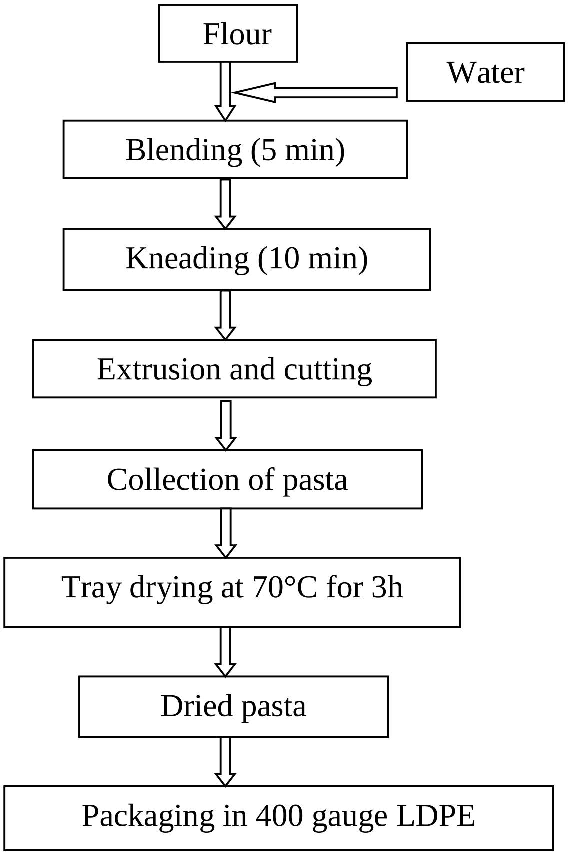

Fig. 3.1 Flow chart for production of millet fortified tuber based pasta products

3.4 Cooking quality of millet fortified tuber based pasta products

The cooking characteristics of experimental pasta samples were determined by following standard cooking procedures.

3.4.1 Cooking time

The pasta products (5 g) were cooked in boiling water (100 ml). The cooking time of pasta was determined by pressing the product between fingers periodically at one min intervals. When the product was completely soft, the time was noted as optimum cooking time (Suda devi *et al.,* 2014).

3.4.2 Swelling power

Swelling power of pasta products was determined by method proposed by Schoch (1964). A known weight (5 g) of pasta was cooked in a glass beaker with 20 times its quantity of boiling water (100 ml) for 20 minutes over a water bath maintained at 100ºC. After cooking, the water was strained out and the cooked pasta was dried to remove surface moisture using filter paper and the cooked sample was weighed. From the initial and final weights of pasta, swelling power was calculated as:

$$\text{Swelling power (g/g)} = \frac{W_2 - W_1}{W_1} \qquad \ldots (3.1)$$

Where,

W_1 = Sample weight before cooking, g

W_2 = Sample weight after cooking, g

3.4.3 Solid loss

Solid loss of pasta products was determined by method proposed by Suda devi *et al*. (2014). Pasta samples were cooked in boiling water for 20 minutes. After cooking, the cooked material was strained out and the whole filtrate was transferred quantitatively in to a pre-weighed petri dish. It was evaporated over a water bath followed by drying in a hot air oven which is maintained at 105 ± 2ºC for 1 hour. The petri dish was again weighed with the dried solids. Then, the solid loss was calculated as:

$$\text{Solid loss}\,(\%) = \frac{M_2 - M_1}{M_0} \times 100 \qquad \ldots \quad (3.2)$$

Where,

M_0 - Initial weight of pasta taken for cooking, g

M_1 - Weight of empty petri dish, g

M_2 - Weight of petri dish with dried solids after evaporation, g

3.4.4 Water absorption ratio

Water absorption ratio was determined by method proposed by Chanu *et al*. (2015). Thirty gram of dried pasta was cooked in a cooking pan for 4 minutes in an approximate ratio of 1:10 pasta/water taking 500 ml of tap water. As soon as the samples were put into the boiled water which is maintained at a temperature of 98-100°C, the cooking period begins and was cooked for 4 minutes. The whole pasta sample was removed and drained. The weight of cooked pasta was measured after 5 minutes and water absorption ratio (WAR) was calculated by following expression.

$$\text{WAR (g/g)} = \frac{W_f}{W_b} \qquad \ldots \; (3.3)$$

Where,

WAR - water absorption ratio, (g/g)

W_f - weight of cooked sample, (g)

W_b- weight of uncooked sample, (g)

3.5 Physical properties of millet fortified tuber based pasta products

3.5.1 Expansion ratio (ER)

Expansion ratio was measured as per the standard method described by Alvarez-Martinez *et al.* (1988). Randomly ten pasta samples were selected and their diameter was measured using a digital vernier calliper. Diameter of each extrudate was measured thrice and average diameter values were found out to calculate ER. ER was calculated using the following equation

$$\text{Expansion ratio} = \frac{D_s}{D_i} \qquad \text{… (3.4)}$$

Where,

ER - Expansion ratio

D_s - Diameter of the specimen, (mm)

D_i - Diameter of the die, (mm)

3.5.2 Bulk density

Bulk density of individual cylindrical pasta extrudates was estimated as the ratio of mass to volume for each sample. Weight of the samples was taken as 50 g using a digital balance, while a 250 ml measuring cylinder (Borosil) was used to measure the volume of each sample. The cylinder was tapped 20 times for uniform compaction (Chanu *et al.,* 2015). The number of replications was three and average bulk density values were expressed as g/ml.

$$\text{Bulk density (g/ml)} = \frac{\text{Mass}}{\text{Volume}} \qquad \text{… (3.5)}$$

3.6 Storage study of millet fortified tuber based pasta products

Storage stability of developed pasta products were studied at ambient conditions by storing them in flexible packages. The six combinations of millet fortified tuber based pasta products were kept under 400 gauge LDPE for three months. The stored pastas were periodically analyzed at monthly intervals for cooking quality and engineering properties in order to study their storage stability. The experimental plan is shown below:

Types of pasta - 6 levels	
A_{100}	P1
A_{98}:G_2	P2
Rg_{60}:Ey_{15}:Py_{20}:D_3:G_2	P3
C_{60}:Ey_{15}:Py_{20}:D_3:G_2	P4
A_{60}:Ey_{15}:Py_{20}:D_3:G_2	P5
Rg_{25}:C_{20}:A_{25}:Ey_{10}:Py_{15}:D_3:G_2	P6
Packaging film: 400 gauge LDPE Storage duration: Three months Sampling interval: Monthly	

Experiment II

3.7 Development of millet fortified tuber based RTE expanded products

Ready to eat (RTE) crispy products were prepared from millets and tuber crops by hot extrusion technology using a Laboratory model Twin screw extruder. Dried yam and drumstick pulp were milled into grits and mixed with other cereal. The grits were passed through ISS 85 mesh in order to obtain grits of uniform particle size and hot extruded to get fluffy, crispy RTE products.

3.7.1 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 Twin-screw extruder is described in Plate 3.4. 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*.

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 extruder barrel receives the feed from a variable speed, co-rotating, 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 water cooling jackets and electric band-heaters. 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 3.4 Laboratory model twin screw extruder

3.7.2 Twin screw extruder operation

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.

3.7.3 Optimization of Twin screw extruder operating parameters for different small millet based ready-to-eat products

The operating parameters of the twin screw extruder mainly, the feed moisture content and the screw speed, were optimized for the various “best selected” seven millet millet fortified tuber based RTE expanded products. Three feed moisture content (12.5, 15 and 17.5% w.b.) and three screw speeds (300, 350 and 400 rpm) were selected to produce extrudates. The extrudates were analyzed for physical parameters like expansion ratio, bulk density, water absorption index, true density, water solubility index etc. Based on the expansion ratio, optimum feed moisture content and screw speed was selected. The selected screw speed was 350 rpm and feed moisture content was 17.5%. Further experiment was carried out with three different level of temperature (100, 110 and 120°C) with constant screw speed and feed moisture content.

3.7.4 Preparation of samples for extrusion of millet fortified tuber based RTE products

Millets are difficult to hot extrude and therefore requires mixing with other agents like rice/corn starches to make expanded products. Both yams and drumstick pulp were milled into grits and passed through ISS 85 mesh in order to obtain grits of uniform particle size and the sieved grits were used for the preparation of hot extruded RTE expanded products. These raw materials were blended in seven different combinations mainly,

P1	Corn
P2	Corn : Rice
P3	Corn : Ragi
P4	Corn : Elephant yam : Purple yam : Drumstick
P5	Ragi : Elephant yam : Purple yam : Drumstick
P6	Ragi : Corn : Rice : Elephant yam : Purple yam : Drumstick
P7	Rice : Elephant yam : Purple yam : Drumstick

The various proportions used under each combination are described below. The combinations were selected in the ratio of 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 $R_{60}:Ey_{15}:Py_{20}:D_{5}$. The amount of raw materials used to produce various flour blends constituted 1000 g each are indicated in Table 3.2.

Table 3.2 Raw material used to prepare seven blends

Blends (%)	**Quantity of raw materials**
C_{100}	C_{1000g}
$C_{50}:R_{50}$	$C_{500g} : R_{500g}$
$C_{50}:Rg_{50}$	$C_{500g} : Rg_{500g}$
$C_{60}:Ey_{15}:Py_{20}:D_{5}$	$C_{600g} : Ey_{150g} : Py_{200g} : D_{50g}$
$Rg_{60}:Ey_{15}:Py_{20}:D_{5}$	$Rg_{600g} : Ey_{150g} : Py_{200g} : D_{50g}$
$Rg_{20}:C_{25}:R_{25}:Ey_{10}:Py_{15}:D_{5}$	$Rg_{200g} : C_{250g} : R_{250g} : Ey_{100g} : Py_{150g} : D_{50g}$
$R_{60}:Ey_{15}:Py_{20}:D_{5}$	$R_{600g} : Ey_{150g} : Py_{200g} : D_{50g}$

3.7.5 Experimental method

The blends in seven different combinations of P1 (C_{100}), P2 (C_{50}: R_{50}), P3 (C_{50}: Rg_{50}), P4 (C_{60}: Ey_{15}: Py_{20}: D_5), P5 (Rg_{60}: Ey_{15}: Py_{20}: D_5), P6 (Rg_{20}: C_{25}: R_{25}: Ey_{10}: Py_{15}: D_5) and P7 (R_{60}: Ey_{15}: Py_{20}: D_5) were extruded at temperatures of 100, 110, and 120ºC at constant speed of 350 rpm and 17.5% moisture content. Kurkure (Manufactured by: PepsiCo India Holdings PVT. Ltd, Ingredients: Rice meal, Corn meal, Gram meal, Spices and condiments) 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.

The second stage of work included storage studies which were done with selected extrudates. The selection of extrudate samples was primarily based on expansion ratio, bulk density and sensory characteristics of extrudates like taste and overall acceptability. Storage studies of these samples were done in aluminium pouches with nitrogen flushing. The flow chart for the preparation of millet based extruded product is given in Fig. 3.2.

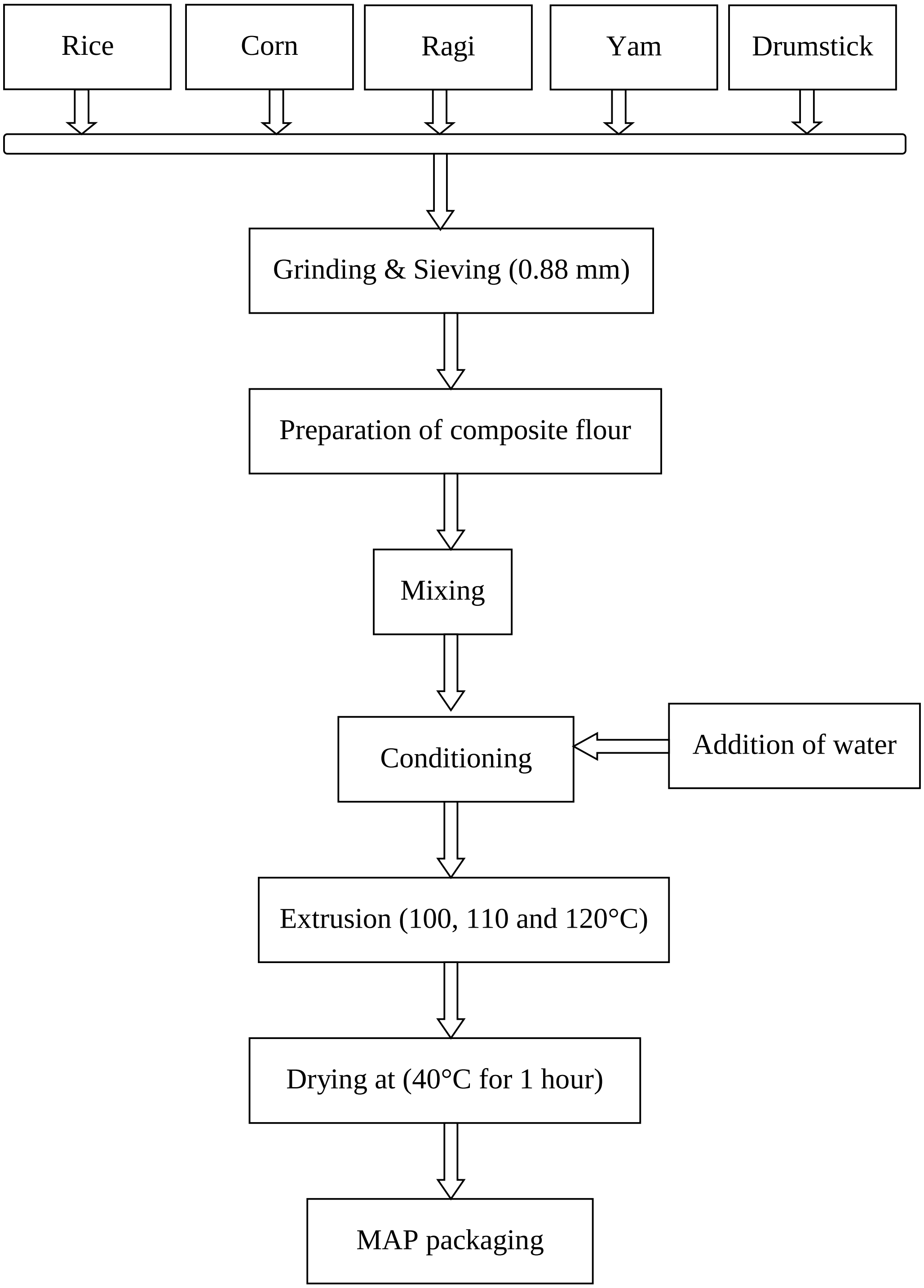

Fig. 3.2 Flow chart for preparation of millet fortified tuber based extruded product

3.7.6 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, 110 and 120ºC) 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 of millet-corn grit blend 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 PE bags, sealed and stored for further analyses.

Table 3.3 Different treatments taken for the RTE product development

Combinations (%)	Temperature (°C)		
	T1 (100)	T2 (110)	T3 (120)
P1 (C_{100})	P1 T1	P1 T2	P1 T3
P2 (C_{50}:R_{50})	P2 T1	P2 T2	P2 T3
P3 (C_{50}:Rg_{50})	P3 T1	P3 T2	P3 T3
P4 (C_{60}:Ey_{15}:Py_{20}:D_{5})	P4 T1	P4 T2	P4 T3
P5 (Rg_{60}:Ey_{15}:Py_{20}:D_{5})	P5 T1	P5 T2	P5 T3
P6 (Rg_{20}:C_{25}:R_{25}:Ey_{10}:Py_{15}:D_{5})	P6 T1	P6 T2	P6 T3
P7 (R_{60}:Ey_{15}:Py_{20}:D_{5})	P7T1	P7T2	P7T3

3.7.7 Sensory evaluation of RTE expanded products

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 millet fortified tuber based 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 (Appendix C) by a panel of 12 judges along with the commercially available product as a control.

3.7.8 Selection of best small millets based RTE expanded products

Among the 21 treatments screening was done, primarily based on sensory characteristics. The best judged products (seven) were the ones which were of good taste and overall acceptability. The selected seven combinations were used for further studies to optimize the operating parameters of the Twin screw extruder.

3.8 Physical parameters of RTE expanded products

The following physical parameters were studied for the millet fortified tuber based RTE expanded products.

3.8.1 Moisture content

The hot air oven method (AOAC, 2005) was used to calculate the moisture content of extruded samples. Extruded samples of approximately 2 g were placed in pre-dried moisture box in an oven. The operating temperature was 105°C for 5-6 h. The samples were taken out of the oven, cooled in a desiccator and weighed by using electronic weighing balance (make: Essae) having a sensitivity of 0.001 g. The fresh and bone dried weights were used to determine the moisture content on wet basis.

$$\text{Moisture content (\% w.b.)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \qquad \dots (3.6)$$

Where, W_1, W_2 and W_3 are weights of empty moisture box, moisture box + sample before drying and moisture box + sample after drying, respectively.

3.8.2 Expansion ratio

The ratio of diameter of extruded product to the diameter of die hole was used to determine the degree of expansion of extrudates (Fan *et al.*, 1996). The diameter of extrudates was determined as the mean of ten random measurements made with a vernier caliper. The extrudates expansion ratio was then calculated as:

$$\text{Expansion ratio} = \frac{\text{Diameter of extruded product (mm)}}{\text{Diameter of die hole (mm)}} \qquad \dots (3.7)$$

3.8.3 Bulk density

The bulk density (BD) was calculated by measuring the actual dimensions of the extrudates (Chinnaswamy and Bhattacharya, 1986). The diameter and length of the extrudates were measured by using digital vernier calliper 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 then calculated by using the following formula, assuming a cylindrical shape of extrudate (Launay *et al.*, 1983). Ten pieces of extrudate were randomly selected and the average was taken (Ding *et al.*, 2005). The experiments were repeated thrice and the bulk density was calculated by using the following equation:

$$\text{Bulk density (g/cm}^3) = \frac{4\text{m}}{\pi d^2 L} \qquad \dots (3.8)$$

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.

3.8.4 True density

True density of extruded millet based RTE expanded products was calculated as per the method recommended by Deshpande and Poshadri (2011). A known weight (1 g) of extrudate was ground and the ground sample was poured into a burette containing toluene. The raise in volume in the burette was noted as the true volume of the sample. Then the true density was calculated as:

$$\text{True density (g/cm}^3) = \frac{\text{Weight of ground sample of extrudate (g)}}{\text{Rise in toulene level (cm}^3)} \qquad \dots (3.9)$$

3.8.5 Measurement of porosity

The porosity of the product depends on the void space present in the product. The porosity of the extruded product depends on the amount of moisture escaped during extrusion process. It is defined as the ratio of the volume of the void space to the volume of the product. A known volume of the extruded product powdered in a grinder and then final volume of the product was noted. The volume of the void space in the extruded product was determined by subtracting the volume of the powder from the initial volume (Jhoe *et al*., 2009).

$$\text{Porosity}(\%) = \frac{V_p - V_{po}}{V_{po}} \times 100 \qquad \dots (3.10)$$

Where,

V_p - volume of the product

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

3.8.6 Water activity (a_w)

The water activity of extrudate was measured by using water activity meter (model: Aqua lab). The sample under test was kept in sample cup in which 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).

