DEVELOPMENT AND QUALITY EVALUATION OF EXTRUDED RTE SNACK FOOD FROM STARCH BASED FOOD PRODUCTS

by

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THESIS

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DECLARATION

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

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Dedicated to

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SYMBOLS AND ABBREVIATIONS

₹	rupees
%	per cent
°C	degree centigrade
*	significant
**	highly significant
<	less than
>	greater than
ΔE	total colour change
^0B	degree brix
a_w	water activity
i.e	that is
ϕ	diameter
AD	apparent density
ANOVA	analysis of variance
BCR	Benefit Cost Ratio
BD	bulk density
BEP	Break Even Point
BI	browning index
CD	critical difference
cm	centimetre
CPCRI	Central Plantation Crop Research Institute

.CRD	Completely Randomized Design
CTCRI	Central Tuber Crop Research Institute
d.b.	dry basis
Eqn.	equation
ER1	expansion ratio based on diameter
ER2	expansion ratio based on cross section area
et al.	and others
Factor A	combination
Factor AB	interaction of A and B
Factor ABC	interaction of A, B and C
Factor AC	interaction of A and C
Factor B	temperature
Factor BC	interaction of B and C
Factor C	speed
FAO	Food and Agricultural Organisation
Fig.	figure
FPME	Farm Power Machinery and Energy
g	gram
g/cm^3	gram per centimeter cube
g/g	gram per gram
g/min	gram per minute
g/ml	gram per millimeter
GDP	Gross Domestic Product

h	hour
IDE	Irrigation and Drainage Engineering
IRR	Internal Rate of Return
J/m^2	joule per meter square
KCAET	Kelappaji College of Agricultural Engineering and Technology
Kcal	kilo calories
Kg	kilogram
kg/h	kilogram per hour
KJ	kilo joule
KVK	Krishi Viighyan Kendra
kW	kilo watt
LWRCE	Land & Water Resources and Conservation Engineering
m	metre
M.C	moisture content
m^3/h	meter cube per hour
MAP	Modified atmospheric package
min	minute
ml	milliliter
mm	millimeter
MoFPI	Ministry of Food processing Industry
MPa	mega pascal
MSTAT	Master of statistics

N	newton
NABARD	National Bank for Agricultural and Rural Development
NaCl	Sodium chloride
N-m	newton metre
NPV	Net Present Value
N-s	newton second
OAI	oil absorption index
p	propability
P	combination
PD	product density
PHT & AP	Post Harvest Technology and Agricultural Processing
r	correlation coefficient
R: B	rice: banana
R: C: B	rice: cassava: banana
R^2	regression coefficient
rpm	revolution per minute
RTE	ready to eat
s	second
S	speed
SME	specific mechanical energy
SPSS	Statistical Package for Social Science
T	treatment, temperature

TPA	texture profile analysis
viz.	namely
w.b	wet basis
w/v	weight by volume
w/w	weight by weight
WAI	water absorption index
WHO	World Health Organisation
WSI	water solubility index
μm	micro metre

Introduction

CHAPTER I

INTRODUCTION

Indian agriculture has an extensive background which goes back to ten thousand years. India is the world's second largest producer of food next to china and has the potential of being the biggest with the food and agricultural sector. Our country has achieved a record food grain production of 241 million tonnes in 2010-11 crop years (Agriculture status in India, 2011). With amble production of raw materials the amount of processed material surge from yard to folk is less. India has the potential to be a leading global food supplier if it employs the right marketing strategies and creates an efficient supply chain. The relevance of food processing sectors is a key link for this efficient supply chain. Though this industry is large in size, it is still at a nascent stage in terms of development of the country's total agriculture and food produce, with a contribution of 2% being processed (Data bank MoFPI, 2011).

The food processing industry is one of the largest industries in India and ranks 5^{th} in terms of production (MoFPI, 2011), consumption, export and expected growth. Availability of raw materials, changing lifestyles and appropriate fiscal policies has given a considerable push to the industry's growth. The food sector contributes to about 28% of India's GDP. This sector serves as a vital link between the agriculture and industrial segments of the economy. Adequate focus on this sector could greatly alleviate our concerns on food security and food inflation. Strengthening this link is of critical importance to reduce wastage of agricultural raw materials, improve the value of agricultural produce by increasing shelf-life as well as by fortifying the nutritive capacity of the food products ensuring remunerative prices to farmers as well as affordable prices to consumers.

The Confederation of Indian Industry (CII) has estimated that the foods processing sectors has the potential of attracting US $ 33 billion of investment in 10 years and generate employment of 9 million person – days (MoFPI, 2011). Processing sector involves primary, secondary and tertiary processing. The initial relates to conversion of raw agricultural produce into a commodity that is fit for human consumption. It involves steps such as cleaning, grading, sorting, packing etc. Secondary and tertiary processing industries usually deal with higher levels of processing where new or modified food products are manufactured and extruded ready to eat (RTE) snacks are the outcome of these sectors.

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. After work they prefer a meal to eat or at the most assemble at home and not ingredients 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. Extrusion is a tertiary process that deals with high expanded snacks. It includes extruded snacks (Kurkure, *Lays* etc.), puffed cereals, popcorns, rice flakes, potato chips, french fries and Indian home made products like papads, kurdai, chakali etc. which may be consumed after frying or roasting (Dias *et al.*, 2009).

The extrusion technology has a pivotal role in the snack and ready to eat breakfast food industry. History shows that the first application of the use of a cooking extruder in the food industry was in producing an expanded cornmeal based snack in a single screw extruder. Most likely, this was either an expanded yellow cornmeal ball or curl that was then coated with some type of seasoning such as cheese and salt. This is very similar to some of the products still offered by today by many snack producers. Single screw extruders were first used in the 1940's, since twin screw extruders were not developed for the food industry until the early 1980's (Harper, 1981). However, twin screw extruders are rapidly becoming the extruders of choice in the food industry.

Extrusion is a multi variable unit operation comprising of mixing, shearing, cooking, puffing and drying in one energy efficient rapid continuous process. It has an important role in the food industry as an efficient manufacturing process. This technology has many distinct advantages like versatility, low cost, better product quality and no process effluents (Fellows, 2000).

This processing technology is widely used to restructure starch and protein based materials thus allowing the manufacturing of a variety of textured convenience foods. Extrusion cooking is a high-temperature short-time (HTST) processing technology in which raw materials are exposed to a combination of moisture, pressure, temperature, and mechanical shear resulting in stable products (Dias *et al.*, 2009). Extrusion has been used to process cereal legume blends for many years (Harper and Jansen, 1985).

When heating and working during the extrusion process, the macromolecules in food ingredients lose their native, organized tertiary structure and form a viscous plasticized material. At the end of the die, fast vaporisation of the water present in food takes place, leading to structural reorganisation and producing a series of textured products. Among these, snacks are the main product made by extrusion (Zuilichem and Leszek, 2011).

In the present study a new RTE food product was developed by blending starch rich food products like rice, banana (Nendran) and cassava which will form a nutritional breakfast kit for the nuclear families with a balanced mix of fibers, proteins, carbohydrates, vitamins and minerals that will ensure nutritional security and food safety.

Rice (*Oryza sativa*) which is our staple food has high digestibility. It is low in fat, low in cholesterol, high in starch and has a high nutritional content. Rice is also an excellent source of energy. It is comprised of 77.5% carbohydrate. Carbohydrate is one of the human body's main sources of energy, the second being fat. Rice also contains a range of important nutrients, including vitamin B, vitamin E, proteins and minerals especially potassium which helps the body to reduce toxins. Rice can contribute significantly to vitamin and mineral intake, although the contribution to micronutrient intake will depend on the proportion of germ, bran and endosperm consumed. A diet based white rice leaves people vulnerable to the neurological disease beriberi due to a deficiency of thiamine (vitamin B_1).White rice is often enriched with some of the nutrients stripped from it during its processing. (Aneesa *et al.*, 2009). A product out of this cereal will be a diet cum expanded snack for the consumers.

Banana (*Musa paradisiaca*) is a tropical fruit, a large berry which is handy and healthy. People with high levels of potassium in their diets have lower chances to suffer from high blood pressure even if they do not care about their sodium intake. Bananas are low in calories, fats, sodium and much of its fibers are soluble-the kinds which help lowering the overall cholesterol. Bananas are highly recommended by health care providers for their patients with low potassium levels. High potassium may also prevent renal calcium loss, in effect preventing bone breakdown. In diarrhea, it contributes to electrolyte replacement, as well as increased absorption of nutrients. One large banana, about 0.23 m in length, packs 602 mg of potassium, 2g of protein, 36g of carbohydrates, 4 g of fiber and carries 140 calories. The banana has been considered as an important food to boost the health of malnourished children. We traditionally use banana as a balanced and supplementary diet for babies of 4 to 10 months.

Vitamins and minerals are abundant in the banana, offering 123 International Unit (IU) of Vitamin A for the large size. A full range of vitamins B are present with 0.07 mg of Thiamine, 0.15 mg of Riboflavin, 0.82 mg Niacin, 0.88 mg vitamin B6, and 29 micro gram (mcg) of Folic Acid. There are even 13.8 mg of vitamin C. On the mineral scale Calcium counts in at 9.2mg, Magnesium 44.1 mg, with trace amounts of iron and zinc. Carotenoid content has antioxidant effects and protects against vitamin A deficiency, resulting in e.g. night blindness. Moderate consumption decreases risk of kidney cancer, possibly due to antioxidant phenolic compounds. In contrast, large consumption of highly processed fruit juice increases the risk of kidney cancer. Putting all of the nutritional figures together clearly shows the banana is among the healthiest of fruits (Aneesa *et al.*, 2009).

Root and tubers are the third important food crops of mankind after cereals and grain legumes. It constitutes either staple or subsidiary food for about one fifth of the world population. Among the tropical tuber crops, cassava occupies first position in terms of area (18.56 m ha) and production (214.52MT) globally with a productivity of 11.56 t/ha (FAO, 2007) and feeds 3% of world population. Cassava (*Manihot esculenta*), is the third largest source of food carbohydrates in the world. Cassava is one of the most important metabolic sources of energy for millions of people in the tropics and is also an important raw material for other industrial uses. There are many expanded snack foods commonly eaten in Asian countries that are based on cassava starch. These products are often formed as pellets and are then expanded into a porous low density product in an oven or fried in oil before consumption. The pellets can also be formed by extrusion cooking.

Cassava starch has been reported to have a particularly high degree of expansion and this is very important to the eating quality of snack foods. The expansion of tapioca chips takes place as a result of rapid water vaporisation inside the amorphous starch matrix at the initial stages of frying, but reaches a plateau before maximum moisture loss. During expansion the starch matrix must accommodate the water vapour within the bubble. Hence starch structure and molecular weight must be of importance as it will govern the viscosity of the matrix (Jorge and Maria, 2003). Cassava expanded snacks have greater consumer acceptance due to its crispiness and taste, along with a feel of traditional meal.

Extrusion of a mixture, instead of only the cereal portion would ensure a nutritious pre-cooked blended product with the elimination of prolonged cooking (Harper, 1989). So a product enriched with these raw materials *viz.* rice, banana and cassava will ensure a food which is safe to consume, nutritious and ready to eat without consuming much time for preparation.

In this back ground, a project entitled “Development and quality evaluation of extruded RTE snack food from starch based food products” was under taken at Kelappaji College of Agricultural Engineering and Technology (KCAET), Tavanur, Kerala in association with Central Tuber Crop Research Institute (CTCRI), Trivandrum, Kerala with the following objectives.

1. To standardise the composition of RTE food from rice, banana and cassava.
2. To standardise the extrusion process parameters.
3. To determine the engineering properties of the extruded RTE snack food.
4. To analyse the organoleptic quality of the newly developed RTE food.
5. To study the economic feasibility of the proposed product technology.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

This chapter reviews the research work done by other investigators on application of high pressure extrusion processing to formulate extruded products. The qualities of these products in terms of their physical, functional, textural and biochemical characteristics during storage are also reviewed.

2.1 Fabricated foods

With advances in food technology, fortification of foods for proper nutrition is becoming more complex. Eating patterns are changing; snack foods and formulated products are becoming a larger part of the diet. At the same time, consumers want food that is convenient, requires minimal preparation and has a good shelf life. The food industry has responded to these expectations - for example, by developing techniques which involve milder processing, fewer additives, less fat, salt and sugar, using environment friendly packaging and by introducing fabricated foods. We are now at the stage where some foods are completely fabricated. Some examples of these foods are margarines, extruded savoury snacks and some fruit flavoured drinks. Thus the changing trends in food habits race from hunter gatherer to farming, farming to process and convenience foods and now it is in the demand of high quality fabricated foods. So with this changing trend a convenience food from different raw materials *viz.* rice, Nendran banana and cassava which will form a snack food that will provide nutritious enrichment and food safety was made as the strategy.

2.2 Raw materials

2.2.1 Rice (*Oryza sativa*)

Bryant *et al.* (2001) studied on the functional and digestive characteristics of extruded rice flour and reported that the data for water absorption and water solubility index for each rice flour and temperature, trends with respect to flow rates were described by fitting a quadratic, log-linear or mean regression model. It showed the R^2 range for these regression models was 0.39 - 0.95. The ANOVA indicated significant main effects for rice, temperature and flow rate as well as a significant temperature by flow rate interaction.

Charunuch *et al.* (2003) investigated on brown rice for basic raw materials in the production of direct expansion extruded snack by twin screw extruder at varying feed moisture (13, 15 and 17%) and screw speed (250, 300 and 350 rpm). Results indicated that main factor (feed moisture or screw speed) 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 extrudate with higher expansion ratio of 8.07 ± 0.79, lower bulk density of 0.07 ± 0.01, higher water solubility index 28.40 ± 2.49 and broad peak in texture measurements for both varieties of brown rice. Owing to the effect of feed moisture and screw speed which were significant on physical properties of extrudates, the appropriate operating conditions was at lower moisture content (13%) and higher screw speed (350 rpm) to achieve expandable structure.

The effects of drying methods and storage time on the aroma and milling quality of rice (*Oryza sativa* L.) were analyzed by Wongpornchai *et al.* (2003) and found that the methods that employed at lower temperature appeared to provide higher concentrations of the key aroma compound, 2-acetyl-1-pyrroline, and lower amounts of the off-flavour compounds, *n*-hexanal and 2-pentylfuran, regardless of the storage time. The sun-drying method yielded contrasting results. Overall, during 10 months storage, as the time increased, 2-acetyl-1-pyrroline concentrations decreased where as *n*-hexanal and 2-pentylfuran contents increased. Head rice yield was most clearly affected in the sample dried by hot air at 70°C, giving a percentage yield slightly less than half of those obtained by the other drying methods. However, no significant variation in the percentages of whiteness was observed among the rice samples obtained from the different drying methods and storage times.

Arora *et al.* (2007) optimised the process parameters for milling of enzymatically pre-treated basmati rice. The optimum process parameters for minimum percentage of brokens and good cooking quality were 0.0015 g/ml of cellulase enzyme concentration, 40°C of pre-treatment temperature and 2 min of pre-treatment time. The process parameters also showed significant effect on broken percentage, time of polishing and optimal cooking time.

Jasim *et al.* (2007) analysed the effect of HP treatment on rheological, thermal and structural changes in basmati rice flour slurry. Rice flour dispersions exhibited a gradual liquid–solid gel transformation as they gelatinised or denatured and behaved as viscoelastic fluid following HP treatment. Mechanical strength of pressurised gel increased with applied pressure and rice concentration. Differential scanning calorimeter thermo grams of rice slurry measured after HP treatment indicated a reduction in peak enthalpy in proportion with the extent of gelatinisation or denaturation of starch and proteins. Pressure-treated rice samples had a progressively lower gelatinisation temperature. A 15 min HP treatment at 550 MPa was found sufficient to complete gelatinisation of protein free isolated rice starch while the slurry required 650 MPa. The presence of proteins might have been responsible for the slower starch gelatinisation in the rice slurry during pressure treatment.

2.2.2 Banana (*Musa paradisiaca*)

Ruales *et al.* (1989) studied on the biochemical qualities of banana flakes made of banana pulp and full-fat soya flour, showed a chemical score of amino acid composition as 89, net protein utilization (NPU) as 55·9, the biological value (BV) as 67·9 and true digestibility (TD) as 83·1.

Lois *et al.* (2003) reviewed on the carotenoid rich bananas and reported that these which are rich in provitamin A carotenoids may offer a potential food source for alleviating vitamin A deficiency, particularly in developing countries. Bananas are an ideal food for young children and families for many regions of the world, because of their sweetness, texture, portion size, familiarity, availability convenience, versatility, and cost. Foods containing high levels of carotenoids have been shown to protect against chronic disease, including certain cancers, cardiovascular disease, and diabetes. Because the colouration of the edible flesh of the banana appears to be a good indicator of likely carotenoid content, it may be possible to develop a simple method for selecting carotenoid-rich banana cultivars in the community.

2.2.3 Cassava (*Manihot esculenta*)

Badrie *et al.* (1991) conducted a study on the effect of extrusion variables on cassava extrudates and reported that cassava flour extruded under varying parameters showed an optimum expansion (2.82) at 11% feed moisture, die temperature (120 to 125°C), screw speed, 520 rpm and feed rate, 250 g/min. Effect of feed moisture was most significant on expansion, bulk density and extrudates moisture. Increasing the temperature, increased expansion and water solubility, but decreased bulk density, extrudates moisture and water absorption. Screw speed most influenced water absorption and solubility. Extrudates moisture correlated negatively ($P<0.01$) with extrudates expansion. Water solubility index of extrudates negatively correlated ($P<0.05$) with extrudates moisture and water absorption index but correlated positively ($p<0.05$) with expansion.

Jisha. *et al.* (2010) conducted a study on the nutritional, functional and physical properties of extrudates from blends of cassava flour with cereal and legume flours and found that low protein and poor functionality limit the use of cassava flour in snack foods, which were modified using blends with cereal or legume flours. Extrudates were prepared at a screw speed of 100 rpm and die temperature of 180°C with different mixed blends from native, malted flour, gram malted cassava and malted and pregelatinised with cereal. Malted flour based extrudates had lower content than native flour. Gram malted cassava based blends gave products with the highest protein. *In vitro* starch digestibility was the highest for pre-gelatinised flour based mixes. Extrudates with low fat and energy have scope as low calorie snacks for obese and diabetic people.

2.3 Conditioning and blending of raw materials

Singh *et al.* (1994a) produced a number of snack products by extrusion forming and then baking and reported that dough mixing time, die shape, and post extrusion processing steps influenced the structure and the texture of the final product.

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

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

Narbutaite *et al.* (2008) studied on the effect of extrusion conditions and cereal types on the functional properties of extrudates in fermentation media and revealed that functional properties of extrudates are strongly related to the cereal type and feed moisture content. The higher feed moisture content (50%) influenced the higher water solubility index of 11%, yet the lower water absorption index of 2.3. The highest values of water solubility index and water absorption index were demonstrated by barley, triticale and rye flour extrudates with 10.1% and 2.31%. Meanwhile, the lowest values of functional properties were observed on triticale, rice and wheat extrudates with 1.8% and 0.63% respectively.

2.4 Extrusion

Extrusion is done with relatively dry materials to plasticise food mass, to reduce microbial load, denature enzymes, gelatinise starch, polymerise proteins and most importantly texturise the end product into a desirable form. Harper (1981) emphasised the importance of extrusion cooking over conventional cooking methods because of versatility, efficiency and economy of space and labour. Transport of material through single screw 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 to compress particles in to a homogenous mass, a kneading section to compress, mix and shear the plasticized food and in high shear screws, a 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.

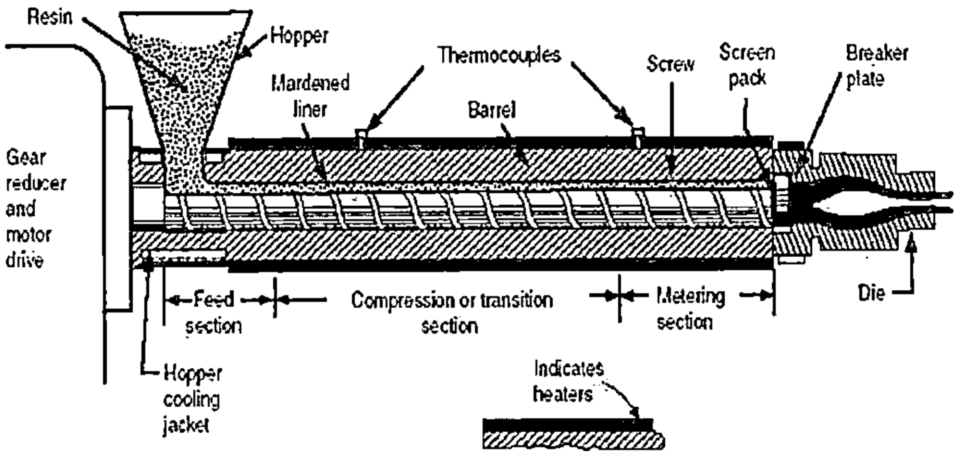

Fig. 2.1 Single screw extruder (Ref: Fellows, 2000)

Single screw extruders have lower capital and operating costs and require less skill to operate and maintain than twin screw machines (Fellows, 2000). Ever since extrusion involves simultaneous mixing, kneading and cooking, it causes a large number of complex changes to a food, including hydration of starches and proteins, homogenization, gelation, shearing, melting of fats, denaturation or re-orientation of proteins, plastification and expansion of the food structure. For many years the empirical knowledge of extruder operators outstripped scientific theory of the sequence and nature of these interactions and their effects. The two factors that most influence the nature of the extruded product are the rheological properties of the food and the operating conditions of the extruder. However, computer modeling of fluid flow behavior and heat transfer inside the extruder barrel has more recently led to a greater understanding of the operation of extruders (Harper, 1989).

Extrusion technology has gained in popularity due to following reasons (Fellows, 2000)

- *Versatility* - A very wide variety of products are possible by changing the ingredients, the operating conditions of the extruder and the shape of the dies. Many extruded foods cannot be easily produced by other methods.

• *Reduced costs* - Extrusion has lower processing costs and higher productivity than other cooking or forming processes. Some traditional processes, including manufacture of cornflakes and frankfurters, are more efficient and cheaper when replaced by extrusion.

• *High production rates and automated production* - Extruders operate continuously and have high throughputs. For example, production rates of up to 315 kg/h for snack foods, 1200 kg/h for low-density cereals and 9000 kg/h for dry expanded pet foods are possible.

• *Product quality* - Extrusion cooking involves high temperatures applied for a short time and limited heat treatment therefore retains many heat sensitive components.

• *No process effluents* - Extrusion is a low-moisture process that does not produce process effluents. This eliminates water treatment costs and does not create problems of environmental pollution.

Lue *et al.* (1991) performed extrusion cooking of corn meal and sugar beet fibre. Studies were made on the expansion properties, starch gelatinisation and dietary fibre content. Sugar beet fibre of different particle size (10-200 mesh) was mixed with corn meal and extruded with a twin screw extruder and reported that increasing the percentage of sugar beet fibre from 10 to 30% resulted in less radial expansion of 0.83 cm and more elongation of the products *i.e* from 2.09 to 4.1 cm. Decreasing the particle size of sugar beet fibre improved the radial expansion from 1.03 to 1.15 cm and longitudinal expansion from 2.09 to 3.33 cm at 10% beet fibre.

A study for preparing extruded snack from rice (*Oryza sativa .L*) and chick pea (*Cicer arietinum. L*) found that, while increasing the proportion of chick pea in the blends the diametric expansion and water holding capacity (W.H.C) decreased but peak shear force and bulk density increased (Bhatnagar *et al.*,1993).

Iwe and Ngoddy (1998) studied proximate composition and functional properties of extrusion cooked soybean and sweet potato blends at 80 rpm, using a die of 6 mm. Extrusion temperature was maintained at 100 ± 3°C and the results indicated that increase in sweet potato content increased carbohydrate values from 34.85 to 80.12%. Protein increased from 4.55 to 50.92% with increase in soy flour from 0 to 100%. Feed moisture did not significantly affect extrudate composition. Increase in sweet potato content and feed moisture increased expansion ratio. Bulk density decreased with decrease in feed moisture from 25 to 18%, but increased with increase in soy flour.

Jiang and Vasanthan (2000) studied the effect of extrusion cooking on the primary structure and water solubility of β-glucans from regular and waxy barley. Water-soluble β-glucan from native and extrusion-cooked barley flours of two barley cultivars, candle (a waxy starch barley) and phoenix (a regular starch barley), was isolated and purified. The purity of β-glucan samples was 85 to 93% (d.b) for candle and 77 to 86% (d.b) for phoenix. The water solubility of β-glucan in the native and extruded flours was different from that of the purified β-glucan samples. The solubility of β-glucan in the native and extruded candle flour was substantially higher 41.52 ± 0.17 than that of β-glucan 32.00 ± 0.14 in phoenix.

A study on physico chemical characteristics, nutritional quality and shelf life of pearl millet based extrusion cooked supplementary foods was done by Sumathi *et al.* (2007). The cold and cooked paste viscosity, the melt energy and also the carbohydrate digestibility of the extrudates indicated that the products were pre-cooked and were of ready-to-eat nature. The millet was blended with grain legumes (30%) and also with defatted soy (15%) separately and extruded to prepare ready-to-eat nutritious foods suitable as food supplements to children and mothers. The foods based on the millet and legumes and also the millet and soy contained 14.7% and 16.0% protein with 2.0 and 2.1 protein efficiency ratio values, respectively. The shelf-life of the foods was about 6 months in different flexible pouches at ambient storage conditions.

Chaiyakul *et al.* (2009) studied the effect of extrusion conditions on physical and chemical properties of high protein glutinous rice-based snack and came to conclusion that high protein nutritious snack obtained from glutinous rice flour; vital wheat gluten and toasted soy grits even at increased feed moisture and reduced barrel temperature. The conditions providing high expansion, low bulk density, and low shear strength of extruded snack were resulted at feed moisture of 20 g/100 g w.b and 180°C.

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

2.5 Optimisation and standardisation of process parameters

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

Modelling product quality during twin screw food extrusion done by Lo *et al.* (1998) showed that high screw speed processes produced an extrudate with low moisture content, bulk density, colour and browning index and reported a marked effect on the extrudate colour value. High screw speed generated a high shear environment which converted the input energy into high product temperature. The lighter colour of the extrudate might be caused by the heat decomposition of the corn meal pigment. Increased screw speed also resulted in a greater radial expansion. It also resulted in a reduction of WAI and an increase in WSI. The reduction in WAI reflects the degradation of starch molecules. WSI increased with the severity of the thermal treatment in the extruder. Increased feed rate raised the bulk density, colour and browning index. The extrudates with high bulk density were darker in colour and increased feed rate increased expansion.

Plahar *et al.* (2003) standardised an extrusion cooking process for production of a high protein weaning food based on peanuts, maize and soybeans. Major factors evaluated included the effects of blend formulation, extrusion temperature and feed moisture content on ease of extrusion and product quality characteristics. Results showed that the bulk density and hardness increased from 180.4 ± 9.2 to 250.4 ± 8.2 kg/m^3 and 7.8 ± 0.9 to 8.0 ± 1.3 N, respectively while expansion index decreased from 4.3 ± 0.8 to 3.4 ± 0.2 with increase in feed moisture content of 13 to 15% at die temperatures of 60 to 125°C and screw speed of 500 rpm.

Nath *et al.* (2007) performed a study on the high temperature short time (HTST) air puffed ready-to-eat potato snacks and reported the effects of process parameters *viz.* puffing temperature (175-275°C), puffing time (15-75s), initial moisture content (30-40%) and air velocity (2.4-4.8 m/s) on quality attributes such as expansion ratio, hardness, ascorbic acid loss and overall acceptability of the products. The optimum product qualities in terms of expansion ratio (4.7 times), hardness (11.21 N) and overall acceptability (7.56) were obtained at puffing temperature of 235.46°C, puffing time of 51.11s, initial moisture content of 36.74% and air velocity of 3.99 m/s.

Aylin *et al.* (2008) studied on twin-screw extrusion of barley–grape pomace blends to evaluate the effects of independent variables, namely die temperature (140-160°C, screw speed (150-200 rpm) and pomace level (2-10%, d.b) on product responses (expansion, bulk density, texture and color). Multiple regression equations were obtained to describe the effects of each variable on product responses. The product responses were most affected by changes in temperature, pomace level and to a lesser extent by screw speed. However, graphical optimisation studies resulted in 155-160°C, 4.47–6.57% pomace level and 150–187 rpm screw speed as optimum variables to produce acceptable extrudates. The results suggest that grape pomace can be extruded with barley flour into an acceptable snack food.

Sibel *et al.* (2008) studied on the response surface methodology for evaluation of physical and functional properties of extruded snack foods developed from food-by-products 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 of the extruded snack food based on rice grit in combination with fruit waste, durum clear flour and PDHF. Response variables are bulk density, porosity, water absorption and water solubility indices and sensory properties of the extruded snacks. Increasing PDHF content caused increase in bulk density and water solubility index, but decrease in porosity and water absorption index of the extruded snacks. Changing process conditions affected the physical and functional properties of produced snacks. The sensory evaluation of extrudates suggests that extrusion of PDHF, fruit waste and durum clear flour in combination with rice grit can produce acceptable extruded snack.

Jiang *et al.* (2011) studied an experimental approach to optimise several processing conditions when extruding soybeans such as bore diameter, temperature, moisture and rotation speed on extrusion efficiencies. As a result, 6 quadratic regression equations of experimental indices under 4 extrusion conditions were separately established. Taking into account the importance of these indices to the nutritional value of soybeans they proposed a set of comprehensive indices to evaluate extrusion efficiency using a fuzzy comprehensive evaluation method.

2.6 Physical Properties

2.6.1 Expansion ratio

Peri *et al.* (1983) cited by Gujsha and Khalil (1990) reported that the expanded volume of cereal is due to the starch content.

Chinnaswamy and Hanna (1988) studied the relationship between amylose content and extrusion-expansion properties of corn starches. Corn starch upto 70% amylose contents were extrusion cooked at different temperatures of 130 to 160°C and moisture contents of 0 to 50% (d.b). The product quality measures of expansion ratio, shear strength and bulk density were studied in relation with the starch amylose content. The expansion ratio of starch increased from 8 to 16.4 as amylose content increased from 0 to 50% and then decreased at any temperature and moisture content.

Chen and Yeh (2001) studied the effect of amylose content on expansion of extruded rice pellet and reported that expansion ratio of rice pellets decreased from 19.25 ± 0.16 to 11.32 ± 0.08 as the amylose content increased from 20 to 80%. Maximum expansion of 19.25 ± 0.16 occurred at 10% equilibrium moisture due to the transition of the pellet from brittle to ductile. Pellet transparency correlated well with expansion ratio and appeared to be a good quality index.

Dandamrongrak *et al.* (2011) conducted experiments to study effect of initial conditions on the expansion ratio of two grains in a laboratory scale, single speed, single screw extruder. Rice and mung bean were used as the material. Three different initial moisture contents of 15, 17.5 and 20% were adjusted for the grains and classified into three groups of less than 14, 12 to 14 and greater than 12 mesh according to particle sizes. Expansion ratio was measured at a constant barrel temperature of 190°C. Response surface methodology was used to obtain optimum conditions between moisture content and particle size of the materials concerned. The lower feed moisture content of 15% provided a better characteristic in terms of high expansion ratio.

Deshpande and Poshadri (2011) studied on the physical and sensory characteristics of extruded snacks prepared from foxtail millet based composite flours and reported that the extrusion of 100 percent barley under the conditions of 240°C and screw speed of 125 rpm resulted in limited expansion of 3.6.

2.6.2 Bulk density and product density

Berglund *et al.* (1994) conducted physicochemical and sensory evaluation of extruded high-fibre barley cereals using a co rotating twin screw extruder. Cereals produced by extrusion of 100% barley had limited expansion and high bulk densities. When blended with 50% rice, the bulk densities were reduced by 50%, and appearance was similar to that of the 100% rice cereal.

Wang *et al.* (1999) studied the effects of moisture, screw speed and barrel temperature on the physical, functional and nutritional characteristics of texturized pea protein using a twin-screw extruder. Increased dough moisture increases product bulk density but decreases water-holding capacity. Raising the screw speed from 135 to 245 rpm reduced bulk density from 0.57 to 0.32 g/cm^3 but increased water-holding capacity from 1.92 to 2.21 g H_2O/g. Bulk density decreased as barrel temperature was increased, whereas water-holding capacity increased.

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 vitamins, minerals and amino acids. Mixed ingredients were adjusted to 16.5 ± 0.5% moisture content and fed at 365 g/min to extrusion process at 165 to 167°C melt temperature by a twin screw extruder operated at 300 rpm. The obtained snack had expansion ratio, bulk density and compression force of 3.9, 58 g/l and 60.17 N, respectively and was subsequently sensory evaluated (9-point hedonic scale) for preference and acceptance together with control samples and popular market snacks.

Cha *et al.* (2001) studied the physical properties of starch-based foams as affected by extrusion temperature and moisture content and reported that the properties of the foams depend largely on the starch moisture content and extrusion conditions. Moisture adsorption isotherms, bulk densities, and expansion ratios of the starch-based foams were studied. The moisture adsorption isotherms of starch-based foams were raising sigmoid curves similar to those of grains and grain products. The bulk density of the starch-based foams decreased from 30 to 25 kg/m^3 as the extrusion temperature increased 120 to 180°C. The highest expansion of 33 occurred when the blends containing normal wheat starch were extruded at 140°C.

Zeinab *et al.* (2010) studied on the physico-chemical characteristics of extruded snacks enriched with tomato lycopene and summerised that increasing the processing temperature from 140°C decreases the product density although the mean density value of products at 180 and 190°C was similar.

2.6.3 Apparent density and porosity

Studies on the twin screw extrusion modification of a corn fiber and corn starch extruded blend carried out by Artz *et al.* (1990) resulted that increase in water holding capacity was probably due to increase in starch gelatinisation and a concurrent reduction in the level of fiber crystallinity as the extrusion temperature was increased. An increase in porosity due to increase in expansion as a result of extrusion at higher temperatures also enhanced the WHC.

Choudhury and Gautam (1999) investigated on the characteristics of extrudates produced by twin screw extrusion of rice flour and presented that screw configuration effect on overall expansion was opposite for apparent density. An increase in die temperature, as a result of screw configuration effect decreases apparent density and increases overall expansion.

Yacu (1995) cited by Choudhury and Gautam (1999) reported that when die temperature was low, less flashing occurred at the die resulting in less overall expansion. A negative correlation between apparent density and overall expansion (R^2=0.97) was observed.

Emir *et al.* (2004) studied the expansion characteristics of a nutritious extruded snack food using response surface methodology to analyze the effect of screw speed (220 - 340 rpm), feed moisture (11.0 - 15.0%, w.b) and feed rate (22.0 - 26.0 kg/h, w.b) on the physical properties (bulk density, expansion, porosity). Expansion and porosity increased with screw speed and feed moisture whereas the opposite was observed for bulk density. Radial expansion was found to be a better index to measure the extent of expansion than the axial and overall expansions, indicated by a higher correlation coefficient. The results obtained in this study can be used for the optimisation of extrusion variables in terms of nutritional value and consumer acceptability of the products.

Quing *et al.* (2005) studied on the effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice based expanded snacks and results showed that true density increases with cereal starch in extrudates. It also explained that apparent density increased with feed rate, moisture content and decrease with temperature.

Thymi *et al.* (2005) studied on the structural properties of extruded corn starch such as apparent density, true density; expansion ratio and porosity of extruded corn grits with varied feed rate (1.16–6.44 kg/h), screw speed (150–250 rpm), product temperature (100-260°C) and feed moisture content (12 to 25 kg/100 kg w.b). Extruded product apparent density, porosity and expansion ratio were found to be dependent on feed moisture content, residence time and temperature while they were not affected by screw speed. More specifically, the apparent density of extruded products had an increasing trend with feed moisture content and residence time, while it decreased with product temperature. Porosity and expansion ratio of extruded products decreased significantly with feed moisture content and residence time, while temperature rise resulted in products of higher porosity and expansion ratio.

2.6.4 Moisture content & water activity

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

Agata *et al.* (2006) studied on the influence of water activity on acoustic emission of flat extruded 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 than in high frequencies. 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 68.1ls, and their energy statistically was not dependent on water activity. However, number of acoustic emission events depended strongly on water activity and decreased almost 20 fold in the a_w range from 0.03 to 0.75.

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

Juan *et al.* (2010) studied the effect of sugar and water contents on non-expanded cassava flour extrudates with a twin screw extruder and reported that SME and WSI decreased as a function of water and sucrose contents. WAI properties were influenced by water content. A non antiplasticising effect of the sucrose content was observed on pasting properties, suggesting that sucrose did not reduce the availability of water available for gelatinising cassava flour during the extrusion process. The nature of the optimum point was characterized as a saddle point for WAI, WSI and

BD, whereas SME showed a maximum. The results indicated to be valuable for the production of non-expanded cassava flour extrudates with desirable functional properties for specific end users.

Meng *et al.* (2010) studied a chickpea flour-based snack using response surface methodology to study the effects of feed moisture content (16 - 18%), screw speed (250 - 320 rpm) and barrel temperature (150 – 170°C) on extruder system parameters (product temperature, die pressure, motor torque, specific mechanical energy and physical properties (expansion, bulk density, hardness). Product temperature and die pressure were affected by all three process variables, while motor torque and specific mechanical energy were only influenced by screw speed and barrel temperature. Desirable products, characterised by high expansion ratio and low bulk density and hardness, were obtained at low feed moisture, high screw speed and medium to high barrel temperature. Product temperature values ranged between 164.1 and 182.4°C. The results showed that feed moisture content had a negative linear effect ($p < 0.01$), while screw speed and barrel temperature had positive linear effects ($p < 0.01$) on expansion.