3.9 Functional properties of RTE expanded products

3.9.1 Water absorption index (WAI) and Water solubility index (WSI)

WAI and WSI were determined by the method described by Anderson (1982). The extruded samples were milled and sieved to get a uniform particle size. About 1 g of sample was placed in a centrifuge tube and 10 ml distilled water was added. After standing for 15 min, the sample was centrifuged at 4000 rpm for 15 min. The supernatant was decanted into Petri dish for determination of its solid content and sediment was weighed. WAI and WSI were calculated as follows:

$$\text{Water absorption index (g/g)} = \frac{\text{Weight of wet sediment}}{\text{Intial weight of dry solids taken}} \quad \ldots (3.11)$$

$$\text{Water solubility index (\%)} = \frac{\text{Weight of dissolved solids in supernatant}}{\text{Weight of dry solids}} \times 100 \quad \ldots (3.12)$$

3.10 Proximate analysis of extruded product

3.10.1 Protein

The crude protein in sample was determined using micro Kjeltec distillation unit (AOAC, 2005, 920.86). A finely ground extrudate sample powder of 0.8 g was taken into a digestion tube. Digestion mixture is prepared by mixing 0.8 g copper sulphate and 7 g of potassium sulphate. Add 0.5 g of digestion mixture and 10 ml of concentrated H_2SO_4 to the sample. The sample was digested in a digestion unit till it became colourless. Then the tubes were cooled and transferred to the distillation unit. Forty ml of NaOH (40%) solution was allowed into the tube. Liberated ammonium was absorbed in boric acid (4%) solution containing mixed indicator (10 ml bromocresol green and 7 ml of methyl red). The pink colour of the boric acid solution was turned to green and this was titrated against 0.1 N HCL until the pink colour was obtained. The percentage protein was obtained by using the following formula.

$$\text{Protein}\,(\%) = \frac{(\text{ml of HCl} - \text{ml of blank}) \times \text{molarity} \times 14.007 \times 100}{\text{mg test portion}} \times 6.25 \quad \ldots (3.13)$$

3.10.2 Carbohydrate

The carbohydrate was estimated as per the procedures outlined by (AOAC 2005, 996.11). Five gram of grinded sample was extracted with 25 ml of 80% alcohol. The extract is then filtered and placed in centrifuge at 6000 rpm for 10 min. The supernatant was taken as clarified solution for further experiment. About 0.5 ml of the clarified solutions was taken in a 100 ml volumetric flask and diluted to the mark with distilled water. From each solution, one ml was taken in a test tube, one ml of 5% phenol solution and 5 ml of 96% concentrated H_2SO_4 were added, later the sample was cooled to room temperature by keeping in a water bath at 25 to 30°C for 20 min. The absorbance of the prepared samples was observed at 515 nm using a spectrophotometer (make: Systronics; model: PC based double beam spectrophotometer 2202). The concentration of carbohydrates in the sample was determined using standard graph.

$$\text{Carbohydratre}\,(\%) = \frac{X}{0.1} \times 100 \quad \ldots (3.14)$$

Where,

X = Concentration of glucose from standard graph

3.10.3 Fat

The crude fat of the flour samples was determined as per AOAC (2005, 920.85) by Soxhlet extraction method using SOCS - PLUS apparatus (make: Pelican Equipments, SCS-08, Chennai, India). Two g of extrudate was weighed accurately and transferred to a thimble. The empty beaker weight was taken and all the beakers were loaded into the system. The acetone was poured into the beaker from the top and boiled for about 30 min at 80°C. After the completion of process time, the temperature was doubled to 160°C for 15-20 min to collect the acetone. All the beakers with residue were dried in hot air oven maintained at 100°C for 1 hour, cooled in a desiccator and again weight was taken. The final weight of the beaker was noted down and fat content was estimated by using the following equation;

$$\text{Fat}\,(\%) = \frac{W_2 - W_1}{W} \times 100 \qquad \dots (3.15)$$

Where,

W_1 = Initial weight of the beaker, g
W_2 = Final weight of the beaker, g
W = Weight of the sample taken, g

3.10.4 Energy content

The energy in any sample is the crucial parameter deciding the nutritive value. This can be computed from the available nutrient information like 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) … (3.16)

3.11 Engineering properties of cold and hot extruded products

3.11.1 Colour characteristics

Colour is important to consumer as a means of identification, as a method of judging quality and the overall objective of colour to the food is to make it appealing and recognizable. Colour of the pasta and 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). The instrument was initially calibrated with a black as well as with standard white plate.

3.11.2 Texture analysis

Textural properties of millet fortified tuber based pasta and 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 pasta products, texture analyser was operated with 10 kg load cell and a sharp blade probe was used. The main objective is to determine the pasta firmness using AACC (16-50) standard method. The test speed was 2 mm/s and the distance between two supports was 45 mm. A force time curve was recorded and analysed by texture Exponent 32 software program (version 3.0). The test was carried out to find the breaking force of the product in terms of Force (N) and distance (mm) and time (min) with a texture analyser. The parallel supports were placed 45 mm apart and the extrudate was placed on the parallel support. The sharp-edged blade was lowered at a speed of 10 mm/s.

For RTE extruded products the experiments were conducted 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 different tests were conducted according to TA settings. The textural properties such as hardness and fracturability were measured by using penetration test (Stable Micro Systems). Crispiness was measured by using shear test.

Penetration test by using cylindrical probe

The penetration test is defined as one in which the depth of penetration (or the time required to reach a certain depth) is measured under a constant load. In the penetration test, the 5 mm cylinder probe was made to penetrate into the test sample and the force necessary to achieve a certain penetration depth or the depth of penetration in a specified time, under defined conditions, was measured and used as an index of hardness.

TA settings

Mode: Measure Force in Compression
Option: Return to Start
Pre Text speed: 1mm/s
Test speed: 1 mm/s
Post Test speed: 10 mm/s
Distance (compression): 4 mm
Data Acquisition Rate: 400 pps

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. Sufficient quantity of snack 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 taken to be the result from the test.

3.12 Analysis of microbial population in extruded product

One gram of sample was weighed and transferred aseptically to 9 ml of sterile distilled water to get 10^{-1} dilution and mixed well. From 10^{-1} dilution, one ml of aliquote was transferred to another test tube containing 9 ml sterile distilled water to get 10^{-2} dilution. Then this procedure was repeated upto 10^{-4} dilution. One ml of aliquot from different dilution was transferred to sterile petri plates for the enumeration of bacteria and triplicates were taken. Poured 15-20 ml of appropriate growth media (nutrient agar for bacteria) at temperature (45-50°C) and the plates were rotated clockwise and anticlockwise directions on the flat surface to have a uniform distribution of colonies. After the solidification of agar, the plates were inverted and incubated at room temperature for 2-5 days (bacteria one day, yeast and fungi three days). Total plate counts (TPC) were determined on plate count agar pour plates and enumerated after an incubation period of 48-72 h at 30°C. The colonies were counted after the incubation period and the number of cfu per ml of sample were calculated by applying the following formula:

Number of colony forming units per ml of the sample

$$\text{No. of cfu/ml} = \frac{\text{Mean number of cfu} \times \text{dilution factor}}{\text{Vol of the sample}} \qquad \ldots (3.17)$$

3.13 Economic analysis

Economic analysis was performed for the optimized composition. The cost of extruded product was determined with the suitable assumptions using standard procedure. The estimation of cost of extruded pasta and RTE product is given in Appendix J & K.

3.14 Statistical Analysis

All the experiments in the study were conducted in triplicate and mean values reported. Factorial completely randomised design (FCRD) was used to analyse the data. After proper analysis, data were accommodated in the tables as per the needs of objectives for interpretation of results. Statistical significance was examined by analysis of variance (ANOVA) for each response. The experimental design was done with the aid of the Design-Expert software version 7.0.0 (Statease Inc., Minneapolis, USA).

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, ragi, rice, atta, elephant yam, purple yam and drumstick blended in different proportions for developing cold extruded (pasta) products and 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.

Experiment 1: Cold extrusion (Pasta)

In the present study, preliminary trials were carried out for selecting best combinations of pasta products. In this stage, based on visual observations (colour and cooked texture) six combinations were selected for further studies. The results obtained are presented and discussed in detail in subsequent sessions.

4.1 Quality parameters of millet fortified tuber based cold extruded pasta products
4.2 Storage studies of millet fortified tuber based cold extruded pasta products
4.3 Sensory evaluation and optimization of cold extruded pasta products

Experiment 2: Hot extrusion (RTE)

Preliminary trials were conducted for optimizing the screw speed and feed moisture content. The results obtained are presented and discussed in detail under the sessions as given below.

4.4 Development of millet fortified tuber based extruded RTE products
4.5 Sensory evaluation of millet fortified tuber based extruded RTE products
4.6 Quality parameters of millet fortified tuber based extruded RTE products
4.7 Storage studies of millet fortified tuber based extruded RTE products
4.8 Optimization and standardization of extruded RTE products
4.9 Economics of producing millet fortified tuber based pasta and RTE products

4.1 Quality parameters of millet fortified tuber based pasta products

The flour with an initial moisture content of 30 percent was used for the cold extrusion with dolly pasta machine. The quality parameters *viz*. cooking, physical and engineering properties of the extruded pasta products are discussed.

4.1.1 Cooking quality of millet fortified tuber based pasta products

Cooking quality namely, cooking time, swelling power, solid loss and water absorption ratio for six combinations of pasta products were determined.

4.1.1.1 Cooking time (min)

The cooking time was determined by methodology explained in 3.4.1. The cooking time required for different millet and tuber based pasta products (P2, P3, P4, P5 and P6) varied from 8.32 to 12.05 min (Table 4.1) and the cooking time was observed for wheat pasta P1 (Control-12.15 min). This was in confirmation with the studies of Aravind *et al.* (2011) who optimized cooking time of spaghetti as 12 min. Wheat pasta showed the longest cooking time due to the fact that its central vein has greater starch content, the component that absorbs the water and transfers it into the center (Gimenez *et al.*, 2012). The lowest cooking time was recorded for P6 (8.32) followed by P3 (8.45). These results are in agreement with the findings of Shukla and Srivastava (2014). It was found that optimum cooking time decreased (6 to 5 min) as the finger millet flour content was increased with the refined wheat flour. Statistical analysis showed that combinations of different raw materials have significant ($p<0.0001$) effect on cooking time of pasta.

4.1.1.2 Solid loss (%)

The solid loss was calculated as per the methodology explained under 3.4.2. The solid loss of various pasta products during cooking varied from 1.23 to 2.26% as shown in Table 4.1. The lowest solid loss (1.23%) was observed with P3 pasta followed by P6 pasta (1.80%) and the highest solid loss of 2.26% was observed in P4 pasta. The wheat pasta (P1) recorded a solid loss of 2.1%. Thus a slight decrease in solid loss was observed in P3 sample which was added with millet flour. Similar trend of solid loss was reported by Petitot *et al*. (2010) for legume flour based pasta and for pigeon pea flour based pasta (Torres *et al.*, 2007). Statistical analysis indicated that various combination of raw materials showed significant (p<0.0001) effect on solid loss.

4.1.1.3 Swelling power (g/g)

The swelling power was determined by methodology explained in 3.4.3. The swelling power of various pasta products during cooking varied from 1.46 to 1.84 (g/g) which is shown in Table 4.1. The highest swelling power of 1.84 g/g was observed in (P4) pasta and the least value 1.46 g/g was observed in (P5). The control sample *i.e.*, wheat pasta (P1) had a swelling power of 1.58 g/g. Swelling power has been directly related with the presence of starch which indicates the ability to absorb water and increase in size (Dendy *et al.*(1993), Kumari and Sangeetha (2013), this might be the reason for more swelling in corn added pasta (P4 and P6). ANOVA also indicated combination of raw materials had significant effects on swelling power of pasta. Similar results were recorded by Gopalakrishnan *et al*. (2011) for sweet potato based pasta (1.4-1.75 g/g).

4.1.1.4 Water absorption ratio (g/g)

Water absorption ratio was determined according to the methodology 3.4.4. The water absorption ratio of various pasta products during cooking varied from 1.68 to 2.06 (g/g) which are presented in Table 4.1. The highest water absorption ratio of 2.06 was observed in (P3) pasta and the least value 1.68 (g/g) was observed in control sample *i.e.*, (P1). Combinations of different raw materials have significant (p<0.0001) effect on WAR of pasta. Hummel (1966) reported that, good quality macaroni products should absorb at least twice their weight after boiling in water. Similar results were obtained in the present study where weight of uncooked pasta samples increased almost twice after boiling. There is an increase in water absorption ratio with increase in millet flour content in pasta, since millet flour contains non-gluten proteins and more starch. This might have resulted in high hydration of starch leading to increase in weight of cooked pasta. Similar type of behaviour was observed for legume flour based pasta (Petitot *et al.* 2010).

4.1.2. Moisture content (% w.b.)

The moisture content of various combinations of pasta was found to be in the range 4.38 to 5.76 (% w.b.) as shown in Table 4.1. Maximum moisture was found in wheat flour added (P5) pasta and the lowest moisture content was recorded in ragi added (P6) pasta. Statistical analysis indicated that various combination of raw materials on moisture content showed significant effect ($p<0.0001$). The moisture content recorded for all the combinations were safe for storage.

Table 4.1 Cooking quality of millet fortified tuber based pasta products

Combinations	**Cooking time (min)**	**Solid loss (%)**	**Swelling power (g/g)**	**WAR (g/g)**	**Moisture content (% w.b.)**
P1(Control)	12.15	2.1	1.58	1.68	5.34
P2	12.05	2.08	1.54	1.81	4.53
P3	8.45	1.23	1.5	2.06	4.63
P4	9.25	2.26	1.84	2.0	5.4
P5	9.35	2.09	1.46	1.78	5.76
P6	8.32	1.80	1.76	1.8	4.38

4.1.3 Physical properties of millet fortified tuber based pasta

The physical properties namely expansion ratio and bulk density for six combinations of pasta products were determined and results are discussed under this heading.

4.1.3.1 Expansion ratio

The expansion ratio of pasta was determined by the procedures described in 3.5.1. The expansion ratio of various pasta products varied from 2.36 to 3.61 (Appendix D1). The highest expansion of 3.61 was observed in P6 pasta and the least value of 2.36 was observed in control sample *i.e.*, P1 as shown in Fig. 4.1 (a). Expansion ratio decreases with increasing level of legumes might be due to the higher fibre, protein and lower starch content of the processed material (Wojtowicz and Moscicki, 2014).

4.1.3.2 Bulk density (g/ml)

The bulk density was determined by methodology explained in 3.5.2. Bulk density (BD) of the extruded pasta samples varied between 0.29 and 0.37 g/ml for different samples as shown in Fig 4.1 (b). The bulk density of P1 pasta (control) was found to be highest 0.37 g/ml and lowest bulk density of 0.29 g/ml was found in ragi added (P6) pasta. The addition of millet flour resulted in decreased bulk density of the extruded pasta. These findings were in agreement with the reported value (0.281-0.301 g/ml) by Chanu and Jena (2015). The analysis of variance indicated that the combination of various flour on the bulk density showed significant ($p<0.0001$) effect.

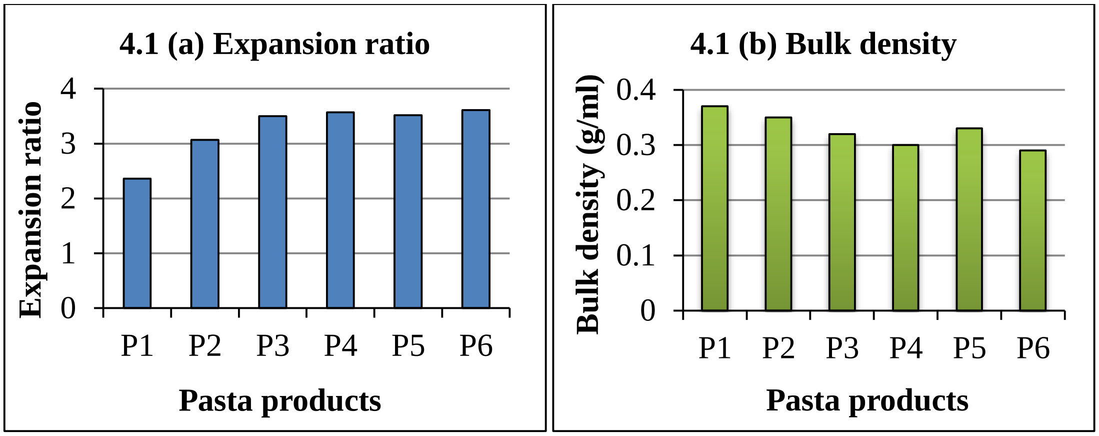

Fig. 4.1 Physical properties of millet fortified tuber based pasta products

4.1.4 Engineering properties of millet fortified tuber based pasta products

The engineering properties namely colour and texture for six combinations of pasta products were determined and results are given under the following headings.

4.1.4.1 Colour characteristics of pasta

The colour values of cooked and uncooked pasta samples were estimated using a colorimeter. The L*, a* and b* values of the developed pasta samples are presented in Appendix (D2). From Fig. 4.2 (a-b), it was inferred that the highest L* value (brightness) of 51.1 and 57.45 for uncooked and cooked pasta samples was found for P1 respectively followed by sample P2 which can be explained due to absence of millet and tuber flour. This increase in lightness in cooked sample might be due to colour loss during cooking. Highest a* value (redness) of 7.31 and 5.7 for both uncooked and cooked pasta samples was observed with the P4 and lowest value of 4.77 and 3.46 for both uncooked and cooked samples was observed in P2 respectively. The b* value (yellowness) was highest with the control (P1) sample of 15.64 and 16.58 for both uncooked and cooked samples respectively and lowest of 7.56 and 7.03 for both uncooked and cooked samples was observed in P3, this might be due to highest amount of ragi flour in both uncooked and cooked pasta samples.

High value of b* is especially desirable for pasta colour, which was high for control. However, due to brown colour of millet flour and yam flour yellowness of pasta samples was masked. Thus a decreasing trend in b* values was observed in case of millet and tuber flour added samples. These results are in agreement with the findings of Chanu and Jena (2015) for millet fortified pasta. The analysis of variance indicated that the effect of various combinations of raw material on the product colour were significant ($p<0.0001$).

4.1.4.2 Textural analysis of pasta

Texture has been defined as one of the important attribute of pasta and textural characteristics are recognized as more important for consumers (Brennan and Tudorica (2007). Firmness (N) values of the uncooked and cooked pasta products varied between 29.92 - 48.44 N and 0.431 - 1.085 N respectively for different samples, which are presented in the Fig. 4.2 (c - d). The high value of 48.44 N and 1.085 N was found in uncooked and cooked sample of P5. The lowest value of 29.92 and 0.431 N for both uncooked and cooked pasta samples was observed in P3 pasta. It might be due to the dilution of gluten strength by the addition of non gluten millet flour which interrupts and weakens the overall structure of pasta. This was in agreement with the study conducted by Krishnan and Prabhasankar (2010) for durum wheat pasta incorporated with sprouted finger millet and green banana flours. Statistical analysis indicated that various combination of raw materials on product texture data showed highly significant ($p<0.0001$).

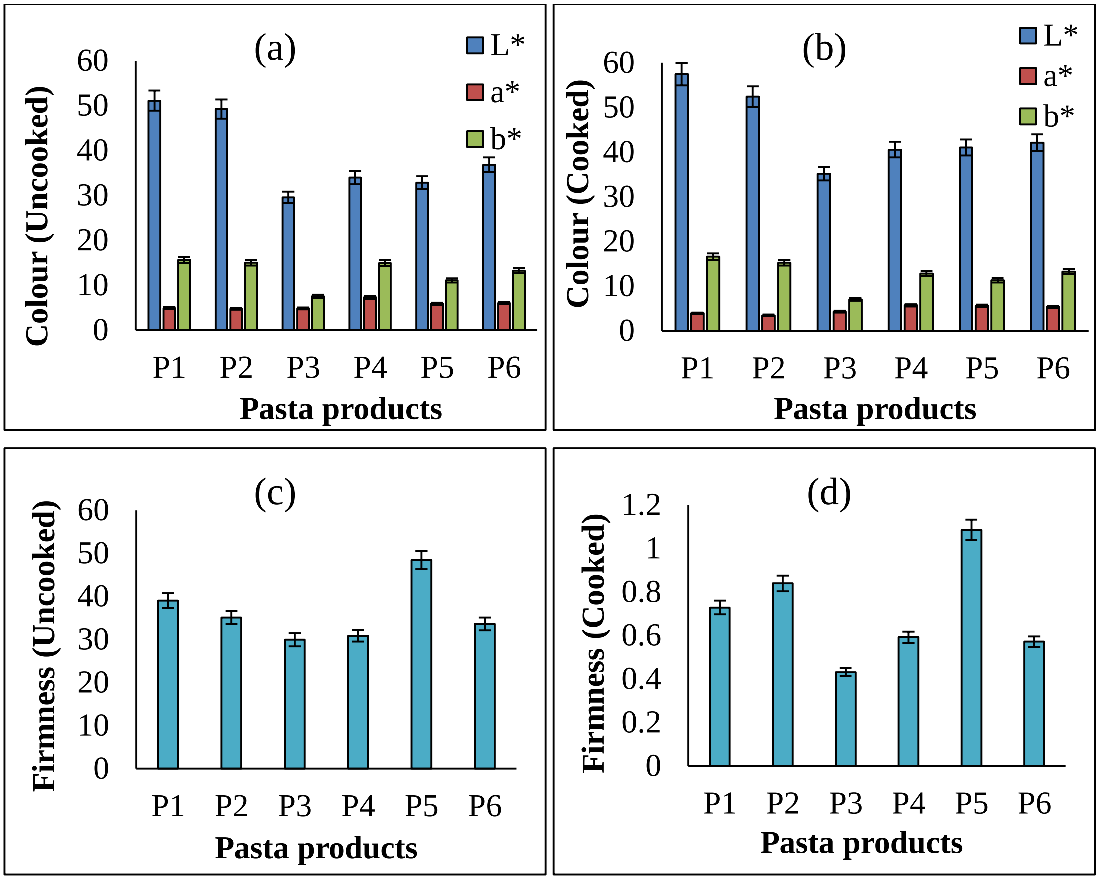

Fig. 4.2 Engineering properties of millet fortified tuber based pasta product

4.2 Storage studies of millet fortified tuber based cold extruded pasta products

The selected millet fortified pasta products prepared from various combinations were stored in LDPE (400 gauge) bags at ambient conditions for a period of three months. The changes in qualities of pasta products are presented below.