Pilli *et al.* (2011) studied on the starch-lipid complexes in model system and real food produced using extrusion-cooking technology *ie.*, (rice starch added with oleic acid) and real food (rice starch added with pistachio nut flour). Both formulas were extruded at the same processing conditions (temperature profiles, screw speed and water feed content). The formation of starch-lipid complexes in real food is strongly dependent on water feed content. In fact, at barrel temperature of 128°C, the highest melting enthalpy of real food (6.7 joule/gram) was obtained only at 21% of water feed content whereas in the model system it was obtained both at 16 and 21%. These results point out the importance to consider all components present in the extruded food in order to study biopolymers modifications that occur during processing. Industrial relevance of this was the additions of lipids alter the physical and chemical properties of starchy foods.

2.7 Functional Properties

Chauhan and Bains (1988) investigated on the effect of some extruder variables on physic-chemical properties of extruded rice legume blends and reported that the magnitude of water solubility index increased perceptibly with the increase in temperature of extrusion.

Gujsha and Khalil (1990) reported on the effect of temperature on properties of extrudates from high starch fractions of navy, pinto and garbanzo beans and found that the Water Absorption Index (WAI) of pinto beans increased significantly with an increase in temperature to132°C. However, a further increase in temperature to 150°C resulted in a decrease of WAI for navy bean as decomposition or degradation of starch began to take place. The Water Solubility Index (WSI) of pinto bean increased significantly with increasing extrusion temperature. Oil absorption capacity (OAC) increased slightly with increasing temperature of extrusion. However, there were no significant differences between the OAC of all extrudates at lower temperatures (110, 120°C). It also summarised that with an increase in temperature, the expansion index of bean extrudates increased.

Bhatnagar and Hanna (1996) studied on the starch based plastic foams from various starch sources and reported that the lower water solubility index is due to the grafting of starch.

Osman *et al.* (2000) studied the oil absorption characteristics of a multigrain extruded and fried snack product as a function of extruder screw speed and cooking temperature. The extruded product was produced using a co rotating twin screw extruder, dehydrated to uniform moisture content and subsequently deep-fat-fried at 192 ± 1°C for 10 to 40s to complete expansion. Significant response surface methodology models were developed for oil absorption and extrudates water absorption index. According to the lowest oil model, absorption (19.9%) was obtained with an extruder screw speed of 218.6 rpm and a cooking temperature of

117.8°C. Water absorption index reached a maximum of 8.8 at a screw speed of 221.9 rpm and a cooking temperature of 109°C. Oil absorption characteristics and extrudate water absorption index were significantly correlated ($r = -0.84$, $P = 0.0002$).

Jorge and Maria (2003) studied the effect of extrusion conditions on the quality of cassava starch extrudates. Response surface methodology was used to determine the effect of the concentration of cassava bran (10–50%), barrel temperature (150–210°C), feed moisture (16–20%) and screw speed (120–180 rpm) on the characteristics of the dried extrudates. The water absorption index and water solubility index were affected by bran level, screw speed and temperature, while only moisture and temperature influenced specific volume. The maximum radial expansion 2.51 was found when all the independent variables were at their lowest levels. Lowest-density extrudates were obtained at 16–18% moisture content and 180–200°C. An increase in bran level from 20 to 60%, increases water absorption index from 5.42 to 7.88 but decreases water solubility index from 20.43 to 11.63% when the temperature was higher than 170°C. Screw speed had a slight effect on those responses, decreasing water absorption and increasing water solubility when changed from 120 to 180 rpm.

2.8 Texture Analysis

Agulera *et al.* (1984) studied on the air classification and extrusion of navy bean fractions and reported that the increase in hardness coincided with an increase in expansion of the extrudates. This property which is a physical quantification of the textural properties, was not significantly different for all extrudates under concern. They also reported that a similar trend for pure corn, where increases in extrusion temperature gave more expanded and softer products.

Amer *et al.* (1984) performed a study on the sensory and instrument measurement of apple texture and summerised the relationships among selected sensory textural attributes. Sensory crispness, hardness, and toughness were closely related to each other however, combinations of several texture profile variables in regression equations generally improved prediction of sensory attributes. Experimental Instron texture profile variables, especially force near midcompression, or the experimental variations on the customary variables, such as mean forces around failure and around full compression, were selected for prediction equations more frequently than the customary variables.

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

2.9 Colour characteristics

Iwe *et al.* (2000) studied on the effect of extrusion cooking of soy–sweet potato mixtures on browning index of extrudates and showed the effect of processing variables such as feed composition, screw speed and die diameter. Response surfaces for the parameters were generated using a second degree polynomial. Increase in feed composition and screw speed increases browning index, but decreases die diameter and feed composition increases browning index.

Ali *et al.* (2008) performed a study on colour changes occur in kiwifruit during dry process in order to determine the magnitudes of the parameters for a corresponding colour change model. The drying experiments were carried out under five air temperatures of 40, 50, 60, 70 and 80°C, at air velocity of 1.0 m/s and kiwifruit slice thickness of 4 mm. The colour parameters for the colour change of the materials were quantified by the Hunter *L* (whiteness/darkness), *a* (redness/greenness) and *b* (yellowness/blueness) system. These values were also used for calculation of the total colour change (delta *E*), chroma, hue angle and browning index. The values of *L* and *b* decreased, while values of *a* and total colour change (delta *E*) increased during hot air drying. The mathematical modeling study of colour change kinetic showed that changes in *L*, *b* values, chroma and browning index fitted well to the first-order kinetic model while delta *E*, *a* value and hue angle followed the zero order kinetic.

Cemalettin and Mustafa (2010) performed modelling the effects of processing factors on the changes in colour parameters of cooked meatballs for studying the simultaneous effects of processing variables such as fat (10-30%), wheat bran (5-15%) and NaCl (0-2%) on the colour changes (L, a, b, whiteness index, saturation index, hue-angle, total colour difference and browning index) of cooked beef meatballs. The results showed that the processing variables had a significant effect on the colour parameters. L and whiteness index values of meatballs were decreased by the wheat bran addition. The 'b' and saturation index values were increased by fat addition. ΔE value was decreased by the wheat bran addition. Increase in the fat content increases the browning index values and salt addition showed an inverse effect.

2.10 Machine properties

Singh *et al.* (1994 b) investigated on the effect of temperature on the extrusion behaviour of flour from sound and sprouted wheat and made results that the specific energy requirement decreased with the increase in temperature. A reduction of 23 - 25% in specific energy requirement for extrusion of flours at 190°C was observed as compared to their counterparts extruded at 145°C and products extruded at 175°C and 190°C did not show appreciable differences with respect to texture. The overall acceptability of extrudates increased significantly with increase in temperature.

Milford *et al.* (1997) studied on the physical and functional properties of twin screw extruded whey protein concentrate corn starch blends and suggested that the higher torque or pressure did not necessarily result in higher expansion ratio or lower unit density. Tapioca corn starches gave highly expanded products but pressures at the die, for these foams were inversely related to expansion ratio for different types of additives.

Adrian *et al.* (2008) studied on the extrusion cooking of a maize-soybean mixture with a brabender single screw extruder. A factorial experimental design was used to analyze the combined effects on radial expansion of two maize endosperm hardness, extrusion temperature and grits moisture content. Surface response methodology was used to study the effects of extrusion conditions on extrudates properties, taking grits moisture (14-18%) and extrusion temperature (155-185°C) as factors. Specific mechanical energy consumption, radial expansion, specific volume and product texture were determined on each extrudate sample. For the maize-soybean mixture, softer maize endosperm resulted in more expanded product than harder one. Texture scores were directly related with specific volume. The best extrusion conditions to obtain expanded products and precooked flour from an maize/soybean (88/12) mixture were 170°C and 14% moisture.

Karunanithy *et al.* (2011) studied on the influence of extruder and feedstock variables on torque requirement during pretreatment of different types of biomass experiments using response surface analysis and reported that extrusion appears to be the more viable continuous biomass pretreatment methods. Torque is an important factor which relates the power consumption during extrusion. The study shows the influence of extruder barrel temperature (45-225°C), screw speed (20-200 rpm), feedstock particle size (2-10 mm) and moisture content (10-50%) on torque and to propose a mathematical model to predict torque requirement during extrusion pretreatment of switchgrass, prairie cord grass, corn stover and big bluestem and statistical analyses revealed that all independent variables had a significant effect on torque.

2.11 Storage Studies

Manisha *et al.* (1997) studied on twin-screw extrusion of rice flour without a die and reported that rice flour with 14% moisture content was extruded at different barrel temperatures (80-120°C) and screw speeds (200-400 rpm). The system parameters as well as the extrudates attributes were mainly dependent on temperature whereas the screw speed imparted a lesser effect. Optimum extrusion conditions for obtaining minimum torque, specific mechanical energy (SME) and bulk density were determined. A positive linear (correlation coefficient $r = 0.78$, significant at a probability level $p \leq 0.01$) relationship existed between SME and bulk density, indicating that low-density extrudates is possible to obtain with low SME. Extrusion of rice flour without a die appears to be an alternative approach to produce processed rice flours with high water absorption index and in vitro starch digestibility.

Lin *et al.* (1998) studied on the effects of lipids and processing conditions on lipid oxidation of extruded dry pet food during storage to show effects of fat type (beef tallow and poultry fat), fat content (0-0.75 g/kg) and processing conditions (initial moisture: 1.6-2 g/kg; screw speed: 200-400 rpm) on lipid oxidation of extruded dry pet food. The results showed that the lipid oxidation rate constant of the extruded dry pet food was a function of fat types, added fat content and feed moisture content. Samples containing a higher fat content resulted in a lower rate of lipid oxidation during storage. Feed moisture content had the same effect as the fat content; the extrudates with a higher moisture content resulted in a lower lipid oxidative rate. Pet foods extruded at 300 rpm had higher lipid oxidation rate than the ones produced at 200 and 400 rpm. Lipid oxidation of the extrudates appeared to be affected mainly by the degree of extrudates expansion. Products with a higher degree of expansion, which had larger cells and thinner cell walls, were more susceptible to oxidation.

2.12 Biochemical Analysis

2.12.1 Analysis of starch, total carbohydrates, total fats and protein

Hsu *et al.* (1977) cited by Wang *et al.* (1999) reported that extrusion texturistion has improved protein digestibility and protein nutritional quality. The functionality of extrusion texturised products is affected by several parameters including moisture content, barrel temperature, screw speed and screw configuration.

Linko *et al.* (1981) cited by Gujsha and Khalil (1990) reported a decrease in expanded volumes of cereals with increasing amounts of protein and lipids.

Bhattacharyya *et al.* (2005) studied the physico-chemical characteristics of extruded snacks prepared from rice, corn and taro by twin screw extrusion. Sodium dodecyl 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 lowest value for the breaking force of extrudates (13.03 N ± 0.88) was found for the extrusion at 159°C.

Dias *et al.* (2008) studied the development and assessment of acceptability and nutritional properties of extruded snacks from germ-free maize flour. The product presented a calorie reduction of up to 47.5% in comparison with products available on the market. The total fat of the extruded product was found to be less than 0.1 per cent as that compared to the snacks found in the market.

Dias *et al.* (2009) studied the increasing concerns about the health risks of saturated and trans fatty acid consumption that led to the development of alternative agents for this use. It shows the use of rapeseed oil as a replacement for partially hydrogenated vegetable oil in snack flavouring. Products with several different rapeseed oil contents were designed, packed, and then stored for twenty weeks at room temperature. Fatty acids compositions, reactive substances, shear strength and sensory acceptability were assessed throughout storage time. Total replacement reduced saturated fat by 72.5% in relation to market available snacks. Trans fatty acids were initially absent in these products.

Ernesto *et al.* (2009) studied the effects of thermoplastic extrusion process parameters (raw material moisture content and temperature) and the addition of functional ingredients (lycopene and soy protein) on quality characteristics for extruded corn snacks with the objective of developing an easy-to-eat functional product. The results showed a reduction in expansion ratio from 22.67 to 7.47 with the addition of lycopene and soy protein isolate from 0 to 0.1% and 0 to 30%, respectively. But increase in soy protein isolate content reduces instrumental hardness. Instrumental hardness was also lower for lower moisture contents and temperatures around 125°C. Red colour intensity increased with the increase in lycopene content, and decreased with the reduction in moisture content and with the increase in temperature.

2.12.2 Sensory

Jing *et al.* (1991) reported on the effects of extrusion conditions on sensory properties of corn meal extrudates and found that temperature and moisture had a significant effect on the flour aroma of extrudates. Increasing the temperature and decreasing the moisture resulted in a marked increase in toasted corn taste probably related to the chemical reactions in corn meal during extrusion cooking. Screw speed has less effect on toasted corn taste. The chemical reactions responsible for toasted corn aroma were probably also responsible for toasted flavour. The denseness of extrudates affected significantly the barrel temperature during extrusion and by the interaction between temperature and screw speed. At low temperature with decreasing screw speed, increases denseness of extrudates. Thus the crispness of the extrudates were related to the denseness of the extrudates.

Hanne *et al.* (2005) studied on the sensory quality of extruded oat, stored in light and darkness in packages with different oxygen transmission rates (including the use of an oxygen absorber), which was evaluated after 3 months of storage at 38°C and 10 months of storage at 23°C. To reduce the costly and time consuming shelf life and packaging evaluation, the possibility of reducing the number of sensory attributes to be analyzed and to accelerate shelf life testing was studied. The intensity of oat odor, paint odor and crispiness were found to describe the main differences among the samples. By increasing the temperature from 23 to 38°C for samples stored in darkness, packaging evaluation tests for extruded oat might be performed in approximately one third of the time. Changes in headspace oxygen concentration in the packages due to oxygen consumption were in agreement with the sensory changes in the oat.

Material and Methods

CHAPTER III

MATERIAL AND METHODS

This chapter deals with the methodologies used to perform the preparation of samples, blending of prepared flours, experiments on extrusion of rice, banana and cassava flour blended in different proportions under different process parameters with standardisation and optimisation. The chapter also describes the standardised methods to carry out the physical, functional, textural and machine tests to analyse the engineering qualities of the developed extrudates and storage characteristics of the best extrudates based on objective and subjective evaluation of extrudates.

3.1 Raw material

Raw materials selected for the study were rice, Nendran banana and cassava (Sreevijaya). Rice and Nendran banana were procured from local markets and the cassava roots were obtained from the CTCRI, Trivandrum.

3.2 Preparation of samples for extrusion

Raw rice procured from market was grounded with the help of a mini mill. Freshly harvested cassava obtained from CTCRI, Trivandrum was cleaned with water in order to remove the surface dirt. The cassava was skinned with a regular knife, again cleaned with running water and later, cut into chipps by using a cassava chipping machine designed at CTCRI (Plate 3. 1). The chips were dried in a hot air oven (Hamco model) at 8 ± 1°C until the moisture content of the chips were brought down to 6%. The dried chips were milled in a hammer mill (Mimac) to obtain the cassava flour (Plate 3. 2). Samples which passed through a 100 micron sieve in a sieving machine were selected for further study. These raw materials were blended in two different combinations mainly, rice: banana and rice: cassava: banana. The various proportions used under each combination are described below.

Rice: banana combinations were selected in the ratios of $R_{60}:B_{40}$, $R_{70}:B_{30}$, $R_{80}:B_{20}$ and $R_{90}:B_{10}$, with an increased amount of rice and decreased amount of banana whereas rice: cassava: banana viz. $R_{70}:C_{20}:B_{10}$, $R_{50}:C_{40}:B_{10}$, $R_{30}:C_{60}:B_{10}$ and $R_{10}:C_{80}:B_{10}$ respectively, with decreased amount of rice, increased amount of cassava and constant amount of banana powder.

Plate 3.1 Cassava chipper

Plate 3.2 Hammer mill (Mimac)

The amount of raw materials used to produce various flour blends constituted 6000 g each for every twelve treatments for the eight combinations and are indicated in Table 3.1.

Table 3. 1 Raw material used to prepare the eight blends

Blend	Quantity of raw materials
R_{60}:B_{40}	3600 g rice flour + 2400 g banana flour
R_{70}:B_{30}	4200 g rice flour + 1800 g banana flour
R_{80}:B_{20}	4800 g rice flour + 1200 g banana flour
R_{90}:B_{10}	5400 g rice flour + 600 g banana flour
R_{70}:C_{20}:B_{10}	4200 g rice flour +1200 g cassava flour + 600 g banana flour
R_{50}:C_{40}:B_{10}	3000 g rice flour + 2400 g cassava flour + 600 g banana flour
R_{30}:C_{60}:B_{10}	1800 g rice flour + 3600 g cassava flour + 600 g banana flour
R_{10}:C_{80}:B_{10}	600 g rice flour + 4800 g cassava flour + 600 g banana flour

3.3 Pre processing and standardisation of flour blends

Every 6000 g material was equally divided into three portions each for proper conditioning. Initial moisture calculated with gravimetric method. Extrusion process was effective when the flour blend had a moisture content of 16%. A calculated quantity of water was added to the blend to achieve 16% moisture content (Jisha *et al.*, 2010) for each 2000 g proportions. This flour was conditioned by storing in a refrigerator at 4°C for 10 - 15 days to attain uniform moisture migration by routine mixing every day prior to extrusion.

3.4 Extrusion process

Extrusion was carried out for these eight different blends under different temperatures varying from 170 to 200°C with an interval of 10°C, with speeds of 80, 100 and 120 rpm for the 96 treatments. The blends were extruded in a single screw stand alone Brabender extruder (Brabender Model AEV 330, Germany) (Plate 3.3 and 3.4).

Plate 3.3 Brabender single screw extruder

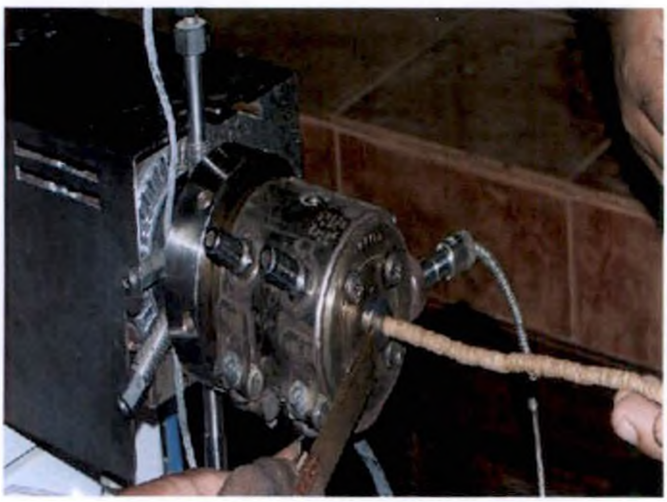

Plate 3.4 Extruder in operation

The Brabender single screw extruder consists of an aluminum hopper of 5 kg capacity through which the flour blend travels to the screw. The screw zone of the extruder can be divided into five sections. The first section allows the flour to get uniformly mixed inside the extruder. The second cooking section consists of a flat plate through which the ingredients get heated up to the required temperature. The third section consists of a rotating screw with pressure variance in which the particles of the blend are brought together. The fourth section contains an extruder die with the required size (ϕ2 mm) to enable puffing of the product and the fifth section is the cutting section where the expelled extrudates were sliced to specific length.

The temperature for the different stages and speed of the screw were set in the brabender software of the extruder, prior to the addition of mix. These settings were employed during the optimisation of the eight blends used for extrusion. The temperature setting for the feeding, compression and shearing zone were 60, 70 and 80°C with a die temperature of 170, 180, 190 and 200°C (Fig 3.1). The speed settings of the extruder were 80, 100 and 120 rpm.