4.2.1 Cooking quality of cold extruded pasta products during storage

The cooking quality namely, cooking time, solid loss, swelling power and water absorption index of the millet fortified tuber based pasta products were analyzed at an interval of one month and results are given below under various headings.

4.2.1.1 Cooking time

The effect of storage on cooking time of pasta products are shown in Fig. 4.3 (a). From the figure, it is seen that cooking time of pasta steadily increased from 12.15 to 12.55 min in the control sample (P1) and 8.32 to 8.55 min for P6 pasta during 3 months of storage. Though the cooking time increased with storage time, the effect was not significant. The same trend was observed with all the pasta products. These results are in agreement with the findings of Kaur *et al.* (2012) for cereal bran enriched pasta.

4.2.1.2 Solid loss

The effect of storage on solid loss of pasta products are shown in Fig. 4.3 (b). From the figure, it can be observed that solid loss of pasta steadily increased with the storage period in all the combinations. Highest solid loss was recorded in case of P4 (2.26 to 2.35%) and lowest in P3 pasta (1.23 to 1.36%) during 3 months of storage. Results of present study showed that storage period had no significant effect on solid loss of various combinations of pasta products. The pasta prepared from millet and tuber based flour exhibited a stable and better cooking quality during 3 months of storage period. This was in agreement to the studies conducted by Pinarch *et al.* (2004) for storing macaroni samples.

4.2.1.3 Swelling power

The effect of storage on swelling power of pasta products are shown in Appendix D3. From the Fig 4.3 (c), it is seen that swelling power of pasta products increased during storage but the effect was not significant. Throughout the storage period maximum value of swelling power was observed in 1.84 to 1.96 g/g in P4 and minimum value of 1.46 to 1.49 g/g for P5 pasta. The variation was statistically non significant. Similar findings have been reported by Pinarch *et al.* (2004), who stated that volume increase was significantly affected by type of macaroni, but storage period had no significant affect on swelling power.

4.2.1.4 Water absorption ratio

The effect of storage on water absorption ratio of pasta products are shown in Fig. 4.3 (d). It was observed that the water absorption ratio of pasta products increased with the storage period but the effect was not significant. Throughout the storage period maximum value of water absorption ratio was observed in P3 (2.06 to 2.12 g/g) and minimum of 1.68 to 1.75 g/g for control (P1) pasta. This might be due to high percentage of millet flour in P3. Since millet flour contains non-gluten proteins and more starch it may have resulted in high hydration of starch leading to increase in weight of cooked pasta. This was in agreement to the storage studies of millet pasta Chanu and Jena (2015).

4.2.2 Effect of moisture content during storage

The moisture content of pasta samples before and after storage for three month in LDPE package is presented in Appendix D4. It was observed that after three months of storage, the moisture content of products increased in all the samples (Fig. 4.4). For a given storage period, the moisture migration was maximum in P5 (5.76 to 7.1%) and P6 had minimum of 4.38 to 5.12%. Similar trend was observed with all other millet fortified tuber based pasta products during storage. Statistical analysis indicated that storage period had significant effect ($p<0.0001$) on moisture content of stored pasta. These results were in agreement with the findings of Srirajrajeshwari and Mamatha (1999) and Sudha devi *et al.*, (2014) who studied the effect of moisture on stored pasta. The increased moisture content of stored pasta was due to the migration of moisture through the packaging material used. Hence, a better packaging design or material could be used for storage of pasta.

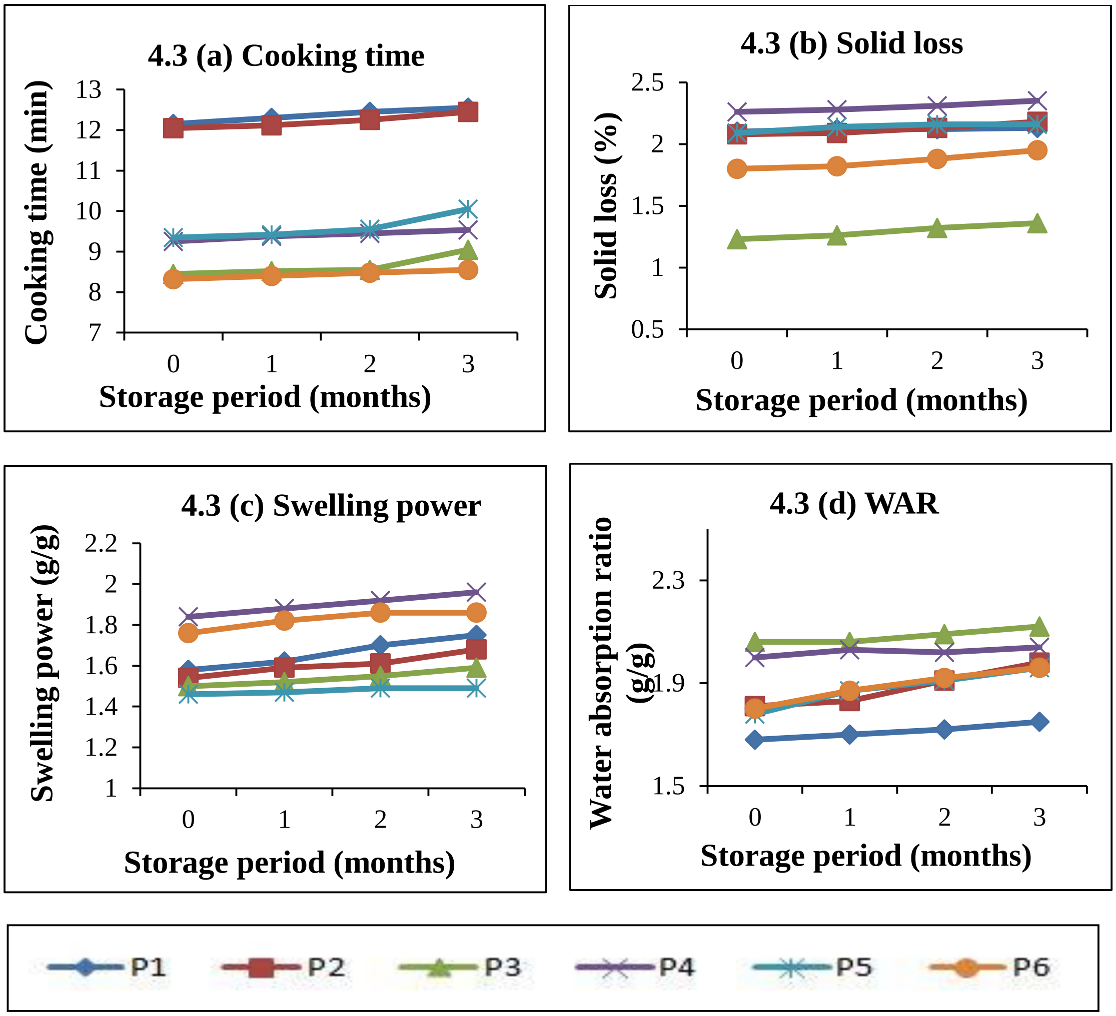

Fig. 4.3 Effect of cooking quality of cold extruded pasta products during storage

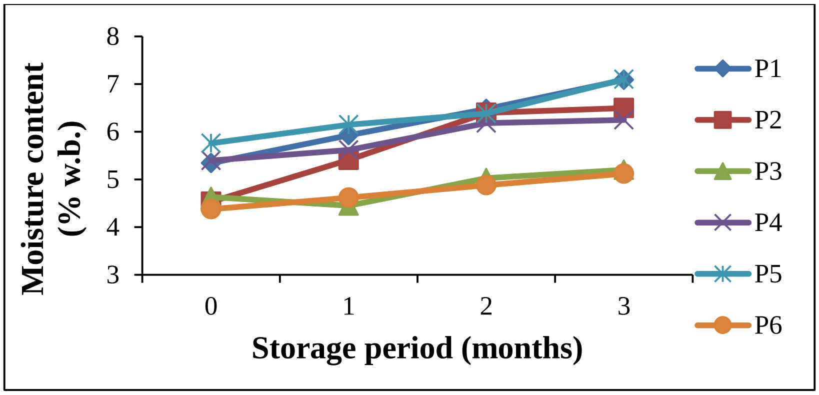

Fig. 4.4 Effect of moisture content of pasta products during storage

4.2.3 Physical properties of cold extruded pasta products during storage

The physical properties namely expansion ratio and bulk density of the millet fortified tuber based pasta products were analyzed at an interval of one month of storage and results are discussed hereunder.

4.2.3.1 Expansion ratio

The effects of storage on expansion ratio of pasta products are shown in Appendix D5. It was observed that expansion ratio of pasta products increased with the storage period but with very little difference. During storage period, maximum expansion ratio was observed in P5 (3.7 to 3.75) and minimum value of 2.36 to 2.4 for control (P1) pasta (Fig. 4.5 (a)). The variation was statistically non significant during storage period. Lesser expansion in P1 might be due to the higher fibre, protein and lower starch content of raw material. The results obtained were in agreement with the studies published by Wojtowicz and Moscicki (2014) and Pinarch *et al.* (2004).

4.2.3.2 Bulk density

The effects of storage on bulk density of pasta products are shown in Fig. 4.5 (b) and it is seen that during storage period bulk density of pasta increased but with very little difference. Throughout the storage period maximum value of bulk density was observed in P1 (0.41 g/ml) and minimum value of bulk density for P6 (0.32 g/ml) pasta after a storage period of three months (Appendix D5). The variation was statistically non significant during storage period. The results obtained were in agreement with the studies published by Ogunlakin *et al.* (2012).

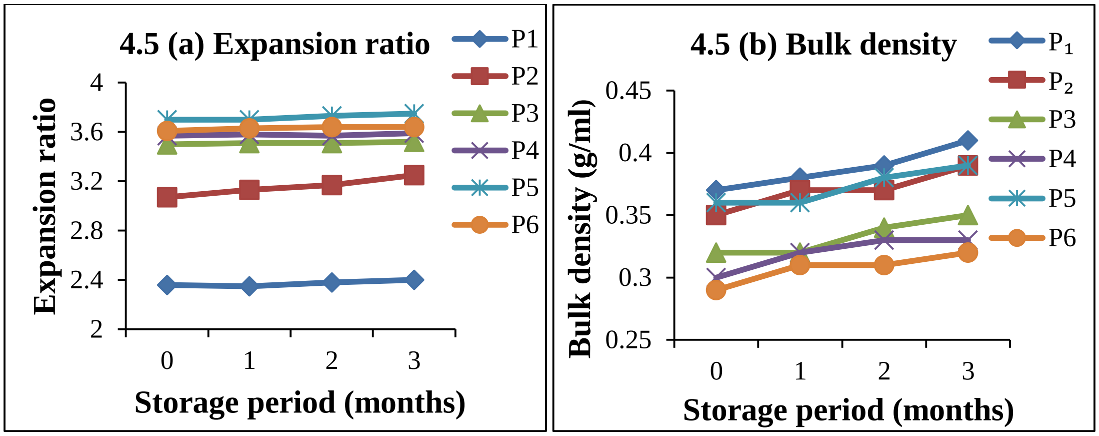

Fig. 4.5 Effect of physical properties of cold extruded pasta products during storage

4.2.4 Engineering properties of cold extruded (pasta) products during storage

The engineering properties namely, colour and texture of millet fortified tuber based pasta products were analyzed at an interval of one month and results are given under following headings.

4.2.4.1 Colour

Colour is an important factor for assessing the visual quality and market value of food products. The influence of colour values (L*, a*, b*) of different pasta products during ambient storage is presented in Appendix D6. Colour values were measured for both cooked and uncooked pasta samples. From Fig 4.6 (a and d), it was inferred that during storage of pasta, P1 and P2 samples showed increasing trend in L* value for both uncooked and cooked samples. In case of other samples there was a decreasing trend in L* value for both uncooked and cooked samples. Results of present study showed that storage period had no significant effect on L* value and the results obtained were in conformation with the studies published by Gull *et al.* (2016) and Alfia *et al.* (2014).

From Fig. 4.6 (b and e), it was inferred that during storage a* value of uncooked P3 sample showed increasing trend, whereas in remaining all the samples a* value decreases. This was in coincidence with the studies of Petitot *et al*. (2010), while faba bean flour was incorporated into semolina pasta, an increase in a* colour value was observed. During three months storage there was a change in a* value in all the samples but variation was statistically not significant. This was in agreement to the studies of Alfia *et al.* (2014).

From Fig 4.6 (c and f), it was seen that during storage of pasta, uncooked pasta showed increasing b* value in P1, P2 and P3 sample and decreasing b* value in remaining samples whereas, in cooked pasta samples b* value increased during storage in P1, P2, P3 and P4 and decreased in other pasta samples. The ANOVA indicated that there was no significant effect on b* value of pasta. This was in agreement to the trend reported by Alfia *et al.* (2014).

4.2.4.2 Texture

Firmness of both uncooked and cooked pasta samples are represented in Appendix D7. It can be noticed from the Fig. 4.7 (a-b) that, minimum value of firmness for both uncooked (31.05 N) and cooked pasta samples (0.46 N) was observed in P3. The maximum value of 51.27 N and 1.14 N was found in uncooked and cooked sample of P5. This was in confirmation with the studies of Carini *et al.* (2014). During storage period there was a slight increase in firmness value but the effect was not significant among different combinations of pasta products. This was in agreement to the studies of Yadav *et al.* (2014) for wheat-pearl millet composite pasta.

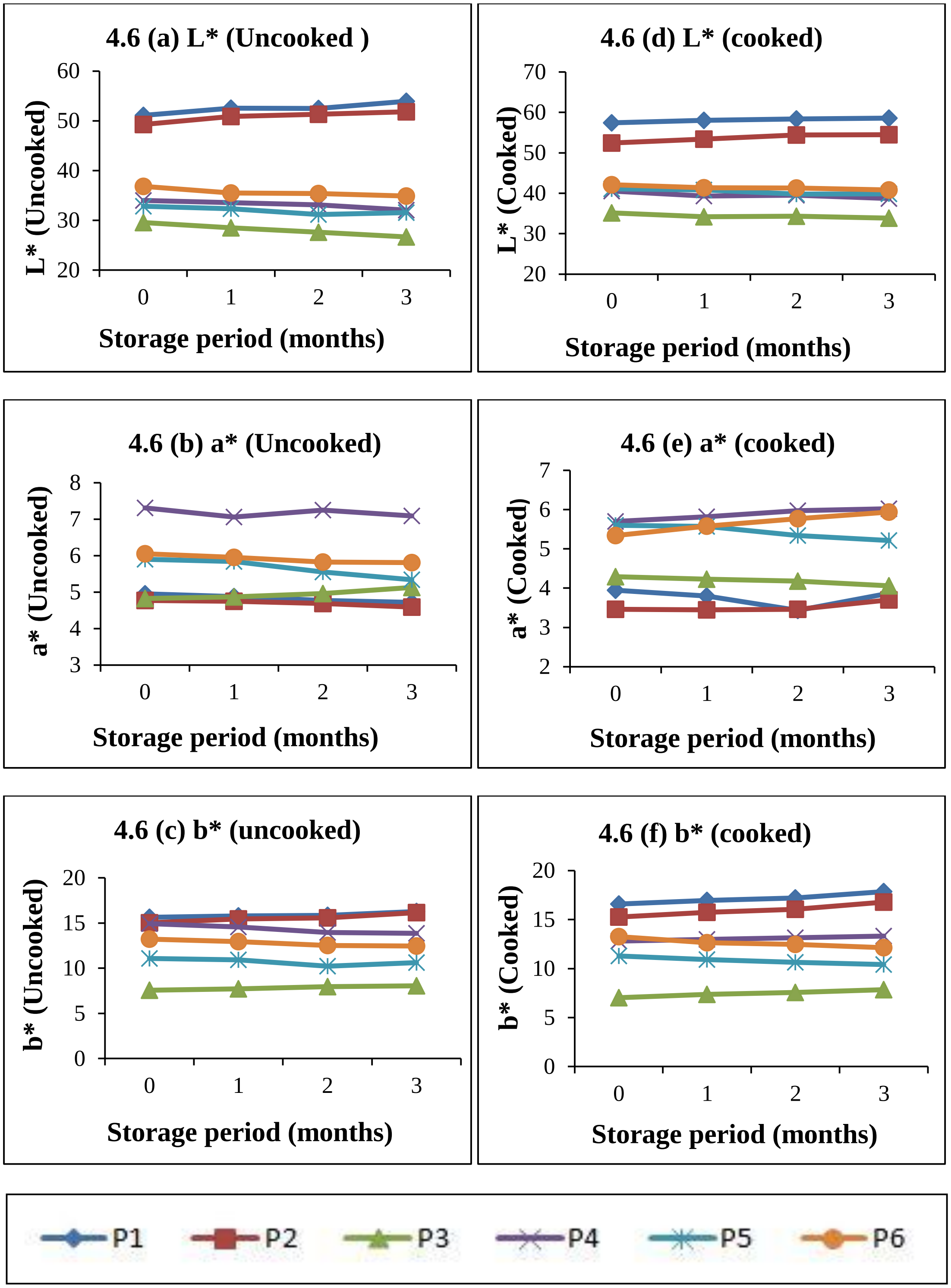

Fig. 4.6 Colour of cold extruded (pasta) products during storage

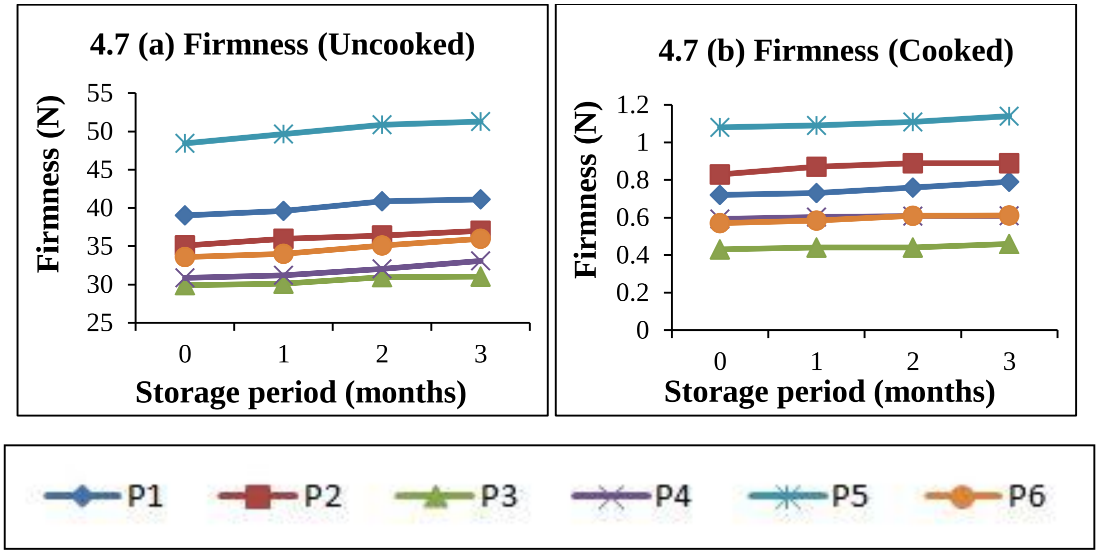

Fig. 4.7 Texture of cold extruded (pasta) products during storage

4.3 Sensory evaluation and optimization of cold extruded pasta product

Sensory analysis denotes the acceptability of the product. Acceptability of pasta was judged, on a nine-point hedonic scale as described in session number III. The sensory analysis was performed before and after three months of storage on the basis of colour, flavor, texture, taste and overall acceptability of the developed pasta product. The six combinations of pasta are kept for sensory analysis is shown in Plate 4.1. The sensory evaluation of the pasta product revealed that there were significant differences among the combinations for the organoleptic qualities.

The quality was judged by the consumer panel team consisting of twelve trained members. Overall acceptability of pasta varied from 6.83 to 8.0. The average scores of pasta product for each characteristic were given in Table 4.2. There is no significant difference was observed after three months of storage, P1 (Control) sample was mostly accepted by sensory panel (overall acceptability 8.0). The second best combination selected by sensory panel was P6 *i.e.*, $Rg_{25}:C_{20}:A_{25}:Ey_{10}:Py_{15}:D_3:G_2$ with overall acceptability of 7.61 as shown in Fig. 4.8. Analysis of variance reveals that the overall acceptability of various extrudate was significant ($p<0.0001$).

Attempts were made to develop a product which would have highest score in sensory acceptability so as to get better market acceptability, minimum cooking time, minimum moisture content, maximum expansion, minimum bulk density, maximum water absorption ratio, maximum swelling power, minimum solid loss, maximum colour value and minimum hardness (Appendix D8). Under these criteria, P6 *i.e.*, $Rg_{25}:C_{20}:A_{25}:Ey_{10}:Py_{15}:D_{3}:G_{2}$ was found as optimum. The response predicted by the Design-Expert 7.0.0 software. Based on optimization and sensory evaluation, P6 sample is selected as a best combination out of all combinations under concern.

Table 4.2 Sensory analysis of millet fortified tuber based pasta products before storage

Combinations	Colour	Texture	Flavour	Taste	Overall acceptability
P1	8.91	7.52	7.35	7.61	8
P2	8.32	7.67	6.82	6.41	7.16
P3	6.05	6.82	6.52	7.54	6.83
P4	7.14	6.41	7.11	6.41	7.38
P5	6.38	6.52	6.76	6.77	7.21
P6	6.67	7.05	7.08	7.76	7.61

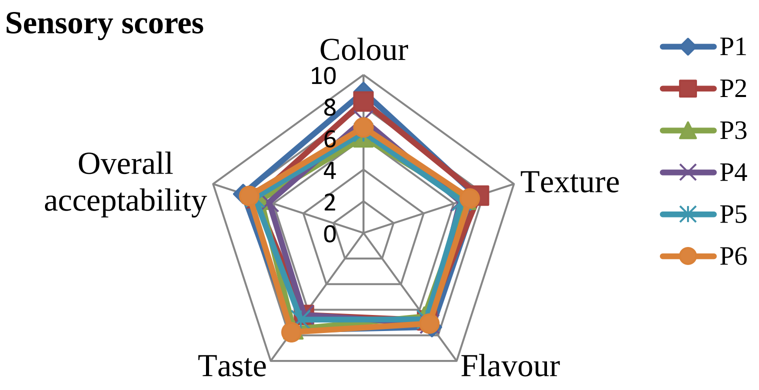

Fig. 4.8 Sensory scores for cold extruded (pasta) products after storage

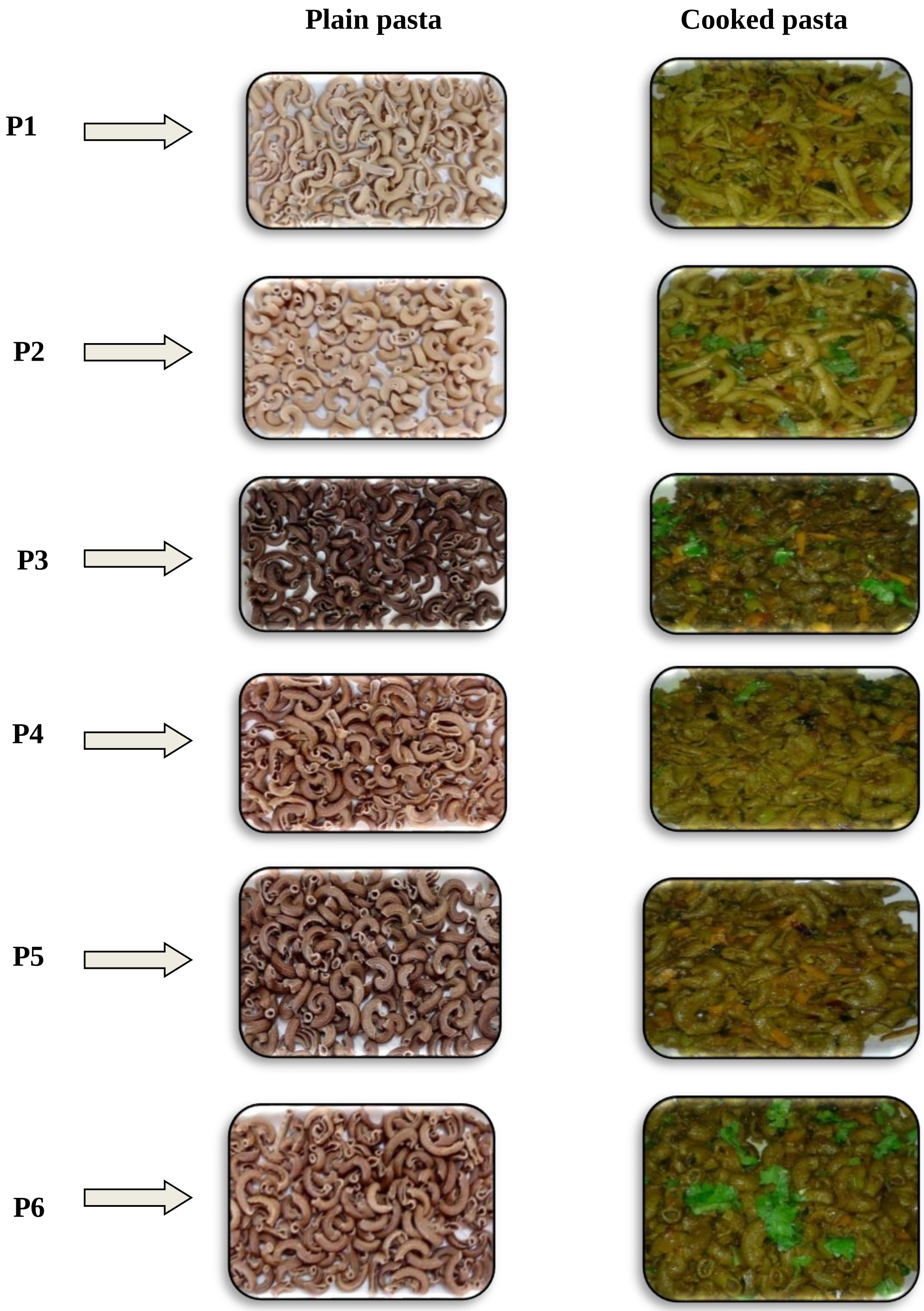

Plate 4.1 Cold extruded millet fortified tuber based pasta products

Experiment 2: Hot extrusion (RTE)

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

4.4 Development of millet fortified tuber based hot extruded RTE products

In the present study preliminary trials were carried out for optimizing the screw speed and feed moisture content. Based on earlier studies conducted by Kharat (2013); Garber *et al.* (1997); Charunuch *et al.* (2014) three screw speeds *viz.,* 300, 350 and 400 rpm and three feed moisture content *i.e.,*12.5, 15 and 17.5% was selected for preliminary experiments. Initially corn flour was used for extrusion at constant temperature of 100°C with three different screw speeds and feed moisture content. Considering the results of preliminary experiments, best conditions (screw speed - 350 rpm and 17.5% - feed moisture content) were selected based on high expansion ratio and low bulk density (Table 4.3 and Table 4.4). Three temperatures *viz.,* 100, 110 and 120°C have been considered based on the works done by Sudha devi, (2012), Kharat, (2013) and Omohimi *et al.* (2013) for further studies.

Table 4.3 Preliminary trials conducted at 15% MC with different screw speeds

15% moisture content		
Screw speed (rpm)	Expansion ratio	Bulk density (g/cm^3)
300	3.68	0.11
350	3.85	0.08
400	3.61	0.13

Table 4.4 Preliminary trials conducted at 350 rpm with different feed MC

Screw speed - 350 rpm		
Feed MC (%)	Expansion ratio	Bulk density (g/cm^3)
12.5	3.36	0.92
15.0	3.75	0.84
17.5	4.10	0.074

Ready to eat (RTE) expanded products were produced using millet-tuber grits combinations under the same operating conditions of the twin screw extruder (*i.e.*, 350 rpm - screw speed and 17.5% - moisture content) with three different temperature (*i.e.*,100, 110 and 120°C). The resultant 21 extrudates from different combination of raw materials with three temperatures were organoleptically tested and results are presented in Table 4.5.

4.5 Sensory evaluation of millet fortified hot extruded RTE products

Sensory evaluation indicates the acceptability of the product and it was judged on a nine-point hedonic scale. The sensory evaluation was carried out on the basis of colour and appearance, flavor, taste, crispiness and overall acceptability of the developed product. The sensory evaluation of the extruded product showed that there were significant differences among the treatments for the organoleptic qualities. Considering the results of sensory evaluation, among the 21 treatments tried, seven combinations were selected (Plate 4.2). The selected treatments were the one which were of good taste and overall acceptability and were given in Table 4.6.

Table 4.5 Mean sensory score card for millet fortified hot extruded RTE products

Treatment	Colour & appearance	Flavour	Taste	Crispiness	Overall acceptability
P1T1	7.6	7.5	6.7	6.45	7.2
P1T2	7	7	7.0	6.23	7.58
P1T3	7.4	8	6.8	6.91	7.35
P2T1	7.5	7	7.2	7	7.31
P2T2	6.9	7.5	7.5	6.55	7.6
P2T3	7.5	8	7.3	6.82	7.47
P3T1	6.5	7	6.8	6.55	6.7
P3T2	7	6	6.9	7.09	7.1
P3T3	6.9	7.5	6.5	6.55	6.9
P4T1	7.3	7	7.0	7.65	8.12
P4T2	6	6.5	6.5	7.27	7.9
P4T3	6	7	6.7	7.36	7.3
P5T1	6.4	6	7.0	7.82	7.5
P5T2	5.9	6.5	6.6	7.49	7.3
P5T3	6	7	6.8	7.36	7.1
P6T1	7	6.5	7.5	7.49	7.2
P6T2	6.4	7.5	7.3	7.36	7.07
P6T3	6.3	7	7.1	7.45	6.8
P7T1	6.5	6.5	7.2	7.36	7.35
P7T2	6	7	7.1	7.64	6.94
P7T3	6	8	7.0	7.09	7.28
$p<0.05$	S	S	S	S	S

P1T2 P2T2 P3T2 P4T1

P5T1 P6T1 P7T1

Plate 4.2 Millet fortified tuber based extruded RTE products

Table 4.6 The selected millet fortified hot extruded RTE products

Combinations	Composition (%)	Temperature (°C)
P1T2	P1 (C100)	T2 (110)
P2T2	P2 (C_{50}:R_{50})	T2 (110)
P3T2	P3 (C_{50}:Rg_{50})	T2 (110)
P4T1	P4 (C_{60}:Ey_{15}:Py_{20}:D_5)	T1 (100)
P5T1	P5 (Rg_{60}:Ey_{15}:Py_{20}:D_5)	T1 (100)
P6T1	P6 (Rg_{20}:C_{25}:R_{25}:Ey_{10}:Py_{15}:D_5)	T1 (100)
P7T1	P7 (R_{60}:Ey_{15}:Py_{20}:D_5)	T1 (100)

4.6 Quality parameters of millet fortified hot extruded RTE products

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

4.6.1 Quality of the hot extrudates based on physical properties

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

4.6.1.1 Moisture content

The moisture content was calculated for all extrudates (seven) and results were in the range of 4.28 to 5.93% which is shown in Appendix E1. From Fig. 4.9 (a) it was observed that, the moisture content was minimum for P4T1 and maximum for P5T1. Statistical analysis indicated that various combination of raw materials showed significant effect ($p<0.0001$) on moisture content. The moisture content recorded for all the combinations were safe for storage. The observed values were in conformation with the trend reported by Sharma *et al.* (2015) for millet-cowpea based extruded snacks.

4.6.1.2 Expansion ratio

Expansion is an important physical property of the developed RTE food. Starch is the main component in cereals which plays an important role during expansion process (Kokini *et al.*, 1992). The expansion ratio of millet fortified tuber based RTE products varied from 2.685 to 4.074 are given in Appendix E1. The maximum expansion ratio (4.074) was observed for P1T2 combination *i.e.*, 110°C temperature whereas, minimum expansion ratio (2.685) was observed for P5T1 *i.e.*, 100°C temperature (Fig. 4.9 (b)). Significant variation ($p<0.0001$) was noticed as regards expansion ratio for the seven combinations under consideration.

This decrease in expansion ratio might be due to the high level of finger millet and yam flour, which is rich in fibre and protein. This lower expansion can also be explained on the basis that, fibre can rupture cell walls and prevent air bubbles from expanding to their maximum potential. These findings were in agreement with the reported value of 2.9 by Sawant *et al.* (2013). 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).

The extruded product expansion increased with increase in the temperature. High temperature results in larger gelatinization of starch. Case *et al.* (1992) reported that, volume of the extrudate increases with increase in starch gelatinization. The increase in temperature increased the degree of superheating of water in the extruder and leading to slightly greater expansion. Similar findings were reported by Ding *et* *al*. (2006) for wheat based expanded RTE snacks and Camire and King (1991) for corn meal based extruded products.

4.6.1.3 Bulk density and True density (g/cm^3)

Bulk density which considers expansion in all the direction varies from 0.07 to 0.18 g/cm^3 and true density varies from 1.49-1.84 g/cm^3 which is presented in Appendix E1. It was observed that the minimum bulk density (0.07 g/cm^3) was observed for P1T2 and maximum bulk density (0.18 g/cm^3) was observed for P5T1. The minimum true density (1.49 g/cm^3) was observed for P1T2 and maximum true density (1.84 g/cm^3) was observed for P5T1 combination (Fig. 4.9 (c-d)). Significant difference ($p<0.0001$) was noticed as regards bulk density and true density for the combinations under concern.

Increasing level of temperature (110°C), the extrudates exiting the die lose more moisture and become lighter in weight resulted in reduced bulk density of extrudate (Koksel *et al.*, 2004). High temperature resulted in the larger extent of starch gelatinization thus the extrudates volume increased and the bulk density decreased (Case *et al.,* 1992). In addition, Mercier and Feillet (1975) reported that the melt viscosity decreases with an increase in temperature. The reduced viscosity would help the bubble growth during extrusion which results in increased expansion ratio of extrudates and ultimately reduction in the bulk density. Similar findings were reported by Park *et al.* (1993) for single screw extrusion of defatted soy flour, corn starch and raw beef blends.

In the present study, increase in bulk density with high level of finger millet flour might be due to the increase in fibre content of feed material. This increased in bulk densities could be due to the presence of fibre content which ruptures the cell walls before the gas bubbles had expanded to their full potential (Lue *et al*., 1991) and also due to partial moltening of starch granules adhered to the cellulosic walls leading to a composite wall of cellulose, gelatinized starch and cellular protein. Formation of this complex wall might have restricted the product's expansion ability (Chang *et al*., 1998). Similar results were obtained by Jin *et al*. (1994) for soy based extrudates and Yanniotis *et al*. (2007) for wheat fibre based extrudates.

4.6.1.4 Porosity

The porosity determination of the extrudates was done with the methodology explained under 3.9.4. The porosity value of extrudates ranged from 58.3 to 77.5% and it is shown in Appendix E1. The maximum porosity (77.5%) was observed for corn extrudates (P1T2) combination *i.e.,* 110°C temperature whereas, minimum porosity (58.3%) was observed for treatment P5T1 *i.e.,* 100°C temperature as shown in Fig. 4.9 (e). The analysis of variance indicated that the effect of various combinations on porosity of extrudates were significant ($p<0.0001$).

The main reason for this increased porosity was due to the high expansion indices exhibited by the corn extrudates (P1T2) at elevated temperature. This was in concordance with the results obtained by Artz *et al*. (1990) and Harper and Jansen (1985).

4.6.1.5 Water activity (a_w)

The water activities of the extrudates were determined by methodologies explained in 3.10.4. 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 0.435 to 0.48 (Appendix E1). The maximum a_w (0.48) was observed for P7T1 combination *i.e.,* 100°C temperature whereas, minimum a_w (0.435) was observed for P1T2 combination *i.e.,* 110°C temperature as given in Fig. 4.9 (f). The result indicated that at elevated temperatures have low a_w, which signifies the safe range of the products for consumption (Linko *et al*., 1982). Significant variations were noted with respect to a_w of each combinations ($p<0.05$) taken for the study.

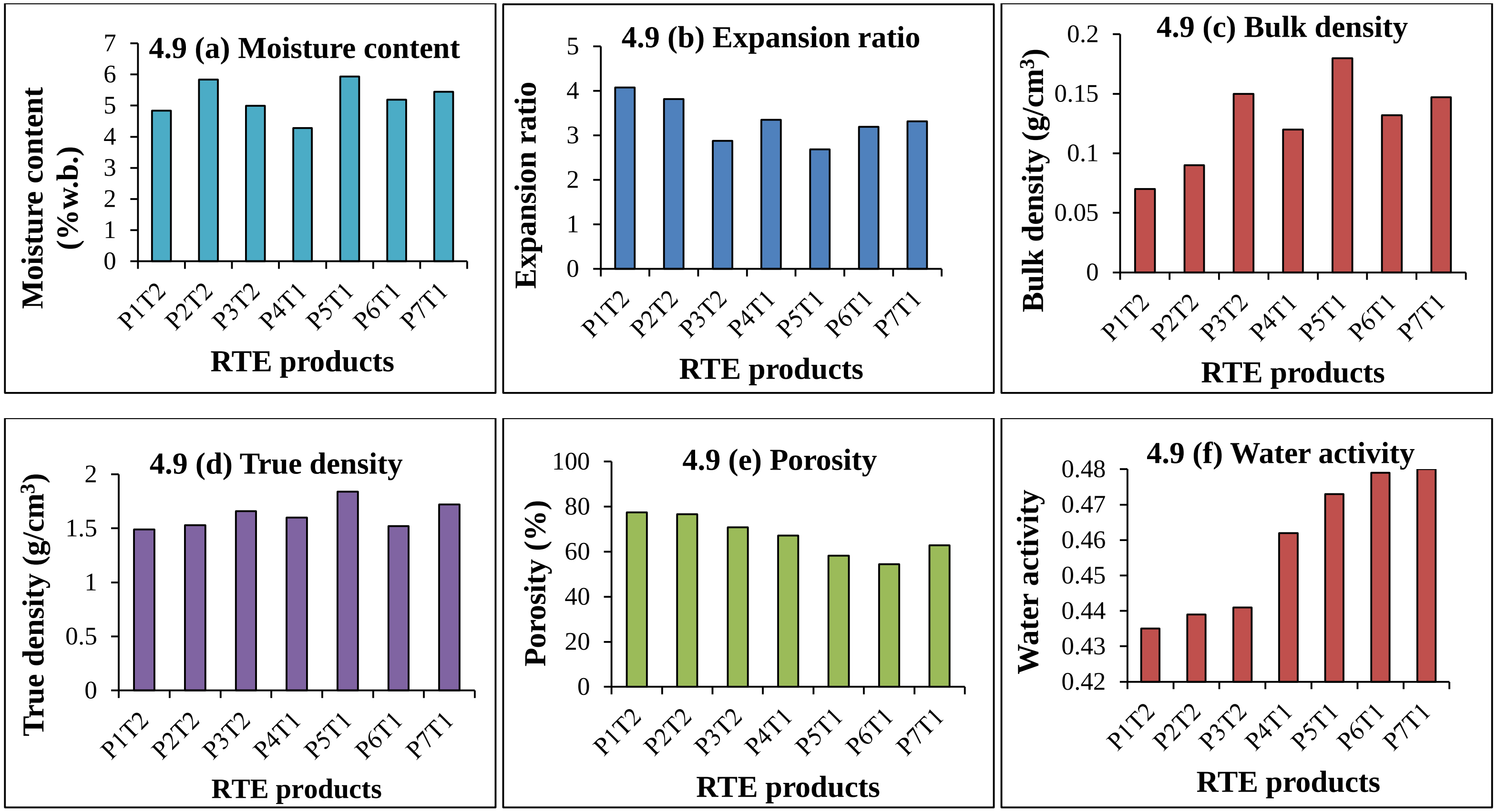

Fig. 4.9 Physical properties of millet fortified tuber based hot extruded RTE products

Water activities exhibited by all the combinations are shown in the Fig. 4.9 (f). The figure clearly shows that water activities of all treatments were safe for storage at a feed moisture of 17.5%. The values of water activity exhibited by the extrudates also confirmed with the necessary moisture for starch gelatinisation essential for efficient enzymatic hydrolysis. This was in agreement to the studies of Linko *et al*. (1982).

4.6.2 Quality of the extrudates based on functional properties

The functional properties of the extrudates determined by standard laboratory procedures as mentioned in chapter III and their results are discussed. Functional properties of the seven extrudates in terms of WSI and WAI are discussed.

4.6.2.1 Water solubility index (WSI %) and Water absorption index (WAI g/g)

Water solubility index indicates the degradation of molecular components, which measures the amount of soluble polysaccharides released from the starch after extrusion (Ding *et al*., 2005). It was observed that the WSI ranged from 13.9 to 24.7% (Table 4.7). The maximum WSI (24.7%) was observed for combination P5T1 *i.e.,* 100°C temperature whereas, minimum WSI (13.9%) was observed for combination P3T2 *i.e.,* 110°C temperature.