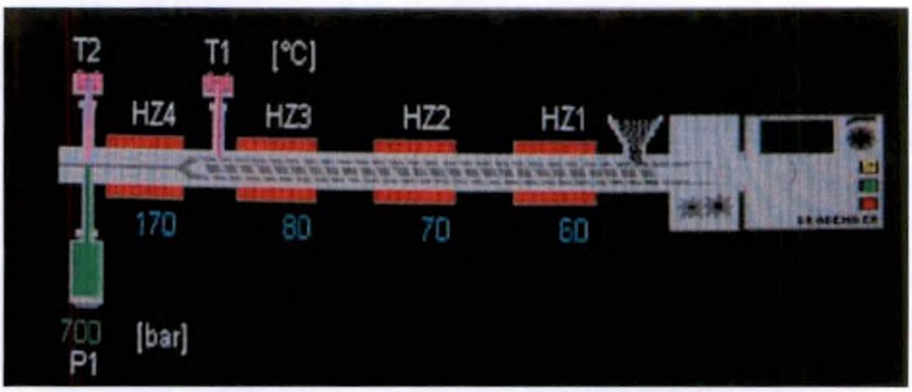

Fig. 3.1 Temperature - speed settings in a brabender extruder

The flour was introduced into the inlet of the extruder and came out through the tip of the die (ϕ2mm). The extrudates were cut at the exit to get uniform pieces of the product. The technical specifications of the Brabender extruder are mentioned in the Table 3.2.

Table 3.2 Technical details of extruder

Parameters	Stand alone extruder
Barrel diameter (mm)	19 mm
Screw length	20 - 25D
Drive power (kW)	1.5 KW
Speed (rpm)	0.2 - 150 min^{-1}
Maximum torque (N-m)	100 N-m
Maximum operating temperature (°C)	450°C
Maximum throughput (kg/h)	Approximately 5 kg/h
Identity number	837415

3.5 Experimental method

The blends of rice: banana and rice: cassava: banana in eight different combinations of P1 (R_{60}:B_{40}), P2 (R_{70}:B_{30}), P3 (R_{80}:B_{20}), P4 (R_{90}:B_{10}), P5 (R_{70}:C_{20}:B_{10}), P6 (R_{50}:C_{40}:B_{10}), P7 (R_{30}:C_{60}:B_{10}) and P8 (R_{10}:C_{80}:B_{10}) were extruded at temperatures of 170, 180, 190 and 200°C at speeds of 80, 100 and 120 rpm each. Kurkure was selected as the control which was taken as the 97th treatment inorder to compare the quality of the snacks. Organoleptic qualities of these processed snacks were done using standard engineering properties including physical, functional, colour, textural and biochemical assessments. Each 12 treatments of the 8 blend took a period of 15 – 20 days duration for development and primary analysis.

The second stage of work included storage studies which were done with selected extrudates. The selection of extrudate samples was based on expansion ratio and bulk density. Storage studies of these samples were done in laminated aluminium pouches with nitrogen flushing. The quality parameters of these extrudates including control were assessed using textural and biochemical analysis.

3.6 Physical properties of extrudates

The physical properties of the extrudates are related with the molecular modifications that occur during extrusion cooking. The physical properties of the extrudates including expansion ratio, bulk density, particle density, apparent density, porosity and water activity were determined in triplicate following the standard methods (Charunuch *et al.*, 2003).

3.6.1 Average diameter

The diameter of the extruded product was determined using a Mitutoyo digital vernier calliper (least count 0.01 cm). Average diameter was calculated from three intermediate diameters, each of ten randomly selected samples from every treatment.

3.6.2 Expansion ratio

One of the most important physical characteristics of any extrudate is its puffing properties. Expansion ratios of the extrusion cooked starches were calculated by dividing average diameter of extrudates with the diameter of die orifice (Plate 3.5) and the cross-sectional area of the extrudates with the cross sectional area of the die orifice (Jhoe *et al.*, 2009).

3.5.1 Flow chart for the production of RTE food from rice: banana and rice: cassava: banana mix

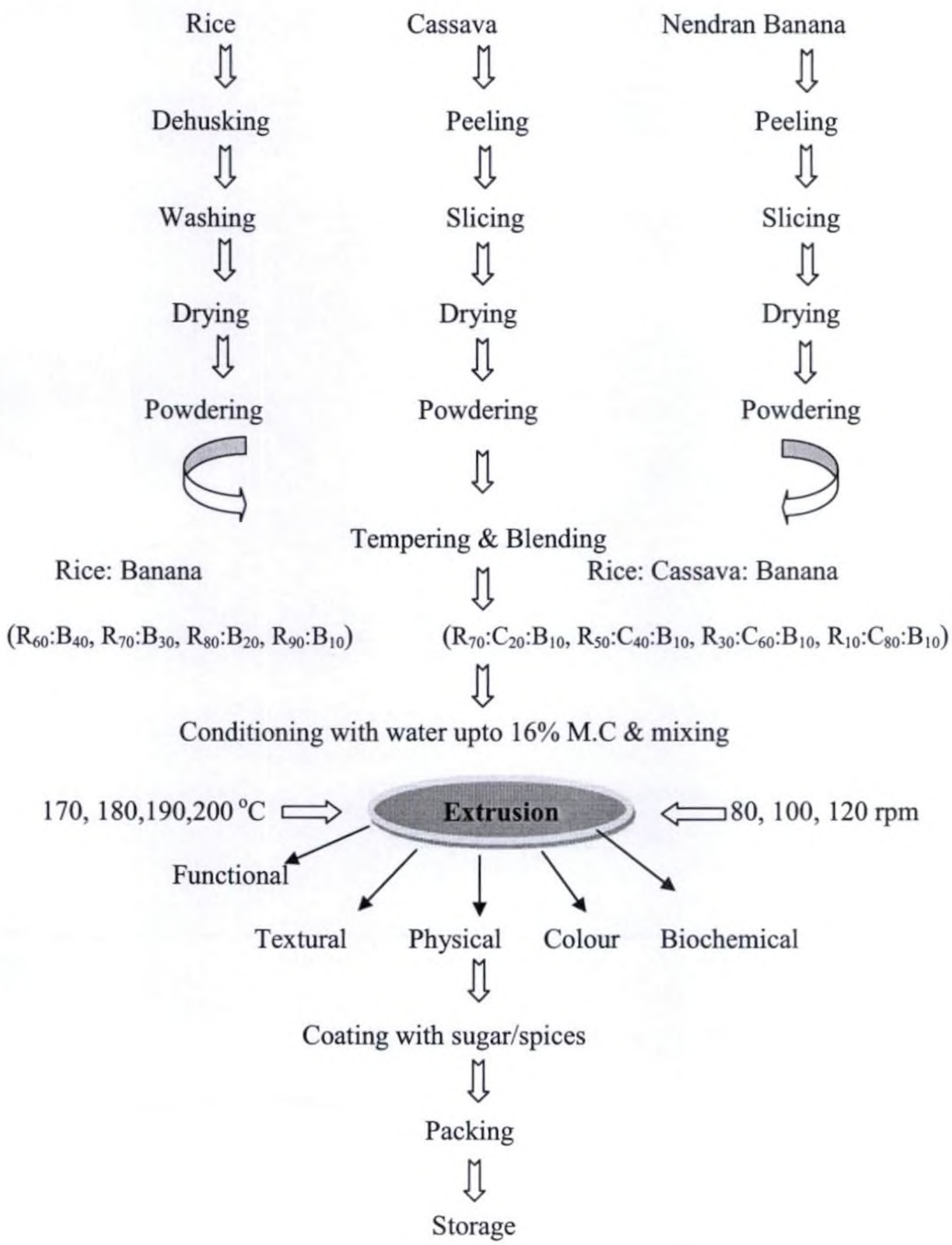

Table 3.3 Different treatments taken for the RTE product development

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) 170	180	190	200
Rice : banana combinations					
P1 (R_{60}:B_{40})	80	T1	T4	T7	T10
	100	T2	T5	T8	T11
	120	T3	T6	T9	T12
P2 (R_{70}:B_{30})	80	T13	T16	T19	T22
	100	T14	T17	T20	T23
	120	T15	T18	T21	T24
P3 (R_{80}:B_{20})	80	T25	T28	T31	T34
	100	T26	T29	T32	T35
	120	T27	T30	T33	T36
P4 (R_{90}:B_{10})	80	T37	T40	T43	T46
	100	T38	T41	T44	T47
	120	T39	T42	T45	T48
Rice : cassava : banana combinations					
P5 (R_{70}:C_{20}:B_{10})	80	T49	T52	T55	T58
	100	T50	T53	T56	T59
	120	T51	T54	T57	T60
P6 (R_{50}:C_{40}:B_{10})	80	T61	T64	T67	T70
	100	T62	T65	T68	T71
	120	T63	T66	T69	T72
P7 (R_{30}:C_{60}:B_{10})	80	T73	T76	T79	T82
	100	T74	T77	T80	T83
	120	T75	T78	T81	T84
P8 (R_{10}:C_{80}:B_{10})	80	T85	T88	T91	T94
	100	T86	T89	T92	T95
	120	T87	T90	T93	T96

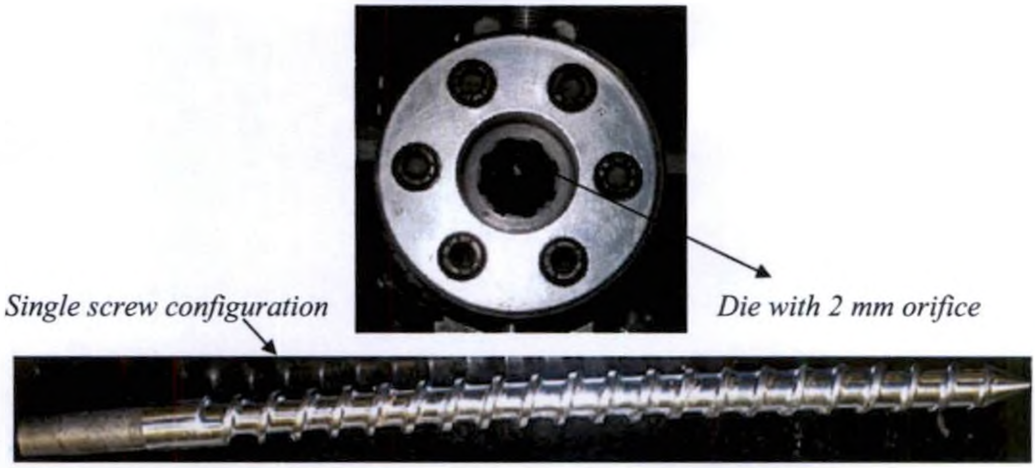

Plate 3. 5 Parts of a Brabender extruder

Therefore expansion ratio is the ratio of the diameter of the product to the diameter of the die orifice. The expansion ratio was calculated in terms of cross sectional diameters using the following formula:

$$ER1 = \frac{D_p}{D_d} \quad \text{---------------} \quad (1)$$

$$ER2 = \left(\frac{D_p}{D_d}\right)^2 \quad \text{-------------} \quad (2)$$

Where

D_p and D_d - diameters of the extrudates and the die orifice, respectively.

ER1- Expansion ratio based on diameter

ER2- Expansion ratio based on cross sectional area

3.6.3 Bulk density

Bulk density is the measure of expansion that has occurred as a result of extrusion. The density was obtained by taking the weight of the 2 cm samples that filled a specific volume (Jhoe *et al*., 2009) and calculated using the formula:

$$\text{Bulk density } (g/cm^3) = \frac{\text{weight of the sample}}{\text{volume of the container}} \quad \text{-----------------------} \quad (3)$$

3.6.4 Product density

The product density was obtained by dividing the weight of the sample (W_{piece}) by its volume (V_{piece}). The latter was computed based on piece dimensions (diameter, d and length, l) measured using digital calipers. (Jhoe *et al.*, 2009). The product densities were calculated by the formula:

$$\text{Product density (g/cm}^3\text{)} = \frac{\text{W piece}}{\text{V piece}} \text{ ------------------------- (4)}$$

3.6.5 Apparent density

The extrudates were powdered and sieved through a 500 μm sieve. These materials were transferred into a 25 ml graduated cylinder and weighed after repeated tapping to ensure that there was no reduction in sample volume (Aneesa *et al.*, 2009). The apparent density of the extruded sample was calculated as mass/unit volume and was replicated three.

3.6.6 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 calculated by subtracting the volume of the powder from the initial volume (Jhoe *et al.*, 2009).

$$\text{Porosity (\%)} = \frac{V_p - V_{po}}{V_p} \times 100 \text{----------------------- (5)}$$

Where

V_p - volume of the product

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

3.6.7 Water activity

Water activity (a_w) is a measurement of the energy status of water in a system. The concept of water activity is of particular importance in determining product quality and safety. It predicts safety and stability with respect to microbial growth, chemical and biochemical reaction rates and physical properties (Anonymous, 2004). The water activity of the developed extrudates was measured using a standard water activity meter (Decagon's Aqua Lab LITE intermediate bench-top water activity meter). The powdered extrudates was placed in a prepared sample cup by making sure the cup is entirely within the chamber (Plate 3.6). Then load the sample and note the readings.

Plate 3.6 Aqua lab water activity meter

3.7 Functional properties

Functional properties of extrudates are dependent on the disintegration of the crystalline structure and the molecular degradation of the molecules of the starch granules. The functional properties like Water Absorption Index (WAI), Water Solubility Index (WSI) and Oil Absorption Index (OAI) were determined in triplicate following the method described by Anderson (1982).

3.7.1 Water absorption and solubility indices

Water absorption and solubility indices were determined by gelling the extrudates with water and separating it by applying a centrifugal force. The ground extrudates (2.5 g) was dispersed in 20 ml of distilled water in a centrifuge tube and stirred for 30 min at room temperature. The samples were then centrifuged for 20 minutes at 8000 rpm (Plate 3.7, C24 Refrigerated Centrifuge REMI). The supernatant was then decanted into a petridish (Plate 3.8).

The water absorption index was calculated as the weight of the sediment obtained after removal of the supernatant per unit weight of original solids on dry basis. The water solubility index was the percentage of dry matter recovered after the supernatant is evaporated. The supernatant was dried in a hot air oven for a period of four hours at 120°C. WSI was the weight of the dry solids in the supernatant expressed as percentage of the original weight of the sample on dry basis. The WAI was the weight of gel obtained per gram of dry ground sample. The water absorption and solubility indices were calculated by the formula:

$$\text{WAI (g/g)} = \frac{\text{Weight of gel}}{\text{Weight of the sample}} \text{ -------------- } (6)$$

$$\text{WSI (\%)} = \frac{\text{Weight of dry matter}}{\text{Weight of the sample}} \times 100 \text{ ---------- } (7)$$

Plate 3.7 C24 Refrigerated centrifuge

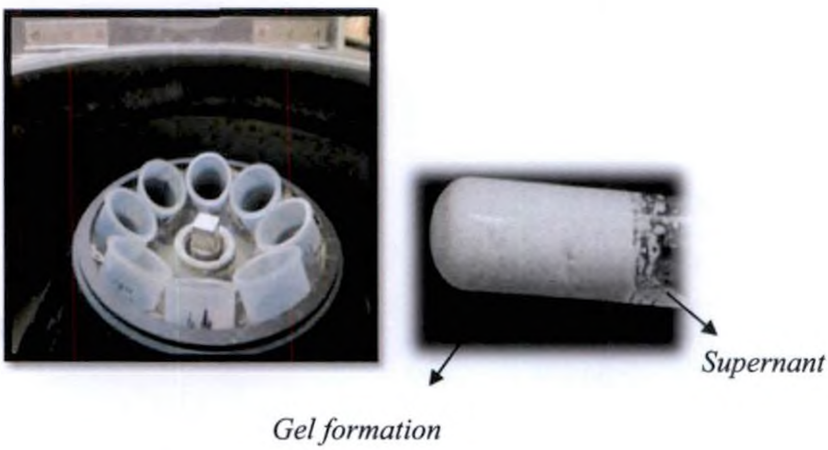

Plate 3.8 Centrifuge tube with gel formation

3.7.2 Oil absorption index

Oil absorption index (OAI) denotes how much oil is bound to matrices in particular food system which could be used as an index of hydro phobicity of the food. Oil absorption index was determined after gelling of the extrudates with oil (Jisha *et al.*, 2010). The ground extrudates was suspended in oil (sunflower oil 72°B) at room temperature and stirred gently. The samples were then centrifuged for 20 minutes at 8000 rpm (C24 Refrigerated Centrifuge, REMI).The oil absorption index was calculated as the weight of sediment obtained after removal of the supernatant per unit weight of original solids on dry basis. The oil absorption index was the weight of the gel obtained per gram of the ground sample. The oil absorption index calculated by the formula:

$$OAI\ (g/g) = \frac{\text{Weight of gel}}{\text{Weight of the sample}} \text{ ---------------- } (8)$$

3.8 Texture analysis

Instrumental analysis of texture in foods provides fast and relatively inexpensive access on product characteristics and consumer acceptance. For the experiment, all extruded samples were air dried in an Indian made Sedac oven at 60°C for three hours or until moisture content of 6% was reached which is ideal operating condition for the texture analyser. Each dried sample with ten replications were kept wrapped in aluminium foils for evaluation in consideration with the irregular surface due to puffing.

The texture analyser (TA .XT plus texture analyser, Stable micro systems Ltd.) (Plate 3.9) was operated with a 100 kg load cell and a sharp blade probe (55 mm wide, 40 mm high and 9 mm thick) used to find the peak force of extrudates in terms of parameters namely, hardness (N), toughness (N-s) and crispness (number of peaks) of extrudates that were 10 cm long (Jisha *et al.*, 2010). The test speed was 2 mm/s and the distance between two supports was 22 mm. A force time curve was recorded and analysed by texture Exponent 32 software program (version 3.0).

The snap test was carried out to find the breaking force of the product in terms of snap force (N) and snap energy (N-s) with a texture analyser using a three point HDP/3PB bend rig. The parallel supports were placed 50 mm apart and the extrudate was placed on the parallel support. The round-edged blade was lowered at a speed of 10 mm/s (Anton and Luciano, 2007). The maximum snap force and the distance were calculated. A force time curve was recorded and analysed to study the texture profile analysis (TPA) using texture Exponent 32 software program (version 3.0). The probes used for the two tests are displayed in Plate 3.10.

Plate 3.9 Experimental set up of TA.XT plus texture analyser

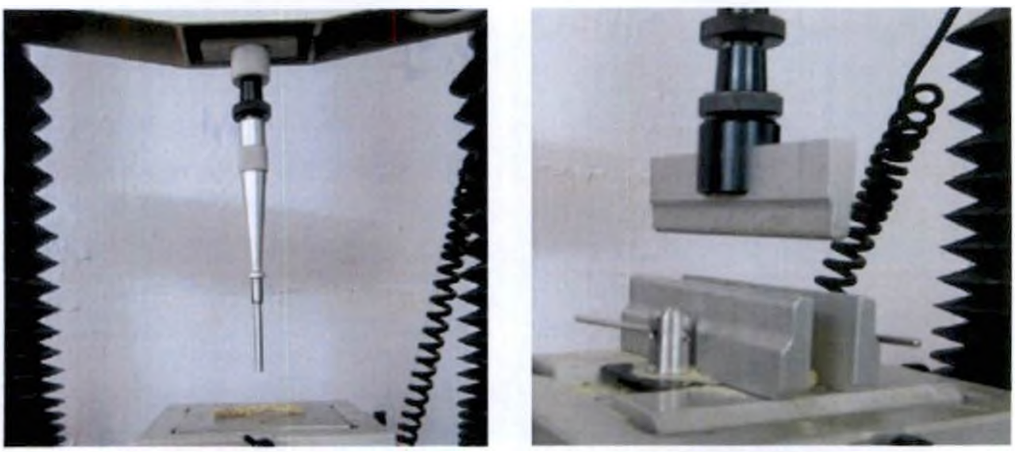

Plate 3.10 Probes for Compression (5mm Stainless steel cylindrical probe) and Snap Test (three point HDP/3PB bend rig)

3.9 Colour characteristics

Product colour is a strong indicator of the thermal history within the extruder. Hunter lab colour flex meter (made by: Hunter Associates Laboratory, Reston, Virginia, USA) (Plate 3.11) was used for the measurement of colour. 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.

This system uses three values viz. 'L', 'a' and 'b' to describe the precise location of a colour inside a three-dimensional visible colour space. The colorimeter was calibrated against standard white and black tiles before each actual colour measurement. For each sample at least four replications performed at different positions and the mean values were taken. For colour measurements extruded samples were ground to pass a 100 mesh U.S sieve. Measurements displayed in L, a and b values represents light - dark spectrum with a range from 0 (black) to 100 (white), the green - red spectrum with a range from - 60 (green) to + 60 (red) and the blue - yellow spectrum with a range from - 60 (blue) to + 60 (yellow) dimensions respectively (Ali *et al.*,2008).

3.9.1 Total colour change (Δ E)

Total colour difference was calculated to compute the greater colour change of the extrudates from the reference material (white tile) using following equation, where subscript "0" refers to the colour reading of standard white tile. White tile was used as the reference and a larger ΔE denotes greater colour change from the reference material (Cemalettin and Mustafa, 2010).

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \quad \text{-------------------- (9)}$$

Where

L - degree of lightness to darkness

Lo - initial value of L

a - degree of redness to greenness

a_o - initial value of a

b - degree of yellowness to blueness

b_0 - initial value of *b*

3.9.3 Browning index

Browning index (BI) represents the purity of brown colour and is considered as an important parameter associated with browning. The BI was calculated using the standard formula:

$$\text{Browning Index, BI} = \frac{100(x-0.31)}{0.17} \quad \text{-------------- (10)}$$

Where,

$$x = \frac{a+1.75\,L}{(5.645\,L+a-3.012\,b)} \quad \text{------------ (11)}$$

Plate 3.11 Experimental set up of Hunter lab colour flex meter

3.10 Machine properties

The mechanical considerations of the experiment with respect to the product diversions was taken into concern with the following machine parameters including feed rate, mass flow rate, volumetric flow rate, specific mechanical energy (SME) and torque.

3.10.1 Feed rate

The feed rate of the blends were determined by making the feed hopper screw to run at a constant speed of 20 rpm. The feed hopper was made stationary from extruder to observe the throughout of the flour for a period of one hour.
(Plate 3.12). The weight of the flour for a known period indicates the feed rate of the product, which is measured in kg /h.

Plate 3.12 Feed hopper of a brabender extruder

3.10.2 Mass flow rate

Mass flow rate (kg/h) of the sample can be determined by taking the total weight of the extruded sample that has been collected over a period of one minute. The total weight of the one minute sample indicates the mass flow rate of the product, which is measured in grams/min.

3.10.3 Volumetric flow rate

Assuming the extruded product to be of a uniform cylindrical shape, the volumetric flow rate of the sample can be measured. The length and the average of ten measurements of the diameter of extruded sample collected over a period of 1 minute were taken. The volume flow rate was calculated using the formula:

$$V\ (m^3/h) = \frac{\pi}{4} d^2 h \text{ -------------------- } (12)$$

V - Volume flow rate (m^3/h)

d - average diameter (m)

h - length of 1 min sample (m)

3.10.4 Torque

The torque required for the run of each treatment during extrusion was displayed on the digital torque meter of the brabender machine (Plate 3.13), which was noted after stabilising the operation of each run in percentage with a maximum torque range of 100%. The torque calculated in tems of maximum range of 100% torque was 150 N-m.

Plate 3.13 Digital torquemeter of a brabender extruder

3.10.5 Specific Mechanical Energy (SME)

Specific mechanical energy is a good quantitative measure in extrusion process and the amount of mechanical energy delivered to the extruded material determines the extent of macromolecular transformations and interactions that takes place, *i.e.* starch conversion and consequently, the rheological properties of the melt (Choudhury and Gautam, 1998). It can be derived from the ratio of net mechanical shear *ie*., power of the extruder to the feed flow rate through the extruder (Stojceska *et al*., 2008). For calculating the SME, the power consumed (Plate 3.14) by each treatment to elevate the extruder from room temperature to extrusion temperature was noted. The SME was calculated using the formula:

$$\text{SME (kWh/kg)} = \frac{\text{Power x 1000}}{\text{W}} \quad \text{------------------- (13)}$$

Where,

SME – Specific mechanical energy, kWh/Kg

Power – Mechanical energy delivered, kWh

W – Weight of the extrudates, g

Fig 3.14 Power meter of an brabender Extruder

3.11 Packaging and storage studies

The extrudates developed were stored in a 400 gauge laminated aluminium bags in replicated kits and the MAP was done along with nitrogen flushing (Plate 3.15). Out of the developed 96 extrudates, the samples which showed better physical qualities such as expansion ratio (ER), bulk density (BD) (Pawar *et al.*,2009) and uniformity in size and shape of extruded snacks were choosen for storage studies under MAP. The textural and biochemical analysis of these samples were undertaken and its total energy content was calculated. The MAP stored extrudates were kept for three months period for shelf life studies and the sensory analysis was performed afterwards.

Plate 3.15 MAP with nitrogen flushing

3.12 Proximate analysis

Proximate composition such as moisture content, starch, total sugars, protein, fat and total energy of selected extrudates were determined by standard procedures with three replications.

3.12.1 Estimation of moisture content

Moisture content of the extrudates was determined on dry basis by Associates of Official Analytical Chemists (AOAC, 2008) method. The extrudates were dried in a Sedac oven at 110°C for 6 h *i.e.*, until constant weight is obtained. The extrudates were weighed in petri plates, dried and cooled in desiccators and weight of the extrudates was noted. Moisture content of the extrudates was calculated using the formula:

$$M\,(\%) = \frac{W_1 - W_2}{W_1} \times 100 \quad \text{----------------} \quad (14)$$

Where,

M - moisture content, (%)

W_1 - Initial weight of sample, (g)

W_2 - Final weight of sample, (g)

3.12.2 Estimation of starch and total sugars

Starch was estimated according to the procedure given by Moorthy *et al.* (2002). A rapid titrimetric method has been standardised, which permits precise quantification of starch and total sugar content in fresh tubers, dry chips, floor and processed products.

3.12.3 Estimation of crude protein

Protein is the most essential nutrient present in many food crops. The major element present in the protein is nitrogen, which generally constitutes 16% of the total make up. Determination of the nitrogen content is the easiest way to compute the crude proteins using Kjeldahl digestion tubes (Plate 3.16) on Kjeldahl apparatus (Plate 3.17). The crude protein content is obtained by multiplying the total nitrogen content by a factor of 6.25 and estimated according to the procedure given by the (AOAC official methods of analysis 2008, Moorthy *et al.*, 2002).

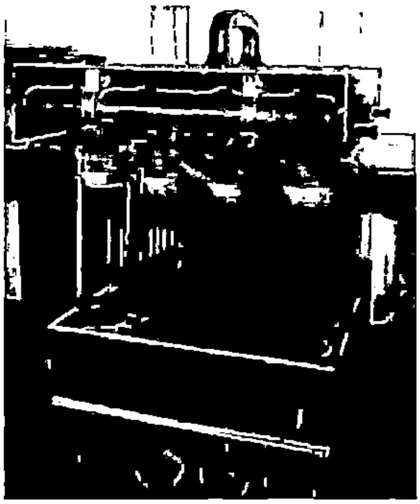

Plate 3.16 Kjeldahl digestion tubes in protein digester

Plate 3.17 Kjeldahl Apparatus

3.12.4 Estimation of fat

The fat (ether extract) present in food crops contribute considerably to the energy content. Approximately 1g of fat gives energy of 9 kcal. Extraction of fat using organic solvent and quantification by gravimetric method is the easiest way to determine the fat content with thermostatic water bath (Plate 3.18). This proximate component was identified with slight modifications in the procedures given by (Folch *et al.*, 1957, Moorthy *et al.*, 2002).

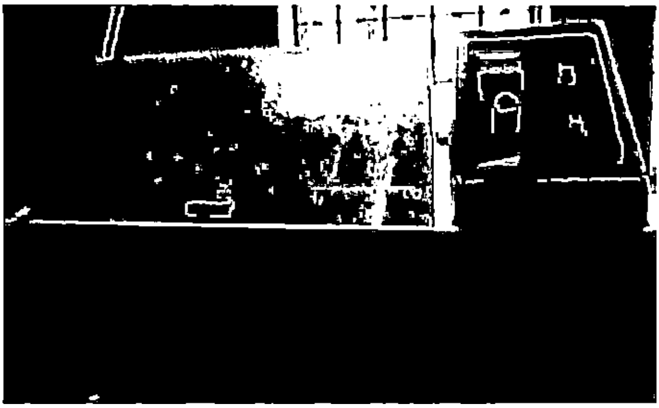

Plate 3.18 Thermostatic water bath

3.12.5 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 starch, sugar, fat and protein content using the Atwater formula method (WHO 1985).

Energy (KJ) = 17 (% protein) + 38 (% fat) + 17 (% starch) + 16 (% total sugar) .....(15)

3.13 Sensory evaluation of extruded products

Sensory quality is a combination of different senses of perception coming into play in choosing and eating a food. Appearance, flavour and mouth feel decides the acceptance of the food. Sensory analysis was done by consuming the product by a sensory panel (Aneesa *et.al.,* 2009). The sensory assessments were conducted from the selected samples, the first nine extrudates along with control

(Kurkure). Sensory characteristics of the extrudates were accessed based on appearance, colour, flavor and texture.

3.13.1 Conducting sensory test

Two sets of sensory evaluations were conducted. In the first set extrudates of different selected treatments were coated with masala and in the second set with sugar and cardamom.

3.13.1.1 Preparation of samples

1. The extrudates of 18 g from different treatments were fried in coconut oil for two minutes and were uniformly coated with chat masala (2 g).
2. The extrudates of 12 g from different treatments were fried in coconut oil for three minutes and were uniformly coated with sugar (2 g) and cardamom (0.1 g).

Marked samples were displayed in uniform coloured plates in a well lighted room for sensory analysis to identify the samples.

3.13.1.2 Panel members

A team of semi trained 12 panel members, whose sensitivity and consistency has been good were selected to conduct the evaluation. They analysed the samples and made judgements on appearance, flavour, taste, texture and overall acceptability based on a nine point hedonic rating scale. The scale was easily understood by each of the panelist and their response was converted to numerical values for computation purpose.

The following nine point Hedonic scale (9 - like extremely, 8 - like very much, 7 - like moderately, 6 – like slightly, 5 – neither like nor dislike, 4 – dislike slightly, 3 – dislike moderately, 2 – dislike very much, 1 – dislike extremely) was used for this purpose (Pawar *et al.*, 2009).

3.14 Economic feasibility of the proposed product technology

Economic analysis was performed for the optimised composition and process parameters. Feasibility analysis of an extruder based food industry was also attempted with required assumptions and appended in Appendix A.

3.15 Experimental design and statistical analysis

Statistical analysis was performed using a Completely Randomised Design (CRD) with three factorial setup. The data of each treatment was analysed for statistical significance using analysis of variance (ANOVA) with function procedure in MSTAT and SPSS. Duncan's multiple range test and Kendall's coefficient of concordance tests was used to identify the significant difference of each selected treatment during storage studies and sensory evaluation. Independent variables for the analysis included combination (P1 (R_{60}:B_{40}), P2 (R_{70}:B_{30}), P3 (R_{80}:B_{20}), P4 (R_{90}:B_{10}), P5 (R_{70}:C_{20}:B_{10}), P6 (R_{50}:C_{40}:B_{10}), P7 (R_{30}:C_{60}:B_{10}), P8 (R_{10}:C_{80}:B_{10})), temperatures (170, 180, 190, 200^{0}C) and speeds (80, 100, 120 rpm). Dependent variables included physical (ER1, ER2, bulk density, product density, apparent density, porosity, water activity), functional (WAI, WSI, OAI), textural (crispness, hardness, toughness, snap force, snap energy) and colour properties ('L' value, 'a' value, 'b' value, total colour change, browning index).

The duncan test carried out for selected samples to analyse the textural properties *viz.*, crispness, hardness, toughness, snap force, snap energy and biochemical (moisture content, starch, sugar, protein, fat and total energy). Kendall's test was carried out for the sensory evaluation of extudates with spice and sugar coatings.

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the results and discussion of the experiments conducted on extrusion with rice, banana and cassava blended in different proportions with respect to process parameters and engineering properties. The second stage on shelf life studies and quality analyses of the selected extrudates with objective and subjective parameters are also discussed. The economic feasibility of the proposed product technology is illustrated with feasible assumptions.

4.1 Extrusion

The flour with an initial standardised moisture content of 16% was used for the extrusion with a single stand alone Brabender extruder. The effect of variation in the blends with respect to quality parameters *viz.* physical, functional, textural and sensory properties of the extruded products at various die temperatures (170, 180, 190 and 200°C) and screw speeds (80, 100 and 120 rpm) are discussed.

4.2 Quality of the extrudates based on physical properties

The physical properties of the extrudates determined by standard laboratory procedures as mentioned in chapter III and their results are discussed. Physical properties of the 96 extrudates in terms of expansion characteristics such as expansion ratio (ER1 and ER2), densities (bulk density, product density, apparent density), porosity and water activity are also discussed.

4.2.1 Expansion ratio based on sectional diameter (ER1)

The expansion ratio (ER1) of the various blends of rice: banana and rice: cassava : banana was calculated as per the methodologies explained under 3.6.2. The experimental data obtained during extrusion are presented in the Fig. 4.1 (a - h). These Figures clearly revealed that the expansion ratio had a significant variation with the process parameters. The ER1 index in terms of diameter varied from 2.6 to

3.2 for rice: banana combinations and 3.0 to 3.8 for rice: cassava: banana combinations (The values of the expansion ratios for all exrudates shown in Appendix B1).

The results inferred that the extrudates had higher expansion at higher temperature and speed. Starch seemed to be the primary cause for the expansion of these extruded snacks. This was in confirmation with the studies of Peri *et al.* (1983), Berglund *et al.* (1994), Yacu (1995) and Deshpande and Poshadri (2011), which showed that expansion, was high at elevated process parameters. The temperature of 180°C and above resulted in good expansion of the products. This was in agreement with studies of Vickers (1985).

The contribution of increased amount of rice in the rice: banana combination and increased amount of cassava in rice: cassava: banana combination resulted in higher expansion. This was due to higher amount of starch content in cassava compared to rice (Jorge and Maria, 2003).

Table 4.1 Interaction effect of combination and temperature on ER1 of extrudates

Temperature (°C)	ER1 at different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	2.95	2.69	2.69	2.71	3.14	3.07	3.15	3.45	2.98
180	3.21	2.66	2.87	2.75	3.32	3.29	3.19	3.45	3.09
190	2.95	2.89	2.86	2.90	3.16	3.22	3.28	3.60	3.12
200	2.82	2.88	2.86	3.05	3.19	3.43	3.37	3.73	3.16
Mean	2.76	2.81	2.87	2.98	3.20	3.25	3.25	3.55	
$CD_B = 0.021$	$CD_{AB} = 0.059$								

A – Combination, B – Temperature & AB - Combination temperature interaction

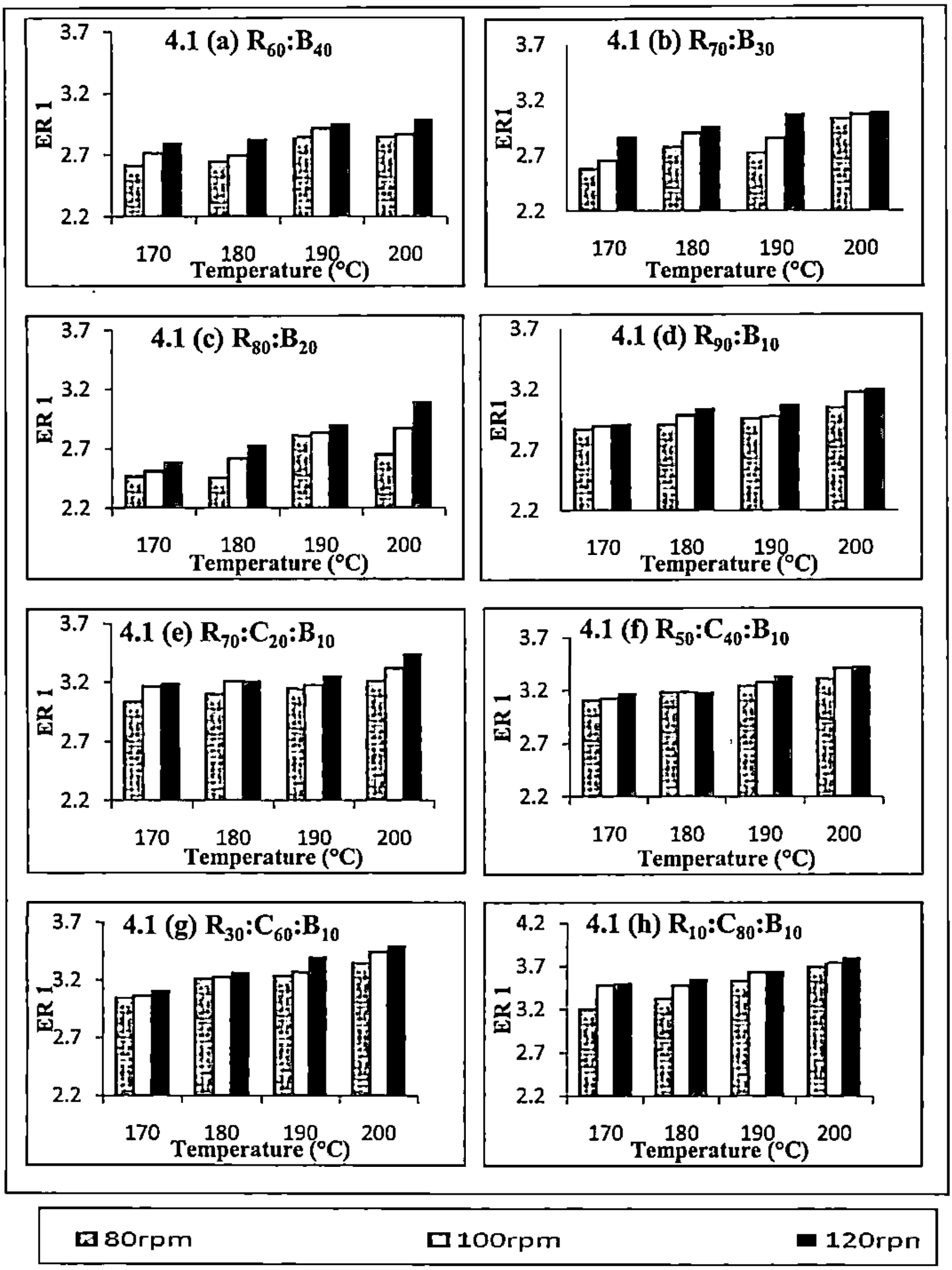

Fig. 4.1 Effect of combination, temperature and speed on ER1 of extrudates

Table 4.1 shows that significant difference ($p<0.01$) in ER1 with each and every treatment for both combinations under different die temperatures. It shows that P8 ($R_{10}:C_{80}:B_{10}$) combinations had high expansion indices followed by other combinations of cassava. For cereal based snacks it revealed appreciable characters for P4 ($R_{90}:B_{10}$) followed by rest of the rice: banana combinations. The interaction with respect to combination speed, temperature speed and between the three factors is shown in Appendix (B1). The variation of expansion ratio in terms of process parameters can be expressed in terms of linear equations as given below.