At low temperature (100°C) and high level of finger millet flour results in increased WSI of the extrudates. Temperature was inversely proportional to WSI *i.e.,* higher the extrusion temperatures, lower the WSI values. This was in conformation with the studies conducted by Divate *et al.* (2015) for finger millet based extrudates (4.24 to 8.85%). Similar findings were achieved by Gutkoski and El-Dash (1999) in extruded oat products.

Water absorption index indicates the amount of water absorbed by starch that can be used as an index of gelatinization of starch. In general, feed moisture content and temperature exert greater effect on the WAI of the extrudate by promoting gelatinization (Ding *et al.*, 2005). From Table 4.7, it was observed that the WAI varied from 4.11 to 6.16 g/g. The maximum WAI (6.16 g/g) was observed for combination P4T1 *i.e.*, 100°C temperature whereas, minimum WAI (4.11 g/g) was observed for combination P2T2 *i.e.*, 110°C temperature.

Table 4.7 Functional properties of hot extruded RTE products

Combinations	**Water solubility index (WSI %)**	**Water absorption index (WAI g/g)**
P1T2	14.2	4.57
P2T2	15.0	4.11
P3T2	13.9	4.35
P4T1	19.5	6.16
P5T1	24.7	4.76
P6T1	23.4	4.93
P7T1	21.6	5.7

It appeared that WAI decreased with increase in temperature. The increase in temperature leads to depolymerisation of amylose and amylopectin and resulted into the reduced water absorption capacity of the product (Smith, 1992 and Colonna *et al.*, 1989). According to Colonna *et al.* (1989), increased degradation of the molecular mass of the starch polymers could be the reason for lowered extrudate water absorption. Similar results were observed by Sobota and Rzedzicki (2009) for extruded product prepared using corn semolina and pea hulls blends.

Increase in corn content and decrease in temperature (P4T1) resulted in high WAI. This could be due to the fact that starch content in the feed material increases hydration rate of extrudate in water. Park *et al*. (1993) reported that higher the corn starch content in feed resulted in high water absorption (WAI) of final extruded products. Significant difference ($p<0.0001$) was noticed with regard to WSI and WAI for all the combinations under concern.

4.6.3 Proximate analysis of extruded products

The standard procedures were used for proximate analysis of extruded product as described in Chapter III. Proximate components in terms of protein, fat, carbohydrate and total energy were calculated as described above. Statistical analysis resulted with significant variations for all properties under concern.

Protein content of extrudates varied between 7.11 to 8.04% (Appendix E2). It was observed that the minimum protein content (7.11%) was recorded for the combination P1T2 *i.e.,* 110°C and maximum (8.04%) was observed in P6T1 *i.e.,* 100°C. The results showed significant ($p<0.0001$) variation with respect to each samples. Protein content of the extrudates decreased with the increase in temperature, it might be due to denaturation of protein at higher temperature. Low amount of protein was also due to the nitrogen losses in the course of extrusion by the formation of isopeptide bonds with simultaneous emission of ammonia (Kasprzak and Rzedzicki, 2008, Jhoe *et al.*, 2009). Similar results were obtained by Stojceska *et al.* (2008) for cauliflower by-products incorporated cereals based ready to eat expanded snacks. Incorporation of cereals, millet and tuber flour (P6T1) results in higher protein content of the extrudate.

Carbohydrate is the important component while assessing the quality and nutritional status of the extruded product. It is directly related to the acceptability of food product. Carbohydrate content of extrudates varied between 68.50 to 74.64%. It was observed that the minimum carbohydrate content (68.50 %) was recorded for the combination P1T2 *i.e.,* 110°C and maximum (74.64%) was observed in P5T1 *i.e.,* 100°C. The results showed significant ($p<0.0001$) variation with respect to each samples. The total carbohydrate content of the extruded product increased due to the decrease in process temperature and also due to the presence of yam and millet flour which is rich in starch. This may be because the degradation of starch at higher temperature. Similar findings have been reported by Camire and King (1991) for corn meal based extruded snacks.

Fat was found maximum in the case of P4T1 (3.49%) and minimum in case of P3T2 (2.30%). The fat content in the extrudates decreased as the temperature increased. This may be due to the burning of fat at high extrusion process temperatures. This variation in fat content during extrusion was caused by the formation of starch-lipid and protein-lipid complexes (Bhatnagar and Hanna, 1994 (a), 1994 (b), Singh *et al*., 2007).

From these proximate compositions, the total energy achieved by each samples was calculated with formula (Ekanayake *et al*., 1999) and found higher for P6T1(1482.38 kJ/100 g). The energy exhibited by these selected extrudates is displayed in Fig. 4.10 and the values for all the combinations are appended in Appendix E2.

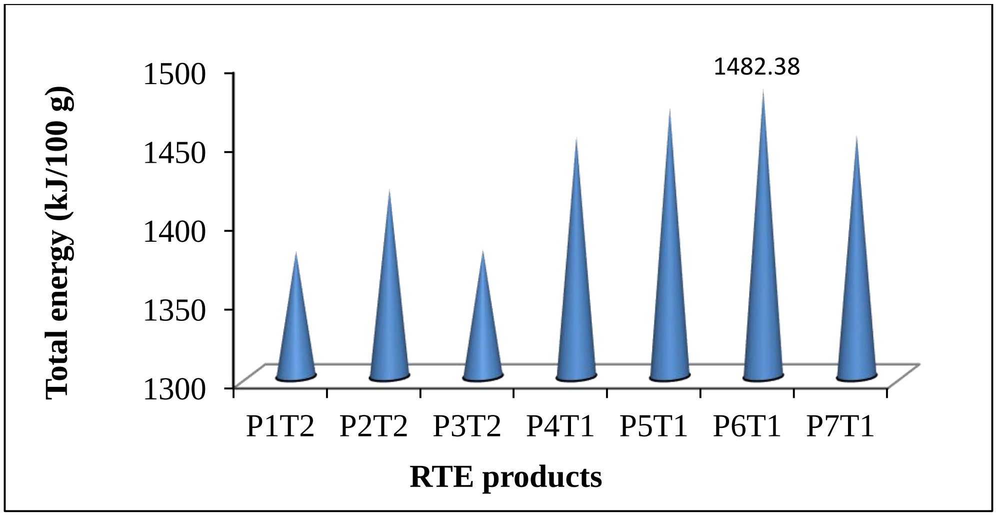

Fig. 4.10 Energy supplied by RTE products

4.6.4 Quality of the hot extrudates based on colour properties

The tri-stimulus colour values were calculated as per the methodologies discussed under 3.11.1. Significant variation ($p<0.0001$) was noticed as regard to L*, a* and b* values for the various combinations under concern.

4.6.4.1 Colour (L* value)

Colour is one of the most vital physical attributes of extrudate product. Colour of various combinations of extrudates varied from 48.59 to 71.72. The maximum colour L* (71.72) was observed for combination P2T2 *i.e.*, 110°C temperature whereas, minimum colour L* (48.59) was observed for combination P5T1 *i.e.*, 100°C temperature (Appendix E3).

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. Similar finding were reported by Camire and King (1991) for expanded corn meal and Ding *et al*. (2006) for rice-based snack.

There was a decrease in L* value with finger millet and yam flour. It might be due to brown colored pigment present in finger millet and yam flour. Similar findings were observed by Costa *et al.* (2009) for lycopene and soy protein incorporated extruded product and Altan *et al*. (2008) for extrusion of barley-tomato pomace blends.

4.6.4.2 Colour (a* value)

The a* value for various combinations of extrudates varied from 5.29 to 9.24. The maximum colour a* (9.24) was observed for combination P4T1 *i.e.,* 110°C temperature whereas, minimum colour a* (5.29) was observed for combination P1T2 *i.e.,* 100°C temperature (Appendix E3). It appeared that with increase in temperature, a* value of the extrudate decreased due to the loss of colour pigments at high temperature. Similar results were reported by Chaiyakul (2009) for rice based snack.

The results showed that there was an increase in a* value with finger millet and yam flour. It might be due to the dark colored pigment present in finger millet and yam flour. Similar findings were reported by Costa *et al.* (2009) for extruded snacks prepared from lycopene and soy protein and Altan *et al*. (2008) for extruded products of barley-tomato blends.

4.6.4.3 Colour (b* value)

The b* value for various combinations of extrudates varied from 20.33 to 35.66. The maximum colour b* (35.66) was observed for combination P1T2 *i.e.,* 110°C temperature whereas, minimum colour b* (20.33) was observed for combination P5T1 *i.e.,* 100°C temperature (Fig. 4.11). It was observed that with increase in temperature (110°C), increased the b* values as the degradation of pigments was accelerated at the high temperature (Altan *et al*., 2008; Altan *et al*., 2009; Ilo and Berghofer, 1999; Ali *et al*., 2008). An increasing addition of corn flour resulted in extrudate becoming more yellow, as recorded by increase in b* values.

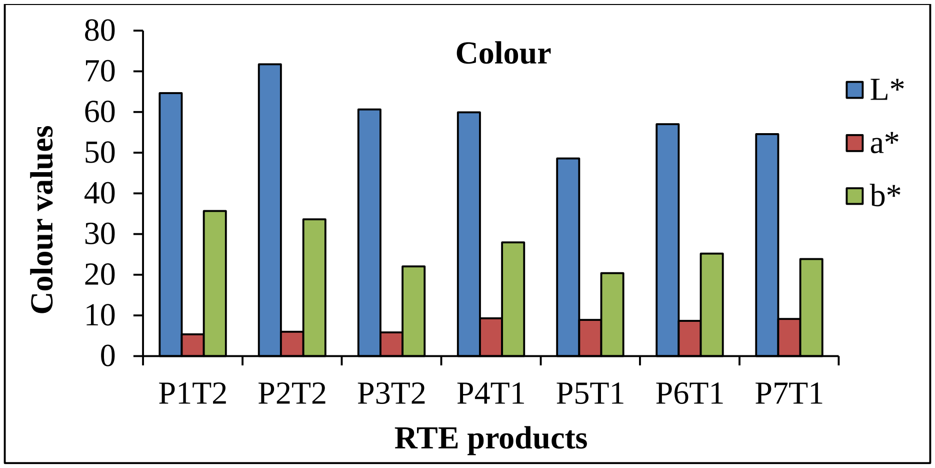

Fig. 4.11 Colour value for extruded RTE products

4.6.5 Quality of the extrudates based on textural properties

The textural properties of the extrudates were determined by the methodology described as per 3.11.2 and their results are discussed. Textural properties are discussed in terms of hardness, fracturability and crispness.

4.6.5.1 Hardness (N)

Hardness of the extrudate varied from 6.01 to 15.8 N. The minimum hardness (6.01 N) was observed for combination P1T2 *i.e.,* 110°C temperature whereas, maximum hardness (19.6 N) was observed for combination P5T1 *i.e.,* 100°C temperature (Appendix E4). Various combinations were found to have significant effect on extrudate hardness.

It was seen that, hardness of the extruded product decreased with an increase in temperature (Fig. 4.12 (a)). 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).

4.6.5.2 Fracturability (N)

Fracturability of the extrudate varied from 1.15 to 2.05 N. The minimum fracturability (1.15 N) was observed for combination P2T2 *i.e.,* 110°C temperature whereas, maximum fracturability (2.05 N) was observed for combination P5T1 *i.e.,* 100°C temperature as given in Fig. 4.12 (b). Various combinations were found to have significant effect on extrudate fracturability.

Temperature had significant effect on fracturability of the developed extruded product. However, increasing temperature decreases the fracturability of the extrudates. Similar results were obtained by Ding *et al.* (2005) for rice-based expanded snacks. Incorporating millet in the feed material and low level of yam flour content resulted in increased fracturability of the extrudate. This was in agreement with the work of Areas (1992) which explained as protein was added to starch rich flours, harder and less expanded products were obtained which results in ‘‘protein-type” extrudates with more value of fracturability.

4.6.5.3 Crispness (N)

Crispness of the extrudate varied from 26.52 to 59.85 N (Appendix E4). The minimum crispness (26.52 N) was observed for combination P5T1 *i.e.,* 100°C temperature whereas, maximum crispness (59.85 N) was observed for combination P1T2 *i.e.,* 110°C temperature as shown in Fig. 4.12 (c). Various combinations were found to have significant effect on extrudate crispness.

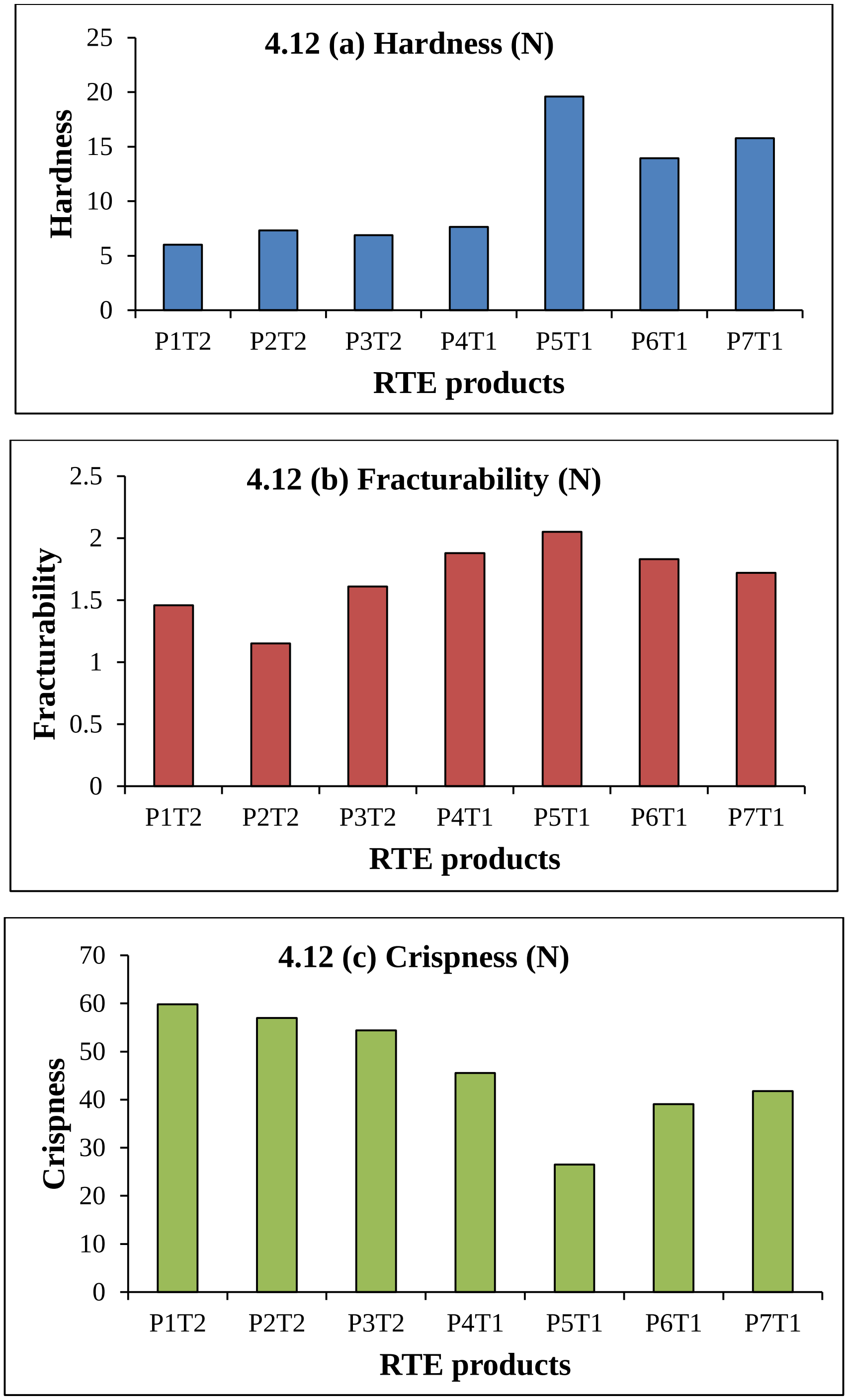

Fig. 4.12 Textural properties of millet fortified tuber based RTE products

Temperature had significant effect on crispness of the developed extruded product. At elevated temperatures extrudates showed maximum expansion with lower density and high crisp factor. Higher crispness was found in case of corn extrudates (P1T2) due to the higher amount of starch content compared with other combinations. The high amount of starch resulted in a product with more expansion which resulted in a softer and crispy product (Agulera *et al*., 1984). Lower crispness was found in P5T1 combination due to reduced starch content and compressed bubble growth would result in a dense product and reduced crispness of extrudate. This was in conformation with the studies conducted by Ding *et al.* (2005) for rice-based expanded snacks.

4.7 Storage studies of millet fortified tuber based 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 (moisture content, water activity, colour and textural properties) of developed RTE extruded products were analysed upto one month with an interval of 15 days and the results are given below.

4.7.1 Moisture and water activity of hot extruded RTE products during storage

The moisture content and water activity of the millet fortified tuber based hot extruded RTE products were analyzed at an interval of 15 days and results are given below under various headings.

4.7.1.1 Moisture content (% w.b.)

The moisture content of the developed hot extruded RTE products before and after storage for one month under MAP is presented in Appendix E5.

It is observed that after one month of storage, the moisture content increased slightly in all the products. For a given storage period, the moisture migration was maximum in P5T1 (5.93 to 6.24%) and P1T2 had minimum of 4.84 to 5.1% (Fig. 4.13 (a)). Increase in moisture content was associated with increase in fibre content (Akhtar *et al.,* 2008 and Elleuch *et al.,* 2011). Similar trend was observed with all other millet fortified hot extruded RTE products during storage.

Statistical analysis indicated that storage period had no significant effect on moisture content of stored RTE products. During storage the products absorb the moisture from the environment. An increase in moisture content in the RTE extruded snacks during storage was reported by Kuna *et al.* (2013).

4.7.1.2 Water activity

The water activity of the developed hot extruded RTE products before and after storage for one month under MAP is presented in Fig. 4.13 (b). It was observed that after one month of storage, the water activity of products increased slightly in all the samples. For a given storage period, the water activity was maximum in P7T1 (0.48 to 0.514) and P1T2 had minimum of 0.435 to 0.459. Similar trend was observed with all other millet fortified tuber based hot extruded RTE products during storage. However, no statistically significant difference was observed in water activity of extruded product during one month of storage period. This was in conformation with the studies of (Hussain *et al.,* 2015) for walnut kernel incorporated rice based snacks.

In general not much variation was observed in water activity of extrudates during one month of storage. As there was increase in temperature resulted in lower value of water activity. 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.

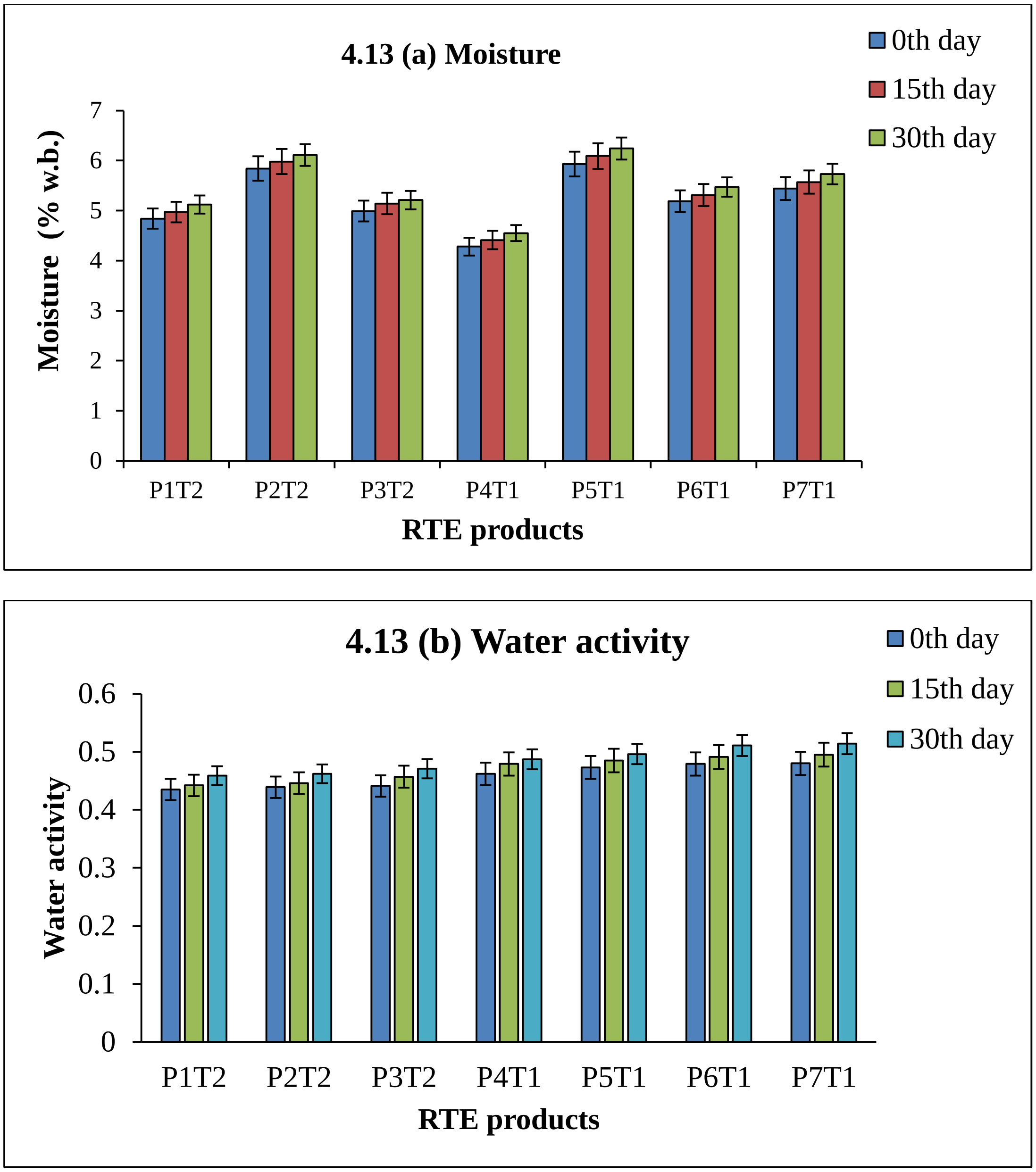

Fig. 4.13 Effect of storage period on moisture content and water activity of hot extruded RTE products

4.7.2 Colour of hot extruded RTE products during storage

The influence of colour values (L*, a* and b*) of different hot extruded RTE products during one month storage is presented in Appendix E6.

Colour values were measured for hot extruded RTE samples. From Fig. 4.14 (a), it was inferred that after one month of storage there was a decrease in L* value ikn all the combinations. For a given storage period maximum colour L* (71.72 to 70.91) was observed for combination P2T2 which could be explained due to absence of millet and tuber flour whereas, minimum colour L* (48.59 to 47.84) was observed for combination P5T1 due to presence of millet and tuber flours. Results of present study showed that storage period had no significant effect on L* value. Similar findings were observed by Altan *et al*. (2008) for extrusion of barley-tomato pomace blends.

Throughout the storage period maximum value of a* was observed in P4T1 (9.24 to 9.57) whereas, minimum colour a* (5.29 to 5.59) was observed for P1T2 combination are shown in Fig. 4.14(b). The results suggested that, during storage a* value of P1T2 and P4T1 products showed an increasing trend, whereas in remaining all the products a* value decreased. During storage there was a change in a* value in all the samples but variation is statistically not significant.

From Fig. 4.14 (c), it was inferred that that after one month of storage there was an increase in b* in P1T2 and P4T1 combinations and in remaining all the combinations there was a decrease in b* value. For a given storage period maximum colour b* was observed in P1T2 (35.66 to 37.18) and minimum colour b* (20.33 to 19.82) in P5T1 combination. An increasing addition of corn flour resulted in extrudate becoming more yellow, as recorded by increase b* values. However, due to brown colour of millet and yam flours, yellowness of RTE products was masked.

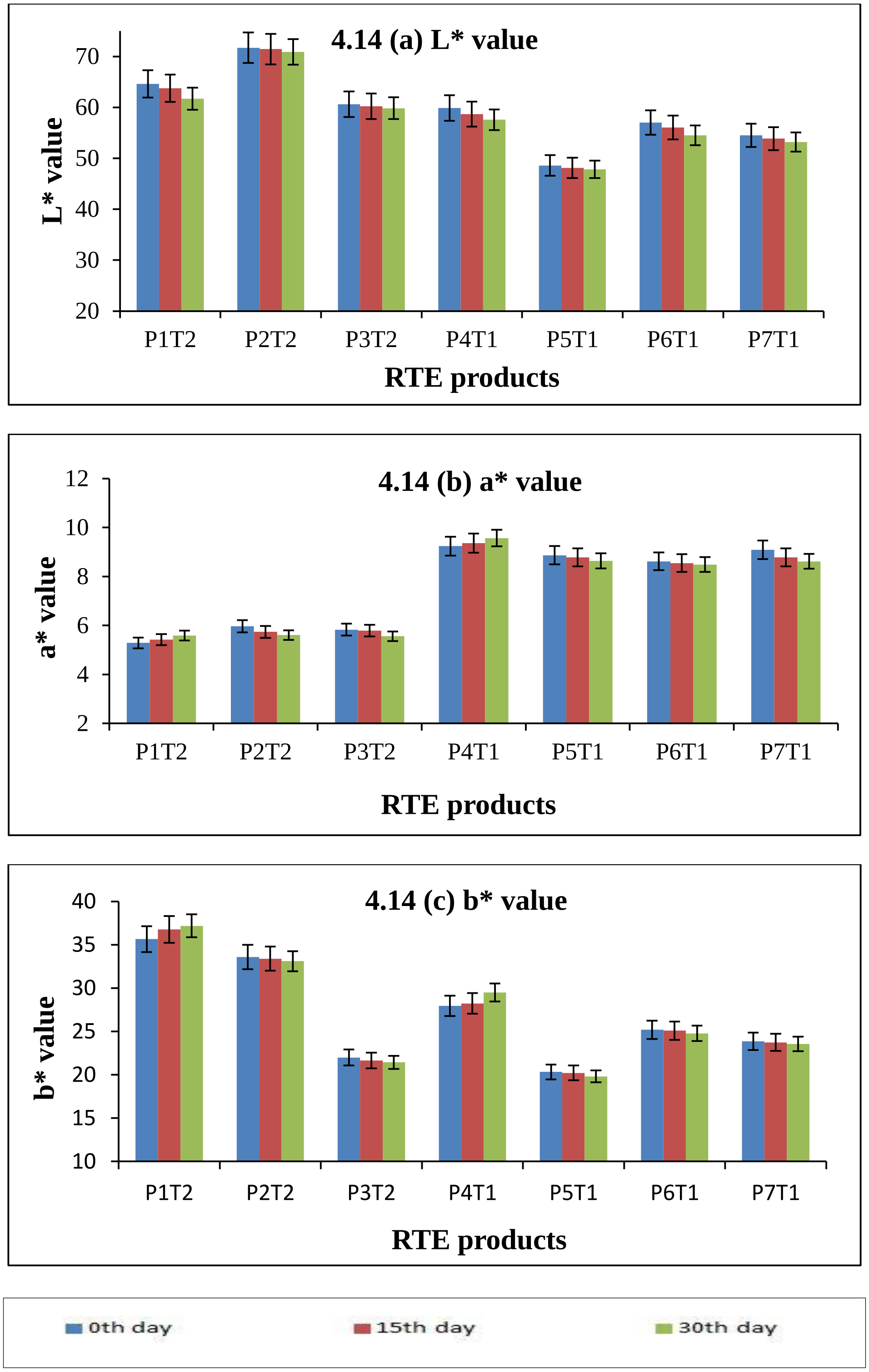

Fig. 4.14 Effect of storage period on colour values of hot extruded RTE products

4.7.3 Textural properties of hot extruded RTE products during storage

The textural properties in terms of hardness fracturability and crispness of extruded products are represented in Appendix E7.

From Fig. 4.15 (a), it was observed that hardness of hot extruded RTE products decreased with the storage period. Throughout the storage period maximum hardness (19.6 to 17.79 N) was observed for combination P5T1 whereas, minimum hardness (6.01 to 4.91 N) was observed for combination P1T2. The hardness shows the inverse relation with moisture. During storage the extrudates absorbs more moisture which results in less force requirement to break the product. Charunuch *et al*. (2008) reported that during 4 months of storage there was a decrease in hardness from 21.38 to 19.44 N for thai rice snacks. Storage had a significant effect on hardness of extrudate.

From Fig. 4.15 (b and c), it is seen that fracturability and crispness of hot extruded RTE products decreased with the storage period but the difference was not significant. Throughout the storage period maximum fracturability (2.05 to 1.94 N) was observed in P5T1 and minimum of 1.15 to 1.08 N was observed in P2T2 combination. The maximum crispness (59.85 to 59.35 N) was observed for combination P1T2 whereas, minimum crispness (26.52 to 25.6 N) was observed for combination P5T1. The ANOVA indicated that there was no significant effect on crispness and fracturability of extruded RTE products with the storage period.

This higher value of crispness positively correlated with the values of expansion with lower densities. The high amount of starch resulted in a product with more expansion which resulted in a softer and crispy product (Agulera *et al.*, 1984). Higher crispness was found in case of corn extrudates due to the higher amount of starch content compared with millet and yam flour. At elevated temperatures extrudates showed maximum expansion with high crisp factor. All the seven combinations after one month of storage resulted in improved quality with less hardness. Similar findings were reported by Aneeshya *et al.* (2008) for hot extruded RTE snack from starch based food products.

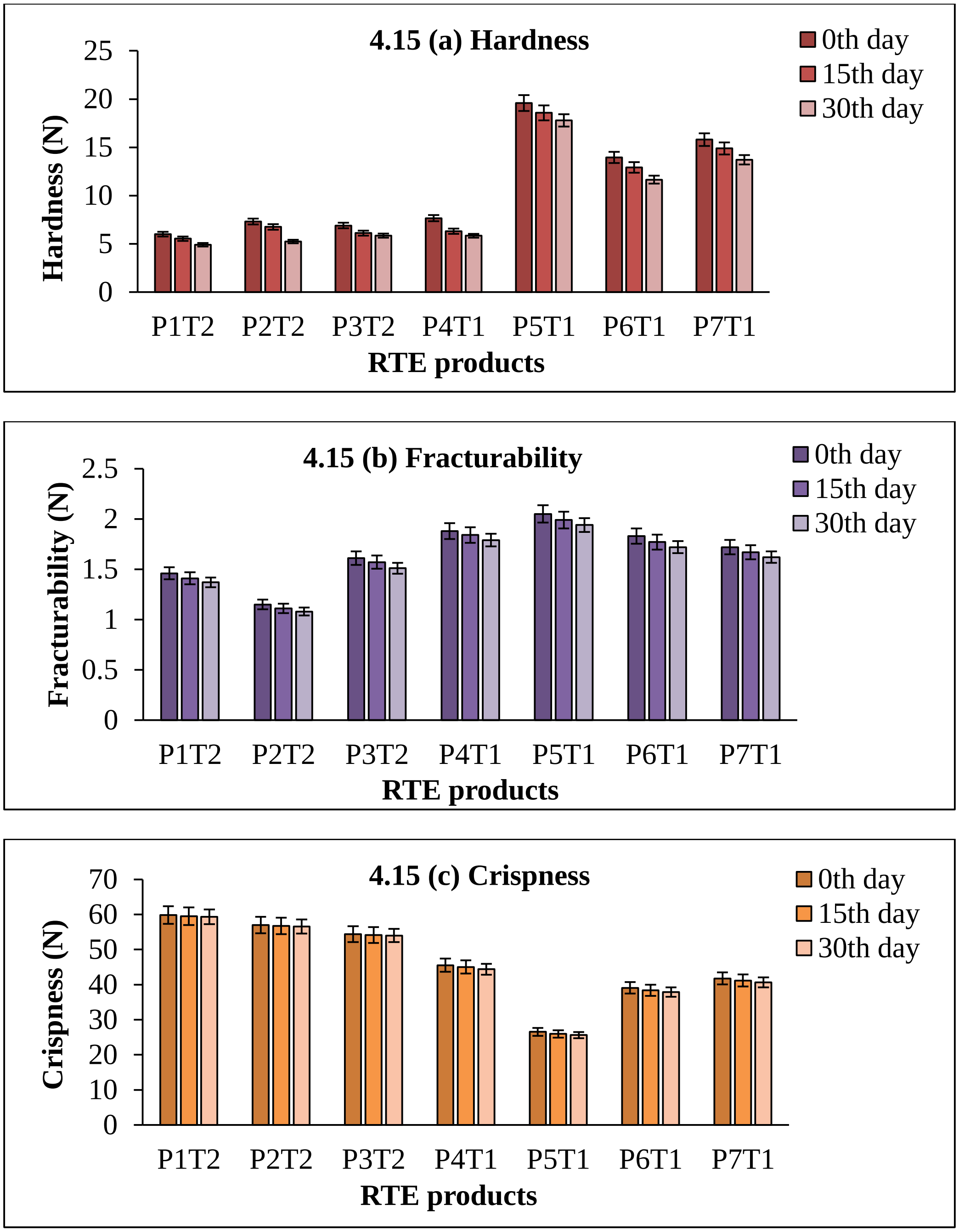

Fig. 4.15 Effect of storage period on textural properties of hot extruded RTE products

4.7.4 Microbial analysis for best judged extruded products

The microbial analysis was carried out for the best judged pasta and RTE products during storage period. The microbial analysis for P6 pasta product packed in LDPE was found safe (TPC 2.54 × 10^4 cfu/g) for the storage period of three months. Similarly, best combination of MAP stored P4T1 hot extruded RTE product also found safe (TPC 1.33 × 10^4 cfu/g) for one month storage period. The maximum permissible microbial limits of aerobic colony count for ready to eat food ranges from 10^4 to less than 10^5 cfu/g (Anon., 2007). The results showed that there was no contamination in both pasta and RTE products during storage period and the product was found to be microbially safe. Similar trend was reported by Sudha devi *et al.* (2013) for pasta products.

4.8 Sensory evaluation of extruded RTE products after storage

The selected seven extruded products after one month of storage was subjected to sensory evaluation by a panel of 12 semi trained members. Overall acceptability of RTE product varies from 7.1 to 8.12 (Fig. 4.16). There is no significant difference was observed after one month of storage. The results revealed that, P4T1 was mostly accepted by sensory panel (overall acceptability 8.12).

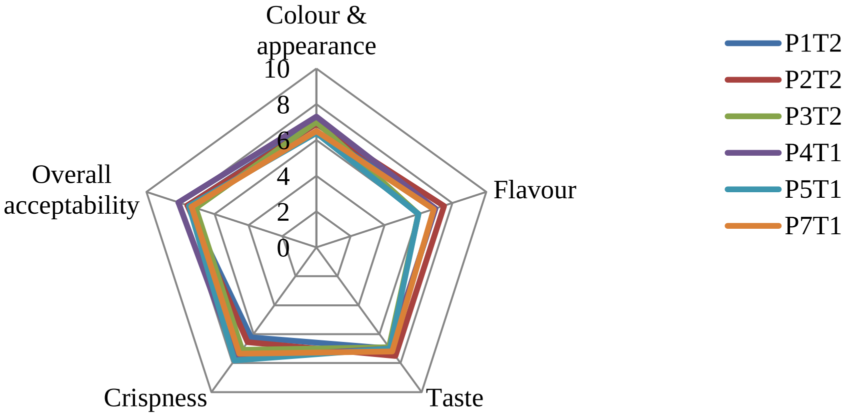

Fig. 4.16 Sensory evaluation of RTE products after storage (one month)

4.9 Optimization and standardization

Attempts were made to develop a product which would have maximum score in sensory evaluation so to get better market acceptability, maximum expansion, water absorption index, colour values and crispness, minimum moisture content, minimum bulk density and hardness. Therefore, among responses, these parameters were attempted to be maintained, whereas other parameters were kept within range. Under these criteria, P4T1 *i.e.*, C_{60}:Ey_{15}:Py_{20}:D_5 combination at 100ºC barrel temperature was found as optimum. The response predicted by the Design-Expert 7.0.0 software. Based on optimization and sensory evaluation, P4T1 sample is selected as a best combination out of all combinations under concern.

4.10 Economics of producing millet fortified tuber based cold extruded pasta and hot extruded RTE products

The cost estimation for the preparation of millet fortified tuber based extruded products were worked out taking all aspects of fixed and variable costs involved in the production of both cold extruded pasta and hot extruded RTE products. The benefit: cost ratio for optimized pasta product packed in LDPE was (2.81:1). The benefit: cost ratio for optimized hot extruded RTE product kept under MAP was (2.62:1). Since the benefit: ratio shows that the developed extruded products are economically favourable and it can be successfully installed. The detailed calculation is presented in Appendix (J & K).

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

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, saves labour and time, provides hygienic products of standard and uniform quality with enhanced shelf life. Extrusion cooking has been used widely in the production of food and food ingredients such as cereal-based snacks including expanded snack foods, baby foods, pasta and modified starch from cereals. The development of new value added products like pasta and expanded products would enhance their food and economic value. Such value added products are more palatable and acceptable to the modern day consumers. So by keeping these points in view the research work entitled "Development and quality evaluation of millet fortified tuber based extruded RTE product" was undertaken in Department of Food And Agricultural Process Engineering, KCAET, Tavanur, Kerala.

Development of ready to cook (RTC) pasta products by using wheat (A), elephant yam (E_y) and purple yam (P_y), millet flour (Rg) and a binding agent guar gum (G) in different combinations and proportions namely P1 (A_{100}), P2 (A_{98}:G_2), P3 (R_{60}:Ey_{15}:Py_{20}:D_3:G_2), P4 (C_{60}:Ey_{15}:Py_{20}:D_3:G_2), P5 (A_{60}:Ey_{15}:Py_{20}:D_3:G_2) and P6 (R_{25}:C_{20}:A_{25}:Ey_{10}:Py_{15}:D_3:G_2). Based on sensory analysis all the six combinations were kept for storage studies.

Ready to eat (RTE) extruded product were developed by using millet and tuber grits blended in different combination and proportions namely P1 (C_{100}), P2 (C_{50}:R_{50}), P3 (C_{50}:Rg_{50}), P4 (C_{60}:Ey_{15}:Py_{20}:D_5), P5 (Rg_{60}:Ey_{15}:Py_{20}:D_5), P6 (Rg_{20}:C_{25}:R_{25}:Ey_{10}:Py_{15}:D_5) and P7 (R_{60}:Ey_{15}:Py_{20}:D_5) under the same operating conditions of the twin screw extruder (*i.e.*, screw speed-350 rpm and feed moisture content-17.5%) with three different temperature (*i.e.*,T1-100, T2-110 and T3-120°C). The resultant 21 extrudates from different combination of raw materials with 3 temperatures were organoleptically tested. Considering the results of sensory evaluation, based on good taste and overall acceptability seven combinations (P1T2, P2T2, P3T2, P4T1, P5T1, P6T1 and P7T1) were adjudged to be best and selected for shelf life study.

The quality parameters *viz*. cooking properties (cooking time, swelling power, solid loss and water absorption ratio), physical properties (expansion ratio and bulk density) and engineering properties (colour and texture) for various pasta products were determined. Pasta products were packed in 400 gauge LDPE and kept for three months period for shelf life studies. Data analysis was performed using the general factorial design in Design Expert Software 7.0.0.

The cooking time required for the sample containing millet and tuber flour was less for P6 (8.32 min) which is less than the cooking time of wheat pasta. The minimum solid loss (1.23%) and maximum water absorption ratio of 2.06 was observed with P3 pasta. Maximum swelling power of 1.84 g/g was observed in (P4) pasta. The moisture content of various combinations of pasta was found to be in the range 4.38 to 5.76 % w.b. and lowest moisture content was recorded in P6 Pasta. Physical properties such as expansion ratio and bulk density varied from 2.36 to 3.61 and 0.29 and 0.37 g/ml respectively for various combinations of pasta products.

The highest L* value (brightness) of 51.1 and 57.45 for uncooked and cooked pasta samples was found for P1 due to absence of millet and tuber flour. Highest a* value (redness) of 7.31 and 5.7 and lowest value (4.77 and 3.46) for both uncooked and cooked pasta samples was observed with the P4 and P2 respectively. The b* value (yellowness) was highest with the control (P1) sample of 15.64 and 16.58 for both uncooked and cooked samples respectively and lowest of 7.56 and 7.03 for both uncooked and cooked samples was observed in P3, this might be due to highest amount of millet flour in both uncooked and cooked pasta samples. Firmness values of the uncooked and cooked pasta products varied between 29.92-48.44 N and 0.431-1.085 N respectively for different samples.