For example, the linear equation for rice: banana combination ($R_{80}:B_{20}$) with process temperature at a speed of 120 rpm can be expressed as

$$ER1 = 0.17\,t + 2.40 \; (R^2 = 0.997) \ldots\ldots\ldots\ldots\ (4.1)$$

For same combination variation in ER1 at a temperature of 200^{0}C can be expressed as

$$ER1 = 0.25\,s + 2.37 \; (R^2 = 0.986) \ldots\ldots\ldots\ldots\ (4.2)$$

And for $R_{50}:C_{40}:B_{10}$combination, the linear equation for a speed of 80 rpm expressed as

$$ER1 = 0.07\,t + 3.02 \; (R^2 = 0.990) \ldots\ldots\ldots\ldots\ (4.3)$$

For the same combination, ER1 at a temperature of 190^{0}C is given as

$$ER1 = 0.06\,s + 3.47 \; (R^2 = 0.871) \ldots\ldots\ldots\ldots\ (4.4)$$

Where, t is the process temperature and s is the speed.

4.2.2 Expansion ratio based on cross sectional area (ER2)

The expansion in terms of cross sectional area was illustrated for the extrudates under study and the data with respect to these are presented in the Fig. 4.2 (a - h). The ER2 of the two combinations varied from 6.5 to 13.3 (rice: banana) and from 9.1 to 14.8 (rice: cassava: banana) (Appendix B1) respectively and was calculated as per the methodologies explained under 3.6.2.

The sectional expansion of the extrudates showed an increase in puffing with respect to increase in process temperature from 170°C to 200°C. Increase in speed resulted in reduced residence time in the barrel with less bulk of material and achieved a high expansion. The expansion showed high regression coefficient (R^2) with temperature in the range of 0.8 to 0.95. These results indicated that influence of product characteristics of products from rice and starchy ingredients depend on physical changes during extrusion. The independent variables used in the study such as die temperature, screw speed and feed rate along with screw configuration resulted in greater mechanical shear which affected the product attributes. This was also reported in previous studies by Choudhury and Gautam, (1998 & 1999). Screw configuration is also a key process variable that affects product transformation.

Table 4.2 Interaction effect of combination and temperature on ER2

Temperature (°C)	ER2 at various combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	7.99	7.24	7.06	7.34	10.06	9.26	10.13	12.07	9.26
180	8.72	8.26	7.15	7.54	10.40	10.84	10.34	12.35	9.63
190	10.27	8.36	8.15	8.42	10.41	10.50	10.89	12.64	9.77
200	10.86	9.28	8.22	8.32	11.63	11.70	11.36	14.07	10.31
Mean	7.65	7.90	8.29	9.46	10.58	10.62	10.68	12.78	
$CD_B = 0.142$	$CD_{AB} = 0.403$								

A – Combination, B – Temperature & AB - Combination temperature interaction

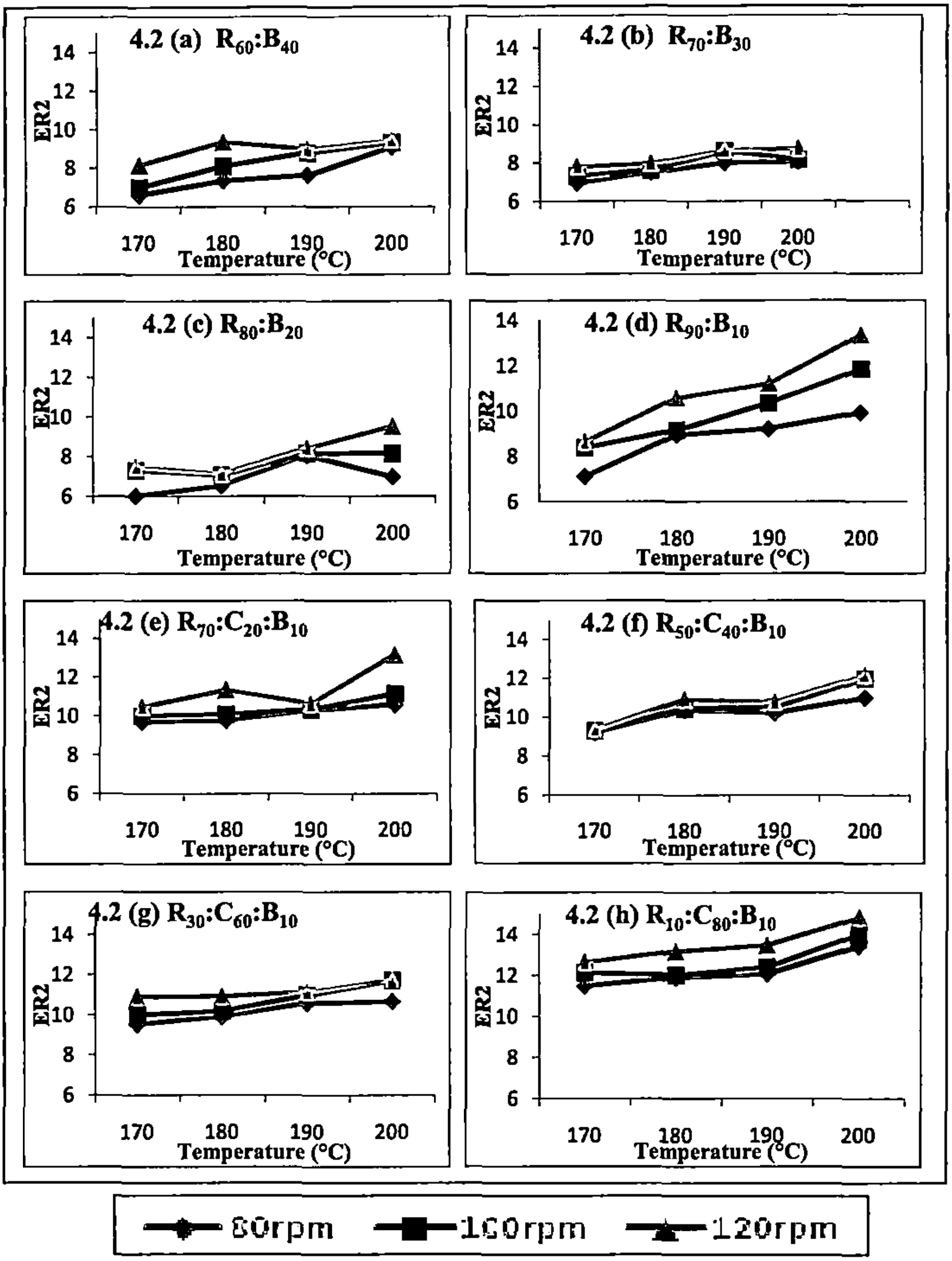

Fig. 4.2 Sectional expansion (ER2) of extrudates based on cross sectional area

The interaction of temperature and combination significantly affected the ER2 (Table 4.2).Maximum expansion was found during higher inlet temperatures of 190°C and 200°C with good expansions at almost all speeds (80, 100 and 120 rpm) with respect to sectional area. This is in agreement to the studies of Badrie *et al.*, (1991) and Jisha *et al.* (2010). The particle size of the materials in the range of (100 micron) under different product temperatures did not show much variation with the characters under study (Garber *et al.*, 1997). The interaction of speed and combination is appended in Appendix (B1).

4.2.3 Bulk density (BD) of extrudates

The bulk density of the extrudates which considered expansion in all directions, was indexed to show the extend of puffing and was determined using the methodologies as per 3.6.3. The bulk density was found to have a tremendous decrease with increase in temperature. A similar trend in bulk density was observed with respect to an increase in speed from 80 to 120 rpm (Table 4.3). The bulk density of these extrudates varied from 0.14 to 0.27 g/cm^3 for rice: banana combinations and from 0.11 to 0.23 g/cm^3 for rice: cassava: banana combinations (The values of BD for all treatments are tabulated in Appendix B1). It was seen that due to lower feed moisture content it provided a better quality product in terms of high expansion ratio and low bulk density (Dandamrongrak *et al.*, 2011). As the extrudates emerged out of the extruder barrel, its moisture rapidly evaporates resulting in modified structure and texture with high expansion ratio and low bulk density. This was in confirmation with the studies of Gujsha and Khallil, (1990).

Table 4.3 Interaction effect of combination and speed on BD

Speed (rpm)	Bulk density (g/cm^3) at various combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	0.27	0.26	0.24	0.22	0.21	0.20	0.16	0.16	0.22
100	0.24	0.24	0.20	0.20	0.19	0.20	0.15	0.15	0.22
120	0.22	0.22	0.20	0.20	0.18	0.19	0.15	0.14	0.20
Mean	0.28	0.25	0.24	0.21	0.20	0.19	0.16	0.15	

The interaction of these combinations with respect to temperature is given in Table 4.4. The increased process temperature and speed contributed to higher expansion which inversely correlated the bulk density with process parameters. This was in confirmation to the reports exhibited by Harper and Jansen (1985), Meng *et al.* (2010). The combinations and their variations with different process parameters are indicated in Fig.4.3 (a - h).

Table 4.4 Effect of Temperature and combination on BD

Temperature (°C)	Bulk density (g/cm^3)								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	0.34	0.31	0.26	0.22	0.23	0.20	0.20	0.19	0.24
180	0.28	0.28	0.24	0.22	0.21	0.21	0.17	0.16	0.22
190	0.20	0.21	0.22	0.21	0.19	0.19	0.15	0.13	0.19
200	0.18	0.17	0.16	0.16	0.16	0.16	0.13	0.12	0.16
Mean	0.28	0.25	0.24	0.21	0.20	0.19	0.16	0.15	

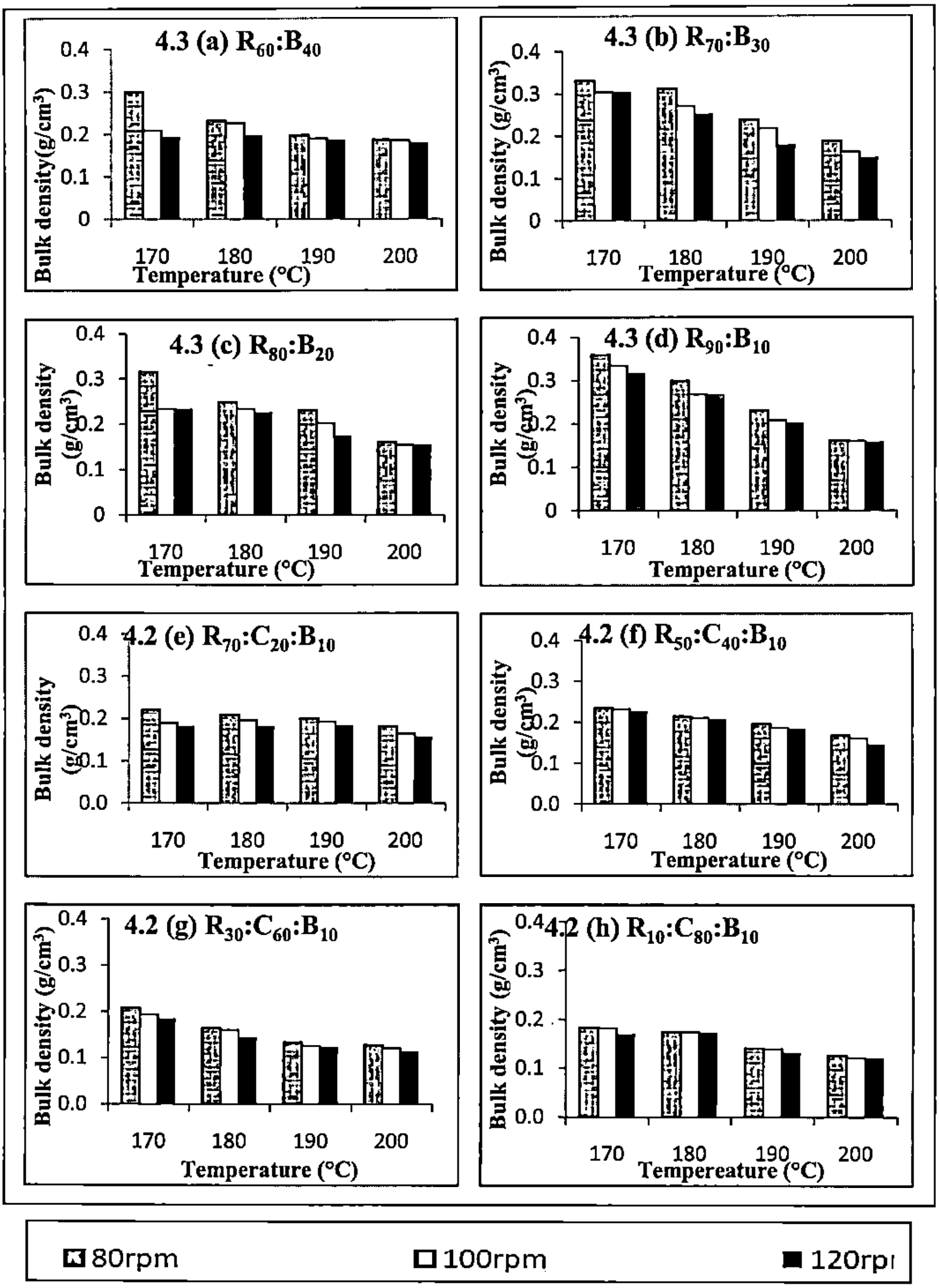

Fig. 4.3 Effect of combination, temperature and speed on Bulk density

From Table 4.4, it clearly shows that the combination which resulted in high expansion resulted in less density. So the property was found less in case of 90% rice and 10% banana in case of rice: banana combinations. For rice: cassava: banana combinations, R_{10}:C_{80}:B_{10} resulted in lesser density compared to other cassava combinations. This reduction in bulk densities with an increase in temperature and screw speed had been reported by Harper, (1989). The extrusion conditions studied had significant effect ($p < 0.01$) for the property under concern (Aylin *et al.*, 2008).

4.2.4 Product density (PD) of extrudates

The PD of the various blends of rice: banana and rice: cassava: banana was calculated as per the methodologies explained under 3.6.4. The difference of the combinations in terms of product densities varied from 0.3 to 1.3 g/cm^3 for rice banana proportions and 0.2 to 0.6 g/cm^3 in case of rice cassava banana combinations. As the screw speed and die temperature increased the product density of the extrudates decreased (Fig. 4.4 (a – h)). This is due to the rapid moisture evaporation at the exit leading to high expansion and low product density. These obtained results were in concurrence with earlier studies of Rzedzicki, (1997), Kasprzak and Rzedzicki, (2008) and Chaiyakal *et al.* (2009).

The results showed that increasing the processing temperature from 170°C to 180°C decreased the product density although the mean density value of products at 190 and 200°C was similar (Zeinab *et al.*, 2010). The study also revealed that increased percentage of rice resulted in high expansion which signified the negative correlation of expansion and density. Out of the two basic combinations considered the cassava extrudates resulted with high expansion and low density. The variations of all treatments with the process parameters are indicated in Appendix (B1).

The analysis of variance (Appendix H) indicated that the effect of various flour blends on the product densities of extrudates were significant ($p < 0.05$). The differential response of the different combinations over different temperature and speed were also taken into consideration. The interaction between combination and temperature are tabulated on Table 4.5.

Table 4.5 Interaction effect of temperature and combination on PD

Temperature (°C)	Product density (g/cm^3)								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	1.32	1.17	0.87	0.74	0.59	0.43	0.42	0.37	0.72
180	1.19	1.03	0.81	0.58	0.59	0.42	0.41	0.31	0.65
190	1.11	0.94	0.78	0.47	0.53	0.35	0.35	0.23	0.60
200	0.83	0.60	0.67	0.36	0.46	0.33	0.33	0.21	0.50
Mean	1.11	0.93	0.78	0.66	0.54	0.38	0.37	0.28	
CD_B = 0.016	CD_{AB} = 0.044								

A - Combination B – Temperature AB – combination temperature interaction

From the Table 4.5, it was seen that increasing the temperature resulted with low densities of the products. The proportions, P4 (R_{90}:B_{10}) showed low densities with respect to rice based extrudates and P8 (R_{10}:C_{80}:B_{10}) for cassava based extrudates. The interaction of speed with respect to different proportions of rice, cassava and banana for the two basic combinations are shown in Appendix (B1). The variation of product density of rice based snack (R_{90}:B_{10}) with process temperature at a speed of 80 rpm can be expressed by the linear equation,

$$PD = 0.14\,t + 0.96\ (R^2 = 0.971) \ldots\ldots\ldots (4.5)$$

whereas, variation in PD at a temperature of 170^{0}C can be expressed as

$$PD = 0.11\,s + 0.95\ (R^2 = 0.989) \ldots\ldots\ldots (4.6)$$

For cassava based extrudates PD can be expressed by the linear equations at 120 rpm,

$$PD = 0.03\,t + 0.44\ (R^2 = 0.967) \ldots\ldots\ldots (4.7)$$

whereas, variation in PD with respect to process temperature at 180^{0}C was

$$PD = 0.03\,s + 0.47\ (R^2 = 0.964) \ \ldots\ldots\ldots (4.8)$$

Where, t is the process temperature and s is the speed.

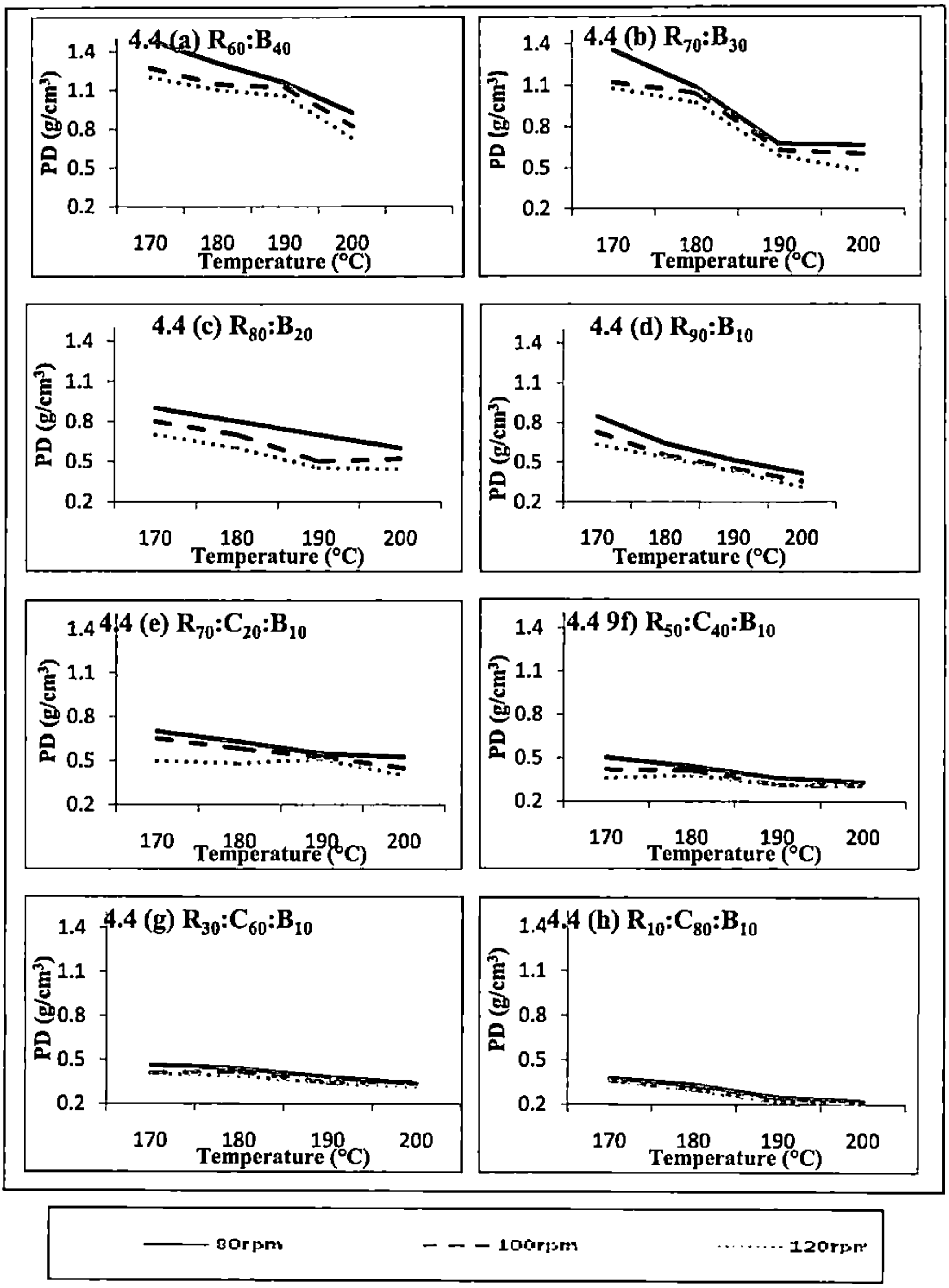

Fig. 4.4 Effect of combination, temperature and speed on PD

4.2.5 Apparent density (AD) of extrudates

Apparent density which is a measurable index of the degree of expansion of the extrudates found to have high implication with respect to temperature and speed and was determined using methodologies explained in 3.6.5. This density of extrudates ranged from 16.2 to 30.1 g/cm^3 for the rice: banana combinations. In consideration with cassava products, it varied from 5.0 to 21.8 g/cm^3 (Appendix B1). The expansion and AD are generally inversely related which shows that they are negatively correlated with starch component. From the viewpoint of higher expansion and lower density, cassava starches were the best with expansion ratios ranging upto 3.8 and these variation in properties with respect to starches also noted by Badrie and Mellowes,(1991), Bhatnagar and Hanna, (1994a, 1994b & 1996), Wang *et al.* (1999).

The model representation of the different combinations with respect to different process parameters are shown in Fig. 4.5 (a – h). Low density achieved at high die temperatures of 190°C. Higher amount of rice results with less density in case of rice: banana combinations (Aneesa *et al.*, 2009). And for the succeeding combination better results achieved for R_{10}:C_{80}:B_{10} combinations with appreciable expansion and texture. This confirmed that, AD increases with cereal starch in extrudates (Quing *et al.*, 2005) and showed that it decreased with increase in temperature (Lazou and Krokida, 2010). Incorporation of different elements viz. rice, cassava and banana elements lowered the apparent density considerably. This is in conformity with the results of Yacu, (1995). From Fig. 4.5 (a – h), it was inferred that with an increase in die temperature as well as screw speed AD decreased which indicated the negative interaction between expansion and density.

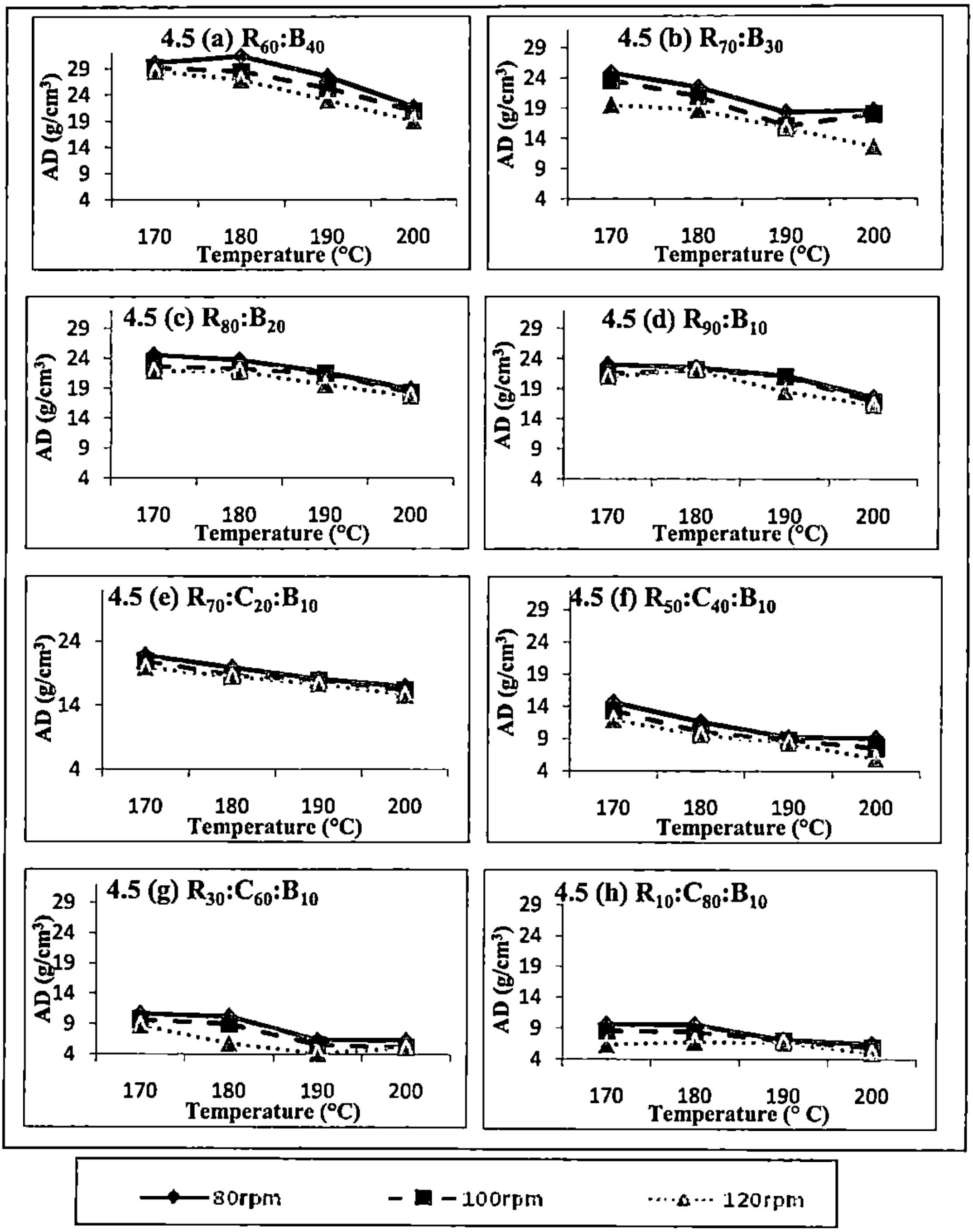

Fig.4.5 Effect of combination, temperature and speed on apparent density

4.2.6 Porosity of extrudates

The porosity determination of the extrudates was done with the methodologies explained under 3.6.6. The porosity value of extrudates ranged from 16.89 to 46.8% for rice: cassava: banana combinations. In case of rice: banana combinations a lesser variation of 2.9 to 24.6% (Appendix B1) was noticed. The main reason for this was the high expansion indices exhibited by the cassava extrudates at elevated temperatures, results with greater amount of pores with appreciable porosity. This was in concordance with the results obtained by Artz *et al.* (1990).

At elevated temperature and speed the extruded snacks had expansion ratio upto 3.8 indicating the high puffing characteristics which shows the positive correlation of porosity and expansion with negative correlation on densities. This general behavior of extrudates was summerised by most of the researchers in their work histories ((Boonyasirikool and Charunuch, (2000), Cha *et al.* (2001), Zeinab *et al.* (2010). The lesser particle size and easiness in the material flow of cassava rich extrudates came up with high expansion which indicated the high degree of expansion (Dandamrongrak *et al.*, 2011).

Table 4.6 Interaction effect of temperature combination on porosity of extrudates

Temperature (°C)	Porosity (%)								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	6.81	5.35	13.65	8.88	16.89	20.81	22.01	27.03	15.18
180	9.44	10.35	13.28	14.97	20.14	25.57	28.11	30.06	18.99
190	11.35	12.47	13.80	18.00	21.57	29.56	30.03	37.04	21.73
200	13.80	14.43	15.90	22.80	21.96	35.51	36.88	46.80	25.85
Mean	10.35	10.65	14.16	16.16	20.14	27.86	30.31	33.87	
$CD_B = 0.397$	$CD_{AB} = 1.124$								

A – combination B – temperature AB – combination temperature interaction

Table 4.6, indicated the porosity of extrudates in terms of temperature which showed that with increased amount of rice in rice : banana combinations and increased amount of cassava in rice : cassava : banana combinations resulted with higher porosity which was attained as a result of increased die temperature and screw speed. This was in confirmation with the studies of Harper and Jansen (1985).

Table 4.7 Interaction effect of temperature speed on porosity of extrudates

Speed (rpm)	**Porosity (%) at different temperature**				
	T1	T2	T3	T4	Mean
80	12.92	16.90	19.60	23.52	18.23
100	15.11	18.92	21.81	26.50	20.59
120	17.51	21.14	23.78	27.54	22.50
Mean	15.18	18.99	21.73	25.85	
$CD_C = 0.344$	$CD_{BC} = 0.689$				

B – temperature C – speed BC – temperature speed interaction

Table 4.7, revealed that higher process parameters were preferential for extrudates for good expansion. Increase in die temperature and screw speed resulted in increased porosity of extrudates and was maximum at 190°C and 200°C at 120 rpm. This was in confirmation with the results of Altan *et al.* (2008) and Aneesa *et al.* (2009). The interaction for speed and combination are appended in Appendix (B1). The porosity of all treatments for the two combinations is displayed in Fig. 4.6 (a – h). The porosity of these extrudates can be expressed in terms of linear equations as given below.

For R_{70}:B_{30} combination, the variation of porosity with process temperature at 120 rpm is given by

$$\text{Porosity} = 0.34\,t - 49.67 \quad (R^2 = 0.909) \;\ldots\ldots\ldots\ldots (4.9)$$

whereas, variation in porosity with respect to speed at temperature of 200^0C is given by

$$\text{Porosity} = 4.67\ s + 6.47\ (R^2 = 0.939) \ldots\ldots\ldots\ldots (4.10)$$

For rice: cassava: banana combination at (R_{10}:C_{80}:B_{10}), the variation of porosity with respect to temperature (t) at 100 rpm is given by

$$\text{Porosity} = 0.42\ t - 49.33\ (R^2 = 0.87) \ldots\ldots\ldots (4.11)$$

Where as, the variation of porosity with respect to speed (s) at 200^0C is expressed as

$$\text{Porosity} = 6.18\ s + 25.24\ (R^2 = 0.961) \ldots\ldots\ldots\ldots (4.12)$$

The porosity values for extrudates under all combinations, shown in Appendix (B1).

These properties varied significantly over different temperatures and speed. When the overall effect of different combinations with regard to temperature and speed were considered the porosity was maximum for R_{10}:C_{80}:B_{10} followed by other cassava combinations under temperature above 180°C at speeds of 100 and 120 rpm respectively. In case of rice: banana combinations, porosity was higher for R_{90}:B_{10}.

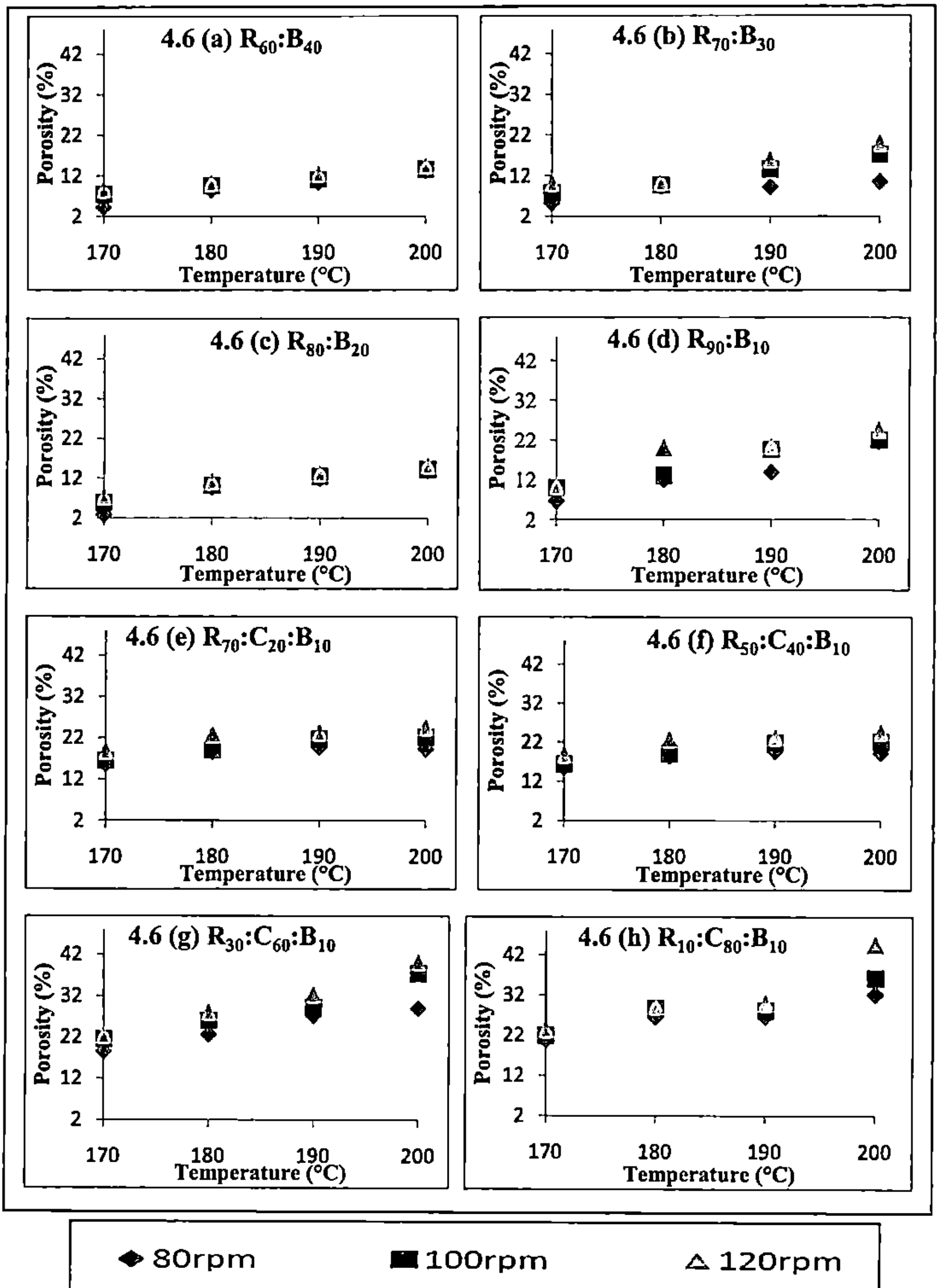

Fig. 4.6 Effect of temperature, speed and combination on Porosity

4.2.7 Water activity (a_w) of extrudates

The water activities of the extrudates were determined by methodologies explained in 3.6.7. This property was used as a critical control point to correlate whether the products made were in a safe level. The a_w of all combinations made out from the eight blends ranged from 0.5 to 0.7. The result indicates that at elevated temperatures have low a_w, which signifies the safe range of the products for consumption (Linko *et al.*, 1982).