During three months of storage, the cooking properties namely, cooking time, solid loss, swelling power and water absorption index increased and it is varied from 8.55 to 12.55 min, 1.36 to 2.35%, 1.49 to 1.96 g/g and 1.75 to 2.12 g/g respectively for various combinations of pasta products but storage period had no significant effect on the cooking properties of pasta products. It is observed that after 3 months of storage, the moisture content of products increased significantly in all the samples. The expansion ratio and bulk density of pasta increased with the storage period but the variation was not significant. Throughout the storage period maximum value of expansion ratio was observed in P5 (3.7 to 3.75) and minimum value of 2.36 to 2.4 for control (P1) pasta and maximum bulk density was observed in P1 (0.41 g/ml) and minimum value of bulk density for P6 (0.32 g/ml) pasta in third month but variation was statistically non significant during storage period.

It was observed that lightness factor L* during storage, P1 and P2 samples showed increasing trend and in remaining other samples there was a decreasing trend in both uncooked and cooked samples. Similarly, both a* and b* values of millet fortified tuber based pasta products mostly decreased or increased with storage. The textural properties in terms of firmness of the uncooked and cooked pasta products increased and it is varied from 33.1 to 51.27 N and 0.46 to 1.14 N respectively. During storage period there was a slight changes in colour and firmness value but variation is statistically not significant.

Sensory evaluation was conducted on a nine point hedonic scale by twelve member’s consumer test panel for colour, texture, flavor, taste and overall acceptability of the developed pasta product. Overall acceptability of pasta varied from 6.83 to 8.0. The combination P1 (Control) mostly accepted by sensory panel (overall acceptability 8.0). The second best combination selected by sensory panel was P6 with overall acceptability of 7.61. As per the design expert software assumptions were made to develop a product which would have maximum score in sensory acceptability so as to get market acceptability, minimum cooking time, moisture content, bulk density, solid loss, hardness and maximum expansion, water absorption ratio, swelling power and colour value. Under these criteria, P6 *ie.,* Ragi (25): Corn (20): Atta (25): Elephant yam (10): Purple yam (15): Drumstick (3): Guar gum (2) was found as optimum. Based on optimization and sensory evaluation, P6 sample is selected as a best combination out of all combinations under concern.

In RTE products quality parameters *viz*. physical properties (moisture content, expansion ratio, bulk density, true density, porosity and water activity), functional properties (WSI and WAI), 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 the MAP was done along with nitrogen flushing. The quality parameters (moisture content, water activity, colour and textural properties) of developed RTE extruded products were analysed upto one month with an interval of 15 days during storage.

The moisture content of selected seven combinations of extruded RTE products ranged from 4.28 to 5.93%, among all P4T1 combination have less moisture content. Increase in process temperature resulted in the enhancement of expansion ratio. Maximum expansion ratio (4.074) was observed for P1T2 and minimum for P5T1 (2.685) combination. This decrease in expansion ratio could be because of high amount of finger millet and yam flour, which is rich in protein and dietary fiber. Bulk density (0.07 to 0.18 g/cm^3) and true density (1.49-1.84 g/cm^3) of the extrudates was found to have a considerable decrease at higher temperature. The maximum porosity (77.5%) was observed for corn extrudates (P1T2). The water activity of all combinations ranged from 0.43 to 0.48. The result indicates that at elevated temperatures have low a_w, which signifies the safe range of the products for consumption.

Water solubility index and water absorption index ranged from 13.9 to 24.7% and 4.11 to 6.16 g/g respectively. The WSI increased with finger millet and lower temperature (100°C) in P5T1. Increase in corn content and decrease in temperature (P4T1) resulted in high WAI.

Extrusion process significantly affected the colour. L* values of various combinations of extrudates varied from 48.59 to 71.72. An increase in L* value was observed with temperature and a decrease in L* value with finger millet and yam flour. The a* value varied from 5.29 to 9.24, it appeared that with increase in temperature a* value of the extrudate decreased due to the loss of colour pigments by high temperature. The b* value ranged from 20.33 to 35.66. An increase in corn flour proportion resulted in yellowness of extrudates, as recorded by increase in b* values.

Hardness of the extrudate varied from 6.01 to 15.8 N. It was seen that, increase in temperature resulted in decreased hardness. Fracturability of the extrudate ranged from 1.15 to 2.05 N. Temperature had significant effect on fracturability of the developed extruded product. However, increasing temperature decreases the fracturability of the extrudate. Crispness of the extrudate varied from 26.52 to 59.85 N. At elevated temperatures extrudates showed maximum expansion with lower density and high crisp factor. Higher crispness was found in case of corn extrudates (P1T2) due to the higher amount of starch content compared with other combinations.

The moisture content of the developed RTE extruded products after storage for one month in MAP packaging increased slightly in all the samples. For a given storage period, the moisture migration was maximum in P5T1 (5.93 to 6.24%) and P1T2 had minimum of 4.84 to 5.1%. The water activity was maximum in P7T1 (0.48 to 0.514) and minimum (0.435 to 0.459) for P1T2. In general the variation in water activity of extrudates was not significant during one month of storage.

For a given storage period there was a decrease in L* value in all the treatment combinations. Maximum colour L* value (71.72 to 70.91) was observed for combination P2T2. Maximum value of a* was observed in P4T1 (9.24 to 9.57) and minimum for (5.29 to 5.59) P1T2 combination. The results suggested that, during storage a* value of P1T2 and P4T1 products showed increasing trend, whereas in remaining treatments, the a* value decreased. Maximum colour b* was observed in P1T2 (35.66 to 37.18) and minimum for (20.33 to 19.8) P5T1 combination. An increase in corn flour resulted in yellowness of the extrudate, as recorded by increased b* values.

Hardness of extruded RTE products decreased with the storage period but the variation was not significant. Maximum hardness (19.6 to 17.79 N) was observed for P5T1 and minimum (6.01 to 4.91 N) for P1T2 combination. During storage, the extrudates absorbed moisture and resulted in less force requirement to break the product. Maximum fracturability (2.05 to 2.19 N) was observed in P5T1 and minimum of 1.15 to 1.23 N in P2T2 combination. The maximum crispness (59.85 to 60.35 N) and minimum (26.52 to 27.44 N) was observed for P1T2 and P5T1 combinations respectively. This higher value of crispness positively correlated with the values of expansion with lower densities. After one month of storage, all the seven combinations resulted in improved quality in terms of crispness with less hardness.

Attempts were made to develop a product which would have maximum score in sensory acceptability. In order to get market acceptability, a treatment combination with maximum expansion, WAI, WSI, maximum colour value and crispness, minimum moisture content, bulk density and minimum hardness was selected as ideal one. Under these criteria, P4T1 *i.e.,* Corn (60): Elephant yam (15): Purple yam (20): Drumstick (5) at 100°C temperature was found as optimum. The response predicted by the Design-Expert 7.0.0 software. Based on optimization and sensory evaluation, P4T1 sample was selected as the best combination out of all combinations under concern.

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CHAPTER VII

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Appendices

APPENDIX A

Vegetable Masala Pasta

Ingredients

- Pasta : 100 g
- Carrot, beans, tomato, capsicum, chilli (chopped) : 1 cup (Volume 250 ml)
- Onion : 1
- Oil : 3 tsp
- Salt, soy suace, chilli suace : to taste

Methods

- Cook the pasta in water
- Drain the water
- Cut the vegetables (carrots, tomatoes, beans, chili and capsicum into small pieces (Approximately 2 to 2.5 cm)
- Fry the onions in the oil and add vegetables to the fried oil
- Cook on slow fire
- Add salt, soy sauce, chilli sauce
- Mixed cooked vegetable with boiled pasta
- Serve hot

APPENDIX B

SENSORY SCORE CARD FOR PASTA PRODUCTS

Name of judge:

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

Score system:

Like extremely 9

Like very much 8

Like moderately 7

Like slightly 6

Neither like nor dislike 5

Dislike slightly 4

Dislike moderately 3

Dislike very much 2

Dislike extremely 1

Characteristics	Sample code					
	A	B	C	D	E	F
Colour & appearance						
Texture						
Flavor						
Taste						
Overall acceptability						

Comments if any: Signature

APPENDIX C
SENSORY SCORE CARD FOR EXTRUDED SNACKS

Date:

Name of judge:

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

Score system:

Like extremely 9

Like very much 8

Like moderately 7

Like slightly 6

Neither like nor dislike 5

Dislike slightly 4

Dislike moderately 3

Dislike very much 2

Dislike extremely 1

Characteristics	Sample code					
	A	B	C	D	E	F
Colour & appearance						
Texture						
Flavor						
Taste						
Crispiness						
Overall acceptability						

Comments if any: Signature

APPENDIX D1

Table D1 Physical properties of millet fortified tuber based pasta products

Combinations	Expansion ratio	Bulk density (g/ml)
P1	2.36	0.37
P2	3.07	0.35
P3	3.5	0.32
P4	3.57	0.30
P5	3.52	0.33
P6	3.61	0.29

APPENDIX D2

Table D2 Engineering properties of millet fortified tuber based pasta products

Combinations	Colour (uncooked)			Colour (cooked)			Texture (uncooked)	Texture (cooked)
	L*	a*	b*	L*	a*	b*	Firmness (N)	Firmness (N)
P1	51.1	4.95	15.64	57.45	3.95	16.58	39.03	0.728
P2	49.25	4.77	15.01	52.42	3.46	15.26	35.08	0.839
P3	29.56	4.82	7.56	35.17	4.29	7.03	29.92	0.431
P4	34	7.31	14.93	40.56	5.7	12.8	30.85	0.592
P5	32.82	5.9	11.09	41.07	5.6	11.29	48.44	1.085
P6	36.84	6.05	13.23	42.12	5.34	13.25	33.59	0.571

APPENDIX D3

Table D3 Effect of storage period on cooking quality of pasta

Cooking quality	Storage period (months)	P1	P2	P3	P4	P5	P6
Cooking time (min)	0	12.15	12.05	8.45	9.25	9.35	8.32
	1	12.3	12.12	8.52	9.38	9.42	8.4
	2	12.45	12.25	8.55	9.45	9.55	8.48
	3	12.55	12.45	9.05	9.54	10.05	8.55
Solid loss (%)	0	2.1	2.08	1.23	2.26	2.09	1.8
	1	2.12	2.09	1.26	2.28	2.14	1.82
	2	2.12	2.13	1.32	2.31	2.16	1.88
	3	2.13	2.18	1.36	2.35	2.16	1.95
Swelling power (g/g)	0	1.58	1.54	1.5	1.84	1.46	1.76
	1	1.62	1.59	1.52	1.88	1.47	1.82
	2	1.7	1.61	1.55	1.92	1.49	1.86
	3	1.75	1.68	1.59	1.96	1.49	1.86
WAR (g/g)	0	1.68	1.81	2.06	2	1.78	1.8
	1	1.7	1.83	2.06	2.03	1.87	1.87
	2	1.72	1.91	2.09	2.02	1.91	1.92
	3	1.75	1.98	2.12	2.04	1.96	1.96

APPENDIX D4

Table D4 Effect of storage period on moisture content of pasta

Combinations	Moisture content (% w.b.) Storage period (months)			
	0	1	2	3
P1	5.34	5.93	6.48	7.09
P2	4.53	5.41	6.4	6.5
P3	4.63	4.75	5.03	5.2
P4	5.4	5.62	6.18	6.25
P5	5.76	6.15	6.38	7.1
P6	4.38	4.62	4.88	5.12

APPENDIX D5

Table D5 Effect of storage period on physical properties of pasta

Physical properties	Storage period (months)	Combinations					
		P1	P2	P3	P4	P5	P6
Expansion ratio	0	2.36	3.07	3.5	3.57	3.7	3.61
	1	2.35	3.13	3.51	3.58	3.7	3.63
	2	2.38	3.17	3.51	3.57	3.73	3.64
	3	2.4	3.25	3.52	3.59	3.75	3.64
Bulk density (g/ml)	0	0.37	0.35	0.32	0.3	0.36	0.29
	1	0.38	0.37	0.32	0.32	0.36	0.31
	2	0.39	0.37	0.34	0.33	0.38	0.31
	3	0.41	0.39	0.35	0.33	0.39	0.32

APPENDIX D6

Table D6 Effect of storage period on colour of pasta

Colour	Combinations	Uncooked pasta				Cooked pasta			
		Storage period (months)				Storage period (months)			
		0	1	2	3	0	1	2	3
L*	P1	51.1	52.56	52.47	53.95	57.45	58.07	58.38	58.6
	P2	49.25	50.89	51.32	51.82	52.42	53.38	54.41	54.49
	P3	29.56	28.51	27.63	26.69	35.17	34.17	34.31	33.86
	P4	34	33.54	33.14	32.05	40.56	39.3	39.54	38.72
	P5	32.82	32.32	31.19	31.57	41.07	40.84	39.78	39.87
	P6	36.84	35.51	35.37	34.88	42.12	41.4	41.31	40.81
a*	P1	4.95	4.88	4.77	4.72	3.95	3.8	3.43	3.87
	P2	4.77	4.75	4.69	4.59	3.46	3.45	3.46	3.7
	P3	4.82	4.87	4.96	5.13	4.29	4.23	4.18	4.06
	P4	7.31	7.06	7.25	7.09	5.7	5.82	5.97	6.02
	P5	5.9	5.84	5.55	5.34	5.6	5.57	5.34	5.21
	P6	6.05	5.95	5.82	5.81	5.34	5.58	5.77	5.94
b*	P1	15.64	15.78	15.84	16.28	16.58	16.94	17.19	17.85
	P2	15.01	15.46	15.58	16.15	15.26	15.74	16.04	16.78
	P3	7.56	7.73	7.97	8.06	7.03	7.37	7.55	7.85
	P4	14.93	14.55	13.95	13.86	12.8	12.97	13.14	13.31
	P5	11.09	10.94	10.23	10.63	11.29	10.91	10.64	10.41
	P6	13.23	12.93	12.52	12.45	13.25	12.63	12.48	12.12

APPENDIX D7

Table D7 Effect of storage period on textural properties of pasta

Texture	Storage period (months)	P1	P2	P3	P4	P5	P6
Uncooked pasta							
Firmness (N)	0	39.03	35.08	29.92	30.85	48.44	33.59
	1	39.59	35.98	30.12	31.22	49.65	34.02
	2	40.87	36.4	30.95	32.05	50.87	35.08
	3	41.11	37.01	31.05	33.1	51.27	35.98
Cooked pasta							
Firmness (N)	0	0.72	0.83	0.431	0.592	1.08	0.571
	1	0.73	0.87	0.44	0.603	1.09	0.584
	2	0.76	0.89	0.44	0.608	1.11	0.61
	3	0.79	0.89	0.46	0.61	1.14	0.612

APPENDIX D8

Table D8 Multi response optimization constraints of experiment

Sl. No.	Parameters	Goal	Lower limit	Upper limit
	Combinations	is in range	P1	P6
1	Bulk density	minimize	0.28	0.38
2	MC	minimize	4.37	5.77
3	Expansion ratio	maximize	2.35	3.8
4	Swelling power	maximize	1.45	1.85
5	Solid loss	minimize	1.22	2.27
6	Water absorption ratio	maximize	1.67	2.07
7	Cooking time	minimize	8.31	12.16
8	L* (Uncooked)	minimize	35	55
9	a* (Uncooked)	is in range	4.75	7.33
10	b* (Uncooked)	maximize	7.55	17
11	L* (Cooked)	minimize	40	50
12	a* (Cooked)	is in range	3.45	5.8
13	b* (Cooked)	maximize	7.02	16.58
14	Firmness (Uncooked)	minimize	29.91	48.45
15	Firmness (Cooked)	minimize	0.409	1.106

APPENDIX E1

Table E1 Physical properties of hot extruded RTE products

Combinations	**MC (% w.b.)**	**ER**	**BD (g/cm^3)**	**TD (g/cm^3)**	**POR (%)**	**a_w**
P1T2	4.84	4.074	0.07	1.49	77.5	0.435
P2T2	5.84	3.814	0.09	1.53	76.6	0.439
P3T2	4.99	2.876	0.15	1.66	70.8	0.441
P4T1	4.28	3.349	0.12	1.6	67.11	0.462
P5T1	5.93	2.685	0.18	1.84	58.3	0.473
P6T1	5.19	3.195	0.132	1.52	61.2	0.479
P7T1	5.44	3.314	0.147	1.72	62.85	0.48

MC: Moisture content; ER: Expansion ratio; BD: Bulk density; TD: True density; POR: Porosity; a_w: Water activity; T: Temperature, °C (T1-100°C, T2-110°C)

APPENDIX E2

Table E2 Proximate analysis of extruded products

Combinations	**Protein (%)**	**Fat (%)**	**Carbohydrate (%)**	**Energy (kJ/100 g)**
P1T2	7.11	3.10	68.50	1379.55
P2T2	7.45	2.87	71.05	1419.15
P3T2	7.28	2.30	70.20	1380.62
P4T1	7.50	3.49	71.58	1452.21
P5T1	7.70	2.53	74.64	1470.46
P6T1	8.04	3.16	73.62	1482.38
P7T1	7.91	3.22	71.85	1453.38

APPENDIX E3

Table E3 Colour of hot extruded RTE products

Combinations	Colour		
	L*	a*	b*
P1T1	64.61	5.29	35.66
P2T2	71.72	5.97	33.59
P3T2	60.62	5.83	22.00
P4T1	59.89	9.24	27.95
P5T1	48.59	8.87	20.33
P6T1	57.02	8.62	25.2
P7T1	54.54	9.09	23.87

APPENDIX E4

Table E4 Textural properties of hot extruded RTE products

Combinations	Texture		
	Hardness (N)	Fracturability (N)	Crispiness (N)
P1T2	6.01	1.46	59.85
P2T2	7.32	1.15	56.98
P3T2	6.89	1.61	54.39
P4T1	7.66	1.88	45.52
P5T1	19.6	2.05	26.52
P6T1	13.96	1.83	39.06
P7T1	15.8	1.72	41.76

APPENDIX E5

Table E5 Effect of storage period on moisture content and water activity of extruded RTE products

Storage period (days)	P1T2	P2T2	P3T2	P4T1	P5T1	P6T1	P7T1
Moisture content (% w.b.)							
0	4.84	5.84	4.99	4.28	5.93	5.19	5.44
15	4.97	5.98	5.14	4.41	6.09	5.31	5.57
30	5.12	6.11	5.21	4.55	6.24	5.47	5.73
Water activity (a_w)							
0	0.435	0.439	0.441	0.462	0.473	0.479	0.48
15	0.442	0.446	0.457	0.479	0.485	0.491	0.495
30	0.459	0.462	0.471	0.487	0.496	0.511	0.514

APPENDIX E6

Table E6 Effect of storage period on colour values of extruded RTE products

Storage period (days)	P1T2	P2T2	P3T2	P4T1	P5T1	P6T1	P7T1
L*							
0	64.61	71.72	60.62	59.89	48.59	57.02	54.54
15	63.76	71.46	60.21	58.68	48.11	56.06	53.87
30	61.71	70.91	59.85	57.57	47.84	54.5	53.22
a*							
0	5.29	5.97	5.83	9.24	8.87	8.62	9.09
15	5.42	5.74	5.79	9.36	8.78	8.55	8.78
30	5.59	5.61	5.56	9.57	8.64	8.49	8.62
b*							
0	35.66	33.59	22	27.95	20.33	25.2	23.87
15	36.77	33.39	21.65	28.23	20.22	25.09	23.74
30	37.18	33.1	21.44	29.49	19.82	24.78	23.55

APPENDIX E7

Table E7 Effect of storage period on textural properties of extruded RTE products

Storage period (days)	P1T2	P2T2	P3T2	P4T1	P5T1	P6T1	P7T1
Hardness (N)							
0	6.01	7.32	6.89	7.66	19.6	13.96	15.8
15	5.54	6.75	6.12	6.31	18.58	12.92	14.89
30	4.91	5.25	5.85	5.84	17.79	11.64	13.72
Fracturability (N)							
0	1.46	1.15	1.61	1.88	2.05	1.83	1.72
15	1.41	1.11	1.57	1.84	1.99	1.77	1.67
30	1.37	1.08	1.51	1.79	1.94	1.72	1.62
Crispness (N)							
0	59.85	56.98	54.39	45.52	26.52	39.06	41.76
15	59.48	56.71	54.14	45.01	25.93	38.35	41.16
30	59.35	56.53	53.99	44.37	25.6	37.91	40.63

APPENDIX F

Factor A - Combinations

ANOVA for different properties of fresh cold extrudate pasta products

Table F.1 **Bulk density**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.017	5	3.480E-003	34.80	< 0.0001	1.000E-002	3.03
Factor -A	0.017	5	3.480E-003	34.80	< 0.0001		
Pure error	1.200E-003	12	1.000E-004				
Cor total	0.019	17			significant		

Table F.2 **Moisture content**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	4.79	5	0.96	9570.8	< 0.0001	1.000E-002	0.20
Factor -A	4.79	5	0.96	9570.8	< 0.0001		
Pure error	1.200E-003	12	1.000E-004				
Cor total	4.79	17			significant		

Table F.3 **Expansion ratio**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	3.92	5	0.78	230.38	< 0.0001	0.058	1.77
Factor -A	3.92	5	0.78	230.38	< 0.0001		
Pure error	0.041	12	3.400E-003				
Cor total	3.96	17			significant		

Table F.4 **Swelling power**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.29	5	0.057	570.90	< 0.0001	1.000E-002	0.63
Factor -A	0.29	5	0.057	570.90	< 0.0001		
Pure error	1.200E-003	12	1.000E-004				
Cor total	0.29	17			significant		

Table F.5 **Solid loss**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	2.00	5	0.40	3993.2	< 0.0001	1.000E-002	0.51
Factor -A	2.00	5	0.40	3993.2	< 0.0001		
Pure error	1.200E-003	12	1.000E-004				
Cor total	2.00	17			significant		

Table F.6 **Water absorption ratio**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.31	5	0.063	626.10	< 0.0001	1.000E-002	0.54
Factor -A	0.31	5	0.063	626.10	< 0.0001		
Pure error	1.200E-003	12	1.000E-004				
Cor total	0.31	17			significant		

Table F.7 **Cooking time**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	45.01	5	9.00	90024.5	< 0.0001	1.000E-002	0.10
Factor -A	45.01	5	9.00	90024.5	< 0.0001		
Pure error	1.200E-003	12	1.000E-004				
Cor total	45.01	17			significant		

Table F.8 **L* (Uncooked)**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	1226.95	5	245.39	1444.83	< 0.0001	0.41	1.06
Factor -A	1226.95	5	245.39	1444.83	< 0.0001		
Pure error	2.04	12	0.17				
Cor total	1228.98	17			significant		

Table F.9 **a* (Uncooked)**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	14.79	5	2.96	422.55	< 0.0001	0.084	1.49
Factor -A	14.79	5	2.96	422.55	< 0.0001		
Pure error	0.084	12	7.000E-003				
Cor total	14.87	17			significant		

Table F.10 **b* (Uncooked)**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	143.94	5	28.79	2.879 E+005	< 0.0001	1.000E-002	0.077
Factor -A	143.94	5	28.79	2.879 E+005	< 0.0001		
Pure error	1.200E-003	12	1.000E-004				
Cor total	143.94	17			significant		

Table F.11 **L* (Cooked)**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	1049.69	5	209.94	2.099 E+006	< 0.0001	1.000E-002	0.022
Factor -A	1049.69	5	209.94	2.099 E+006	< 0.0001		
Pure error	1.200E-003	12	1.000E-004				
Cor total	1049.69	17			significant		

Table F.12			**a* (Cooked)**				
Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	13.45	5	2.69	791.39	< 0.0001	0.058	1.23
Factor -A	13.45	5	2.69	791.39	< 0.0001		
Pure error	0.041	12	3.400E-003				
Cor total	13.49	17			significant		

Table F.13			**b* (Cooked)**				
Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	168.09	5	33.62	19333.6	< 0.0001	0.042	0.33
Factor -A	168.09	5	33.62	19333.6	< 0.0001		
Pure error	0.021	12	1.739E-003				
Cor total	168.12	17			significant		

Table F.14			**Firmness (Uncooked)**				
Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	701.82	5	140.36	1.404 E+006	< 0.0001	1.000E-002	0.028
Factor -A	701.82	5	140.36	1.404 E+006	< 0.0001		
Pure error	1.200E-003	12	1.000E-004				
Cor total	701.82	17			significant		

Table F.15			**Firmness (Cooked)**				
Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.81	5	0.16	245.13	< 0.0001	0.026	3.62
Factor -A	0.81	5	0.16	245.13	< 0.0001		
Pure error	7.891E-003	12	6.575E-004				
Cor total	0.81	17			significant		

APPENDIX G

Factor A - Storage period

ANOVA for different properties of selected (P6) pasta product during storage

Table G.1 **Bulk density**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	1.900E-003	3	6.333E-004	2.87	0.0809	0.015	4.83
Factor -A	1.900E-003	3	6.333E-004	2.87	0.0809		
Pure error	2.651E-003	12	2.209E-004				
Cor total	4.551E-003	15			not significant		

Table G.2 **Moisture content**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	1.23	3	0.41	39.46	< 0.0001	0.10	2.15
Factor -A	1.23	3	0.41	39.46	< 0.0001		
Pure error	0.12	12	0.010				
Cor total	1.36	15			significant		

Table G.3 **Expansion ratio**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	2.400E-003	3	8.000E-004	0.13	0.9403	0.078	2.16
Factor -A	2.400E-003	3	8.000E-004	0.13	0.9403		
Pure error	0.074	12	6.149E-003				
Cor total	0.074	15			not significant		

Table G.4 **Swelling power**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.027	3	8.933E-003	1.16	0.3641	0.088	4.80
Factor -A	0.027	3	8.933E-003	1.16	0.3641		
Pure error	0.092	12	7.679E-003				
Cor total	0.12	15			not significant		

Table G.5 **Solid loss**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.055	3	0.018	2.22	0.1385	0.091	4.87
Factor -A	0.055	3	0.018	2.22	0.1385		
Pure error	0.099	12	8.214E-003				
Cor total	0.15	15			not significant		

Table G.6 **Water absorption ratio**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.057	3	0.019	2.28	0.1317	0.091	4.84
Factor -A	0.057	3	0.019	2.28	0.1317		
Pure error	0.10	12	8.353E-003				
Cor total	0.16	15			not significant		

Table G.7 **Cooking time**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.12	3	0.040	0.24	0.8652	0.40	4.79
Factor -A	0.12	3	0.040	0.24	0.8652		
Pure error	1.96	12	0.16				
Cor total	2.08	15			not significant		

Table G.8 **L* (Uncooked)**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	8.43	3	2.81	0.99	0.4302	1.68	4.72
Factor -A	8.43	3	2.81	0.99	0.4302		
Pure error	34.04	12	2.84				
Cor total	42.47	15			not significant		

Table G.9 **a* (Uncooked)**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.16	3	0.052	0.67	0.5853	0.28	4.72
Factor -A	0.16	3	0.052	0.67	0.5853		
Pure error	0.93	12	0.078				
Cor total	1.09	15			not significant		

Table G.10 **b* (Uncooked)**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	1.61	3	0.54	1.48	0.2694	0.60	4.70
Factor -A	1.61	3	0.54	1.48	0.2694		
Pure error	4.34	12	0.36				
Cor total	5.94	15			not significant		

Table G.11 **L* (Cooked)**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	3.50	3	1.17	0.30	0.8226	1.96	4.73
Factor -A	3.50	3	1.17	0.30	0.8226		
Pure error	46.13	12	3.84				
Cor total	49.63	15			not significant		

Table G.12 **a* (Cooked)**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.80	3	0.27	1.70	0.2199	0.40	6.99
Factor -A	0.80	3	0.27	1.70	0.2199		
Pure error	1.88	12	0.16				
Cor total	2.67	15			not significant		

Table G.13 **b* (Cooked)**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	2.67	3	0.89	2.54	0.1058	0.59	4.69
Factor -A	2.67	3	0.89	2.54	0.1058		
Pure error	4.20	12	0.35				
Cor total	6.87	15			not significant		

Table G.14 **Firmness (Uncooked)**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	13.89	3	4.63	1.64	0.2322	1.68	4.85
Factor -A	13.89	3	4.63	1.64	0.2322		
Pure error	33.87	12	2.82				
Cor total	47.76	15			not significant		

Table G.15 **Firmness (Cooked)**

Source	Sum of squares	df	Mean square	F value	p-value Prob > F	Std. Dev.	C.V. (%)
Model	4.835E-003	3	1.612E-003	1.95	0.1748	0.029	4.83
Factor -A	4.835E-003	3	1.612E-003	1.95	0.1748		
Pure error	9.897E-003	12	8.248E-004				
Cor total	0.015	15			not significant		

APPENDIX H

Factor A - Combination

ANOVA for different properties of fresh hot extruded RTE products

Table H.1 **Expansion ratio**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	4.29	6	0.71	44.05	< 0.0001	0.13	3.82
Factor -A	4.29	6	0.71	44.05	< 0.0001		
Pure error	0.23	14	0.016				
Cor total	4.51	20			significant		

Table H.2 **Bulk density**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.025	6	4.215E-003	186.24	< 0.0001	4.757E-003	3.75
Factor -A	0.025	6	4.215E-003	186.24	< 0.0001		
Pure error	3.168E-004	14	2.263E-005				
Cor total	0.026	20			significant		

Table H.3 **True density**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.29	6	0.048	13.16	< 0.0001	0.060	3.71
Factor -A	0.29	6	0.048	13.16	< 0.0001		
Pure error	0.051	14	3.623E-003				
Cor total	0.34	20			significant		

Table H.4 **Porosity**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	1397.30	6	232.88	35.28	< 0.0001	2.57	3.85
Factor -A	1397.30	6	232.88	35.28	< 0.0001		
Pure error	92.42	14	6.60				
Cor total	1489.72	20			significant		

Table H.5 **Water activity**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	7.031E-003	6	1.172E-003	4.04	0.0147	0.017	3.72
Factor -A	7.031E-003	6	1.172E-003	4.04	0.0147		
Pure error	4.062E-003	14	2.902E-004				
Cor total	0.011	20			significant		

Table H.6 **Water solubility index**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	371.52	6	61.92	131.40	< 0.0001	0.69	3.63
Factor -A	371.52	6	61.92	131.40	< 0.0001		
Pure error	6.60	14	0.47				
Cor total	378.12	20			significant		

Table H.7 **Water absorption index**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	9.82	6	1.64	47.98	< 0.0001	0.18	3.74
Factor -A	9.82	6	1.64	47.98	< 0.0001		
Pure error	0.48	14	0.034				
Cor total	10.29	20			significant		

Table H.8 **L***

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	979.78	6	163.30	31.55	< 0.0001	2.28	3.82
Factor -A	979.78	6	163.30	31.55	< 0.0001		
Pure error	72.46	14	5.18				
Cor total	1052.24	20			significant		

Table H.9 **a***

Source	Sum of squares	df	Mean squares	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	55.99	6	9.33	121.66	< 0.0001	0.28	3.66
Factor -A	55.99	6	9.33	121.66	< 0.0001		
Pure error	1.07	14	0.077				
Cor total	57.06	20			significant		

Table H.10 **b***

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	605.49	6	100.91	92.25	< 0.0001	1.05	3.88
Factor -A	605.49	6	100.91	92.25	< 0.0001		
Pure error	15.32	14	1.09				
Cor total	620.80	20			significant		

Table H.11 **Hardness**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	516.73	6	86.12	521.64	< 0.0001	0.41	3.68
Factor -A	516.73	6	86.12	521.64	< 0.0001		
Pure error	2.31	14	0.17				
Cor total	519.04	20			significant		

Table H.12 **Crispness**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	2484.00	6	414.00	119.01	< 0.0001	1.87	4.03
Factor -A	2484.00	6	414.00	119.01	< 0.0001		
Pure error	48.70	14	3.48				
Cor total	2532.70	20			significant		

Table H.13 **Fracturability**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	1.60	6	0.27	69.79	< 0.0001	0.062	3.70
Factor -A	1.60	6	0.27	69.79	< 0.0001		
Pure error	0.054	14	3.831E-003				
Cor total	1.66	20			significant		

Table H.14 **Moisture content**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	6.06	6	1.01	27.21	< 0.0001	0.19	3.69
Factor -A	6.06	6	1.01	27.21	< 0.0001		
Pure error	0.52	14	0.037				
Cor total	6.58	20			significant		

APPENDIX I

ANOVA for different properties of selected (P4T1) hot extruded RTE product during storage period

Factor A - Storage period

Table I.1 **Moisture content**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.18	2	0.091	2.97	0.0893	0.18	3.97
Factor -A	0.18	2	0.091	2.97	0.0893		
Pure error	0.37	12	0.031				
Cor total	0.55	14			not significant		

Table I.2 **Water activity**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	1.630E-003	2	8.150E-004	2.28	0.1446	0.019	3.97
Factor -A	1.630E-003	2	8.150E-004	2.28	0.1446		
Pure error	4.286E-003	12	3.572E-004				
Cor total	5.916E-003	14			not significant		

Table I.3 **L***

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	13.46	2	6.73	1.23	0.3272	2.34	3.99
Factor -A	13.46	2	6.73	1.23	0.3272		
Pure error	65.78	12	5.48				
Cor total	79.25	14			not significant		

Table I.4

a*

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.28	2	0.14	1.00	0.3955	0.37	3.97
Factor -A	0.28	2	0.14	1.00	0.3955		
Pure error	1.67	12	0.14				
Cor total	1.95	14			not significant		

Table I.5

b*

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	6.73	2	3.36	2.62	0.1135	1.13	3.97
Factor -A	6.73	2	3.36	2.62	0.1135		
Pure error	15.40	12	1.28				
Cor total	22.12	14			not significant		

Table I.6

Hardness

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	8.93	2	4.46	62.28	< 0.0001	0.27	4.05
Factor -A	8.93	2	4.46	62.28	< 0.0001		
Pure error	0.86	12	0.072				
Cor total	9.79	14			significant		

Table I.7

Fracturability

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	0.020	2	0.010	1.89	0.1930	0.073	3.99
Factor -A	0.020	2	0.010	1.89	0.1930		
Pure error	0.064	12	5.372E-003				
Cor total	0.085	14			not significant		

Table I.8 **Crispness**

Source	Sum of squares	df	Mean square	F value	p- value Prob > F	Std. Dev.	C.V. (%)
Model	3.32	2	1.66	0.52	0.6090	1.79	3.98
Factor -A	3.32	2	1.66	0.52	0.6090		
Pure error	38.53	12	3.21				
Cor total	41.85	14			not significant		

APPENDIX J

Economics of developed cold extruded pasta product

Estimation of cost of production for preparation of cold extruded pasta product by using single screw extruder (Pasta machine)

Cost of machineries		
Cost of pasta machine	=	Rs 4,65,000/-
Cost of blancher cum drier	=	Rs 2,50,000/-
Cost of hammer mill	=	Rs 1,10,000/-
Cost of slicer	=	Rs 25,000/-
Miscellaneous item	=	Rs 50,000/-
Total cost	=	Rs 9,00,000/-
25% subsidy therefore, total cost (C)	=	Rs 6,75,000/-

Assumptions

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 = $\frac{C - S}{L \times H} = \frac{675000 - 67500}{10 \times 2200}$ = Rs 27.61/h

ii. Interest = $\frac{C + S}{2} \times \frac{i}{H}$

$\frac{675000 + 67500}{2} \times \frac{15}{100 \times 2200}$ = Rs 25.31/h

iii. Insurance and taxes = 2% of initial cost

$\frac{2}{100 \times 2200} \times 675000$ = Rs 6.136/h

Total fixed cost = i + ii + iii = Rs 59.056/h

2.Total variable cost of extrusion

i. Repair and maintenance = 5% of initial cost

$\frac{5}{100 \times 2200} \times 675000$

= Rs 15.34/h

ii. Electricity cost

a) Energy consumed by the extruder = 0.4 kw/h

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

$0.4 \times 8 \times 7$

Rs 22.4/day

b) Energy consumed by drier and hammer mill = 2 kw/h

Cost of energy consumption/h = $2 \times 8 \times 7$

Rs 112/day

iii. Labour cost = Rs 400/day

iv. Packaging cost = Rs 1000/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	Ragi	25	100	2500
2	Corn	20	70	1400
3	Atta	25	35	875
4	Elephant yam	10	200	2000
5	Purple yam	15	175	2625
6	Drumstick	3	500	1500
7	Guar gum	2	850	1700
Total cost of raw materials				Rs 12600

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

= Rs 14,149.74/-

Therefore total cost of production of 100 kg of extruded pasta product

= Fixed cost + Variable cost

=59.056 + 14,149.74

= Rs 14,208.796/100kg of pasta product

= Rs 142.08/kg of pasta product

The market selling price of 1kg of pasta product = Rs 400/kg

$$\text{Benefit - cost ratio} = \frac{400}{142.08} = 2.81$$

Therefore the total production cost of 1kg of pasta product was found to be Rs. 142.08/-. The benefit cost ratio of the production was found to be 2.81:1.

APPENDIX K

Economics of developed hot extruded RTE product

Estimation of cost of production for preparation of hot extruded RTE product by using twin screw extruder

Cost of machineries		
Cost of twin screw extruder + coating machine	=	Rs 17,00,000/-
Cost of blancher cum drier	=	Rs 2,50,000/-
Cost of hammer mill	=	Rs 1,10,000/-
Cost of packaging machine	=	Rs 1.00,000/-
Cost of slicer	=	Rs 25,000/-
Miscellaneous item	=	Rs 50,000/-
Total cost	=	Rs 22,35,000/-
25% subsidy therefore, total cost (C)	=	Rs 16,76,250/-

Assumptions

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 = $\frac{C - S}{L \times H} = \frac{1676250 - 167625}{10 \times 2200}$ = Rs 68.57/h

ii. Interest = $\frac{C + S}{2} \times \frac{i}{H} = \frac{1676250 + 167625}{2} \times \frac{15}{100 \times 2200}$ = Rs 62.85/h

iii. Insurance and taxes = 2% of initial cost

$\frac{2}{100 \times 2200} \times 1676250$ = Rs 15.23/h

Total fixed cost = i + ii + iii = **Rs 146.65/h**

2.Total variable cost of extrusion

i. Repair and maintenance = 5% of initial cost

$\frac{5}{100 \times 2200} \times 1676250$ = Rs 38.096/h

ii. Electricity cost

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

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

$7.5 \times 8 \times 7$

= Rs 420/day

b) Energy consumed by drier and hammer mill = 2 kw/h

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

$2 \times 8 \times 7$ = Rs 112/day

iii. Energy requirement for MAP = 2 kw/h

$2 \times 8 \times 7$ = 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	Corn	60	70	4200
2	Elephant yam	15	200	3000
3	Purple yam	20	175	3500
4	Drumstick	5	500	2500
5	Salt + masala	15	50	750
Total cost of raw materials				Rs 13,950

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

=Rs 17032.096/-

Therefore total cost of production of 100 kg of extruded product

= Fixed cost + Variable cost

= 146.65 + 17032.096

= 17178.746/100 kg of RTE product

= Rs 171.78/kg of RTE product

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

$$\text{Benefit - cost ratio} = \frac{450}{171.78} = 2.62$$

Therefore the total production cost of 1kg of extruded RTE product was found to be Rs. 171.78/-. The benefit cost ratio of the production was found to be 2.62:1.

DEVELOPMENT AND QUALITY EVALUATION OF MILLET FORTIFIED TUBER BASED EXTRUDED RTE PRODUCTS

by

SEEMA B. R.
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ABSTRACT OF THE THESIS

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Kerala Agricultural University

Department of Food and Agricultural Process Engineering
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ABSTRACT

As the eating patterns are changing day by day, snack foods play very important role in the diet of the modern consumer. Extrusion technology has a pivotal role in the snack and ready to eat breakfast food industry. The development of new value added products like pasta and expanded products would enhance their food, and economic value. Such products are more palatable and acceptable to the modern day consumers. So the present study was undertaken to develop ready to cook (RTC) pasta and ready to eat (RTE) expanded products from corn, ragi, rice, atta, elephant yam, purple yam and drumstick. Six combinations of pasta products consists of flour mix containing tuber, wheat, millet flour and a binding agent like guar gum in different proportion. The quality parameters *viz*. cooking properties (cooking time, swelling power, solid loss and WAR), physical properties (expansion ratio and bulk density) and engineering properties (colour and texture) for various pasta products were determined. Pasta products were packed in 400 gauge LDPE and kept for storage studies up to three months. For development of RTE product, preliminary trials was conducted and based on those trials feed moisture content and screw speed were fixed. The blends of seven different combinations were extruded at temperature of 100, 110 and 120°C at a screw speed of 350 rpm and 17.5% feed moisture content. Considering the results of sensory evaluation, seven combinations were selected out of 21 extrudates. The seven extruded product was evaluated for physical, functional, colour and textural properties. The proximate composition in terms of protein, fat, carbohydrate and total energy were also analysed. The extruded products were stored in aluminium pouches and with nitrogen flushing. The quality parameters (moisture content, water activity, colour and textural properties) of stored RTE products were analysed upto one month with an interval of 15 days. Based on optimization and sensory evaluation, Ragi(25%): Corn(20%): Atta(25%): Elephant yam(10%): Purple yam(15%): Drumstick(3%): Guar gum(2%) *i.e.,* P6 pasta sample and Corn(60%): Elephant yam(15%): Purple yam(20%): Drumstick(5%) *i.e.,* (P4T1) RTE product was selected as the best combination out of all combinations under concern.