The a_w exhibited by all the combinations are shown in the Fig. 4.7 (a – h). From the Figure, it clearly shows that water activities of all treatments approximately ranged below one with constant feed moisture of 16%, explaining the high degree of expansion during extrusion cooking of cereal based materials even at low moisture levels. The values of water activity exhibited by the extrudates also confirmed with the necessary moisture for starch gelatinisation essential for efficient enzymatic hydrolysis. This is in agreement to the studies of Linko *et al.* (1982). Water activity can be expressed in terms of linear equations as given below

For R_{70}:B_{30}combination, the variation of water activity with temperature (t) at a speed of 120 rpm is given by

$$a_w = -0.001\ t + 0.915\ (R^2 = 0.852)\ \ldots\ldots\ldots\ (4.13)$$

whereas, variation in a_w with respect to speed (s) at a temperature of 190^{0}C is expressed as

$$a_w = -0.015\ s + 0.663\ (R^2 = 0.964)\ \ldots\ldots\ldots\ (4.14)$$

For rice: cassava: banana combination, R_{50}:C_{40}:B_{10} variation of a_w can be expressed by the linear equations,

$a_w = -0.001\ t + 0.911\ (R^2 = 0.984)$ ....(4.15) at a speed of 120 rpm

whereas, variation in a_w with respect to speed (s) at temperature of 200^{0}C is given by

$$a_w = -0.015\ s + 0.636\ (R^2 = 0.964)\ldots\ldots\ldots\ (4.16)$$

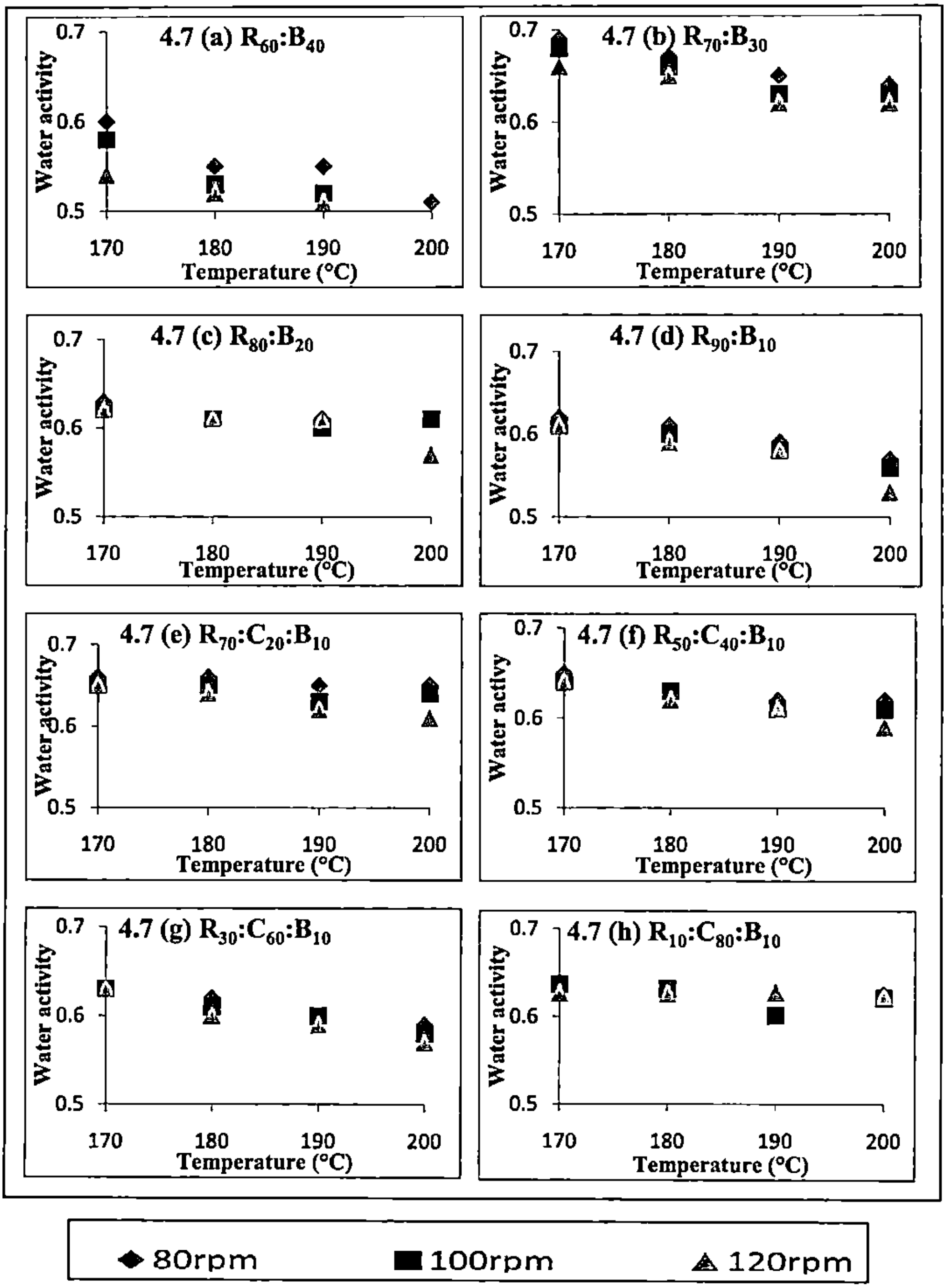

Fig. 4.7 Effect of combination, temperature and speed on a_w of extrudates

Table 4.8 Interaction effect of combination and temperature on a_w of extrudates

Temperature (°C)	a_w at different combinations								
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**Mean**
170	0.59	0.68	0.60	0.61	0.62	0.64	0.63	0.57	0.62
180	0.60	0.65	0.62	0.62	0.65	0.64	0.62	0.59	0.61
190	0.59	0.66	0.57	0.62	0.66	0.63	0.62	0.59	0.61
200	0.63	0.65	0.58	0.61	0.65	0.61	0.61	0.56	0.60
Mean	0.56	0.66	0.61	0.59	0.63	0.61	0.62	0.60	
$CD_B = 0.0011$	$CD_{AB} = 0.0036$								

A – combination B – temperature AB – combination and temperature interaction

From Table 4.8, it reveals the lower a_w of the extrudates at higher temperature of 200^{0}C and can conclude that for achieving minimal a_w a temperature above 190^{0}C was advisable. The interaction between speeds and combinations are appended in Appendix (B1).

Water activity was found minimum in the case of all rice: banana and rice: cassava: banana combinations. Significant variations are seen with respect to each and every combination ($p < 0.01$) taken for the study of a_w after extrusion process (Appendix B1).

4.3 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 96 extrudates in terms of WAI, WSI and OAI are discussed.

4.3.1 Water absorption and solubility indices of extrudates

The water absorption index (WAI) and water solubility index (WSI) of the various blends of rice: banana and rice: cassava: banana was calculated as per the methodologies explained under 3.7.1. The experimental data obtained during extrusion for WAI and WSI are presented in the Fig. 4.8 (a - h) and 4.9 (a – h). The WAI of the extrudates out of rice: banana varied from 10.93 to 18.00 g/g and for rice: cassava: banana it ranged from 23.6 to 37.81 g/g. WSI of these varied from 2.20 to 19.0% for cereal based extrudates and 3.50 to 23.50% for cassava based extrudates (Appendix B2).

Table 4.9 Interaction effect of combination and temperature on WAI of extrudates

Temperature (°C)	WAI (g/g) at various combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	18.00	12.91	12.81	13.11	37.81	33.80	26.44	28.45	21.31
180	12.56	14.11	11.25	11.51	28.80	26.75	25.10	25.01	20.25
190	11.98	13.33	11.27	12.12	24.67	25.62	28.87	25.78	20.19
200	11.53	11.21	10.93	11.23	23.63	23.66	25.32	24.32	18.39
Mean	15.88	11.57	11.38	11.33	27.11	26.44	25.24	22.22	
CD_B = 0.466	CD_{AB} = 1.5								

A – combination B – temperature AB – combination temperature interaction

The interaction between combination and temperature (Table 4.9) indicated that WAI of extrudates out of rice : banana and rice : cassava : banana showed a gradual decrease with increase in temperature from 170°C to 200°C due to the gelatinisation of starch that results in hydration of the pores of extrudates (Linko *et al.*, 1982). The WAI of rice: cassava: banana combinations were more than the rice: banana combinations due to the increased proportion of starch which resulted in increased porosity and expansion of extrudates (Singh *et al.*, 1994b, Iwe *et al.* 2000).

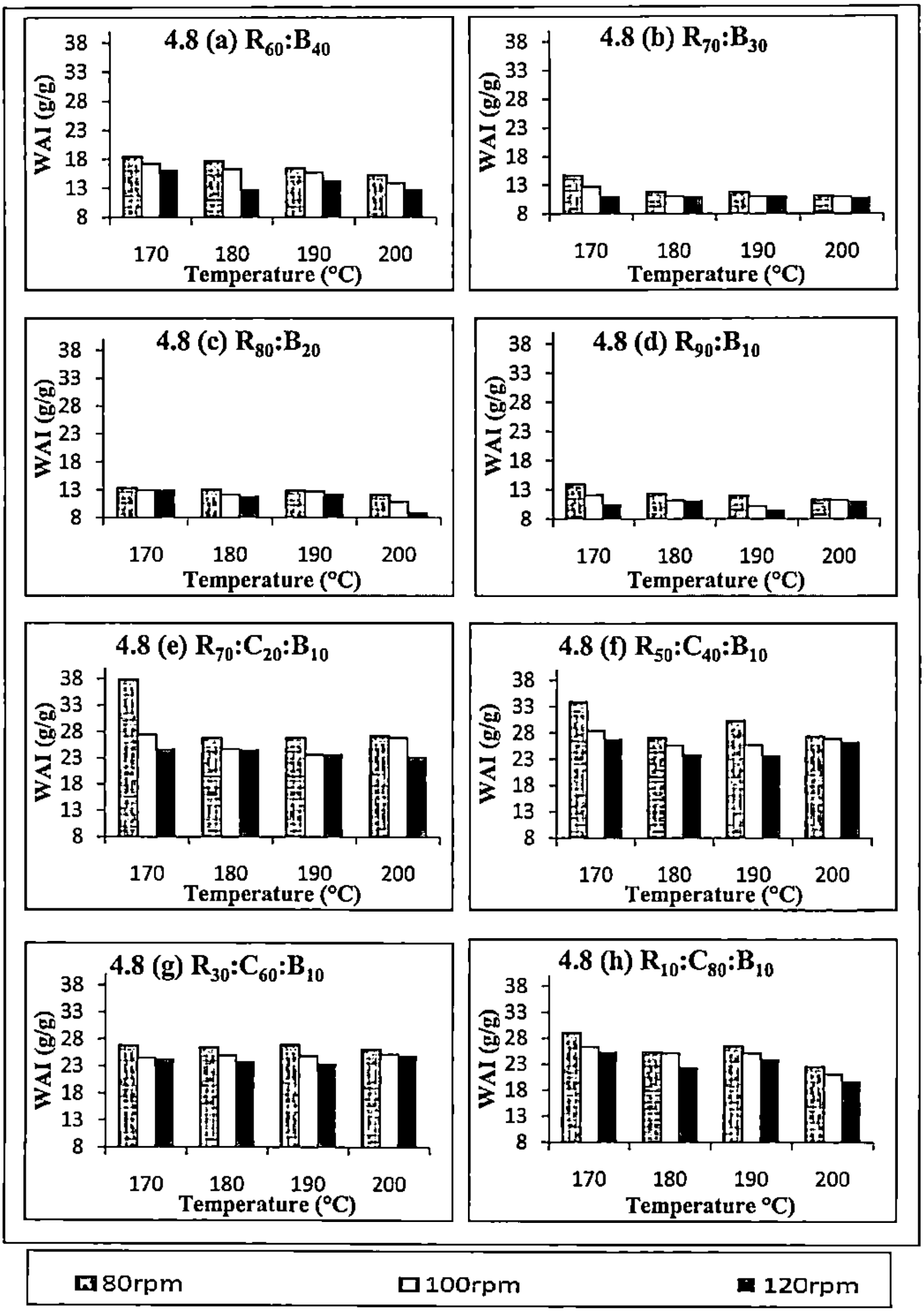

Fig. 4.8 Effect of combination, temperature and speed on WAI of extrudates

Table 4.10 Interaction effect of combination and temperature on WSI of extrudates

Temperature (°C)	WSI (%) of extrudates at various combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	2.40	3.64	4.93	8.58	3.48	4.45	9.21	11.26	10.30
180	5.22	6.12	6.05	11.31	6.13	9.28	10.27	15.20	11.50
190	7.09	8.67	12.44	14.35	11.14	11.34	14.06	18.07	12.29
200	8.81	10.68	17.75	18.46	12.16	13.62	18.91	22.56	18.66
Mean	5.58	6.85	9.92	13.90	9.98	11.22	15.44	18.82	
CD_B = 1.55	CD_{AB} = 4.4								

A – combination B – temperature AB – combination temperature interaction

Table 4.10, shows the magnitude of WSI of these extrudates increasing perceptibly with increase in temperature of extrusion. The main reason was due to the degradation of starch which began to take place at elevated temperatures that correlated with the parboiling conditions and results in the greater shearing of the flour to undergo cooking. These results were in confirmation with the studies of Gujsha and Khalil, (1990), Chauhan and Bains, (1988), Jorge and Maria, (2003) and Ding *et al.* (2006).

WAI, an indicator of the ability of flour to absorb water depends on the availability of hydrophilic groups which bind water molecules and on the gel-forming capacity of macromolecules. These results indicated the low WAI, which shows the hydrophobicity of the product. The higher values of WSI, shows the rupture of granular structure, making free gelatinisation so that it get easily dispersible in cold water. Significant variation was seen with respect to process parameters for each and every treatment in consideration with WAI and WSI.

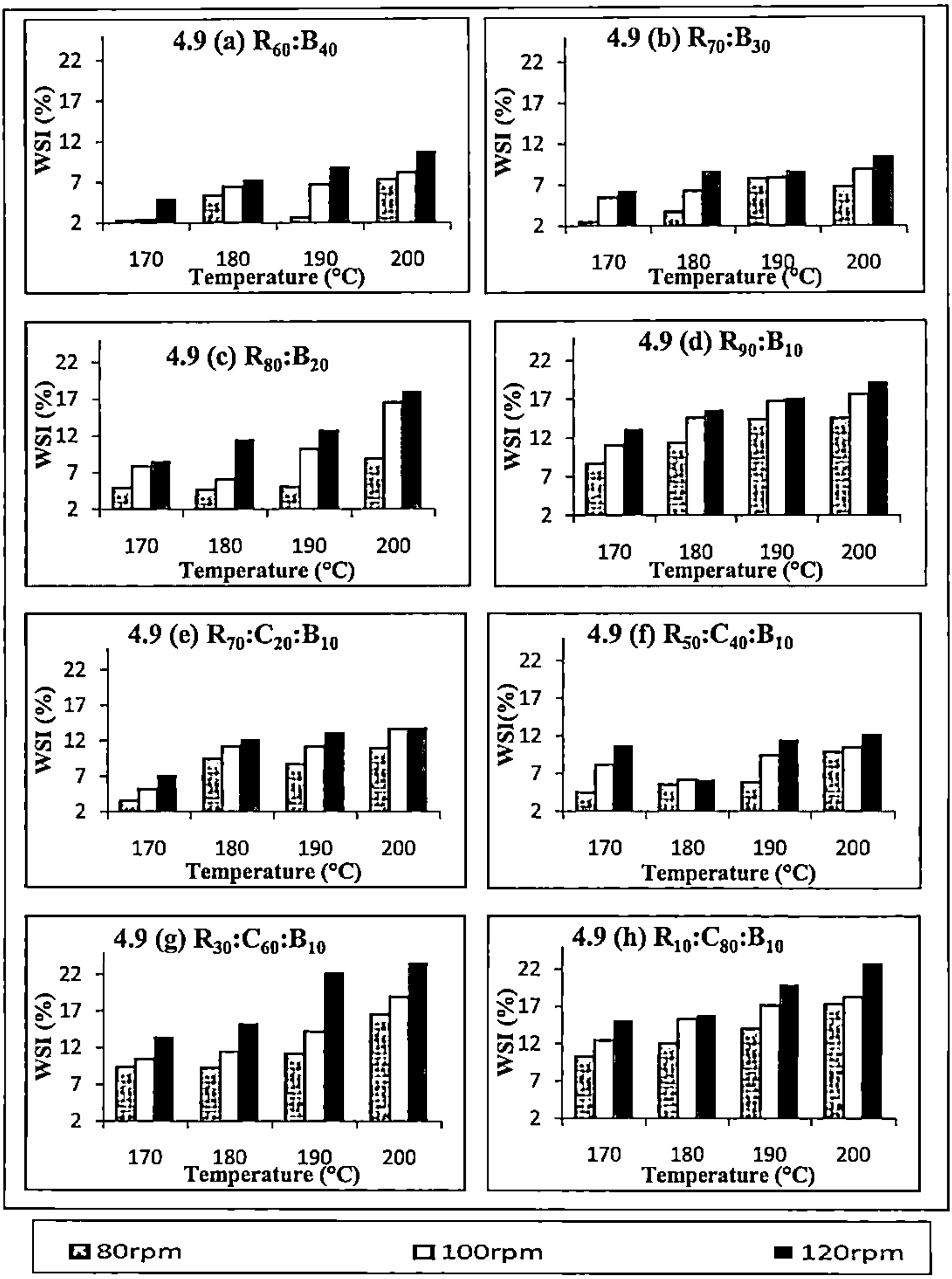

Fig. 4.9 Effect of combination, temperature and speed on WSI of extrudates

From Figure 4.8 and 4.9 it is clear that WAI of the extrudates decreased with increase in temperature whereas WSI of these products showed an increase with increase in temperature. The general explanation regarding this is during a dry heating process like extrusion, which is a high temperature short time process the modification of starch granular structure takes place which consequently produces a pregelatinised flours and this results with a redistribution of the starch molecules in a continuous phase. Similar results were obtained by Badrie and Mellowes (1991), Choudhury and Gautam (1998), Gonzalez *et al.* (2007) and Stojceska *et al.* (2008).

The WSI of extrudates can be expressed using linear equations as given below

For R_{80}:B_{20} combination, the interaction of WSI with temperature at a speed of 120 rpm can be expressed as

$$WSI = 2.28\ t + 5.38\ (R^2 = 0.93) \quad \text{.......... (4.17)}$$

whereas, variation in WSI with respect to speed (s) at a temperature of 200°C can be expressed as

$$WSI = 4.50\ s + 5.30\ (R^2 = 0.964) \quad \text{.........(4.18)}$$

For rice: cassava: banana of R_{70}:C_{20}:B_{10} WSI can be expressed by the linear equations at 120 rpm

$$WSI = 2.06\ t + 6.35 (R^2 = 0.81) \quad \text{.........(4.19)}$$

whereas, variation in WSI with respect to process temperature (t) at 190^{0}C is

$$WSI = 2.28\ s + 6.40\ (R^2 = 0.996) \quad \text{.........(4.20)}$$

4.3.2 Oil absorption indices (OAI) of extrudates

The OAI of extrudates were also determined by the procedures described in 3.7.2. This property exhibited in the range of 0.8 to 2.4 g/g for rice: banana and 1.9 to 2.4 g/g for rice: cassava: banana extrudates. The OAI increased with increase in temperature of the die. Higher expansion achieved by the extrudates due to elevated temperatures and speed increased the air pockets that resulted in increased oil absorption characteristics of the extrudates. Owing to the acute increase in pores, OAI was higher for cassava based snacks compared to the other combination. OAI achieved by all combinations are shown in Fig. 4.10 from 4 (a - h).

Table 4.11 Interaction of temperature and combination on OAI of extrudates

Temperature (°C)	OAI (g/g) of extrudates at various combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	0.91	0.90	0.94	1.85	1.94	1.96	1.86	2.02	1.75
180	0.97	0.94	0.99	2.06	1.96	1.90	1.99	2.10	1.85
190	1.32	1.99	1.79	2.11	2.29	1.97	2.05	2.20	1.86
200	1.85	1.20	1.85	2.44	2.42	2.10	2.32	2.64	2.03
Mean	1.26	1.26	1.92	2.11	1.98	2.06	2.15	2.24	
$CD_B = 0.06$	$CD_{AB} = 0.163$								

A – combination B – temperature AB – combination temperature interaction

Table 4.11 indicated increase in OAI property (Appendix B2) with increase in temperature. This was in agreement with the studied show by Singh *et al.* (1994b). Significant variation was analysed with respect to the process parameters under concern. Thus oil absorption index negatively correlated with WSI whereas positively correlated with WAI (Osman *et al.*, 2000). Linear equation for OAI can be expressed as

For rice: banana of R_{90}:B_{10} combination, the variation of OAI with process temperature (t) at a speed of 80 rpm can be expressed as

$$OAI = 0.22\ t + 1.39\ (R^2 = 0.983) \ldots\ldots\ldots (4.21)$$

whereas, variation in OAI with respect to speed (s) at a temperature of 180°C can be expressed as

$$OAI = 0.16\ s + 1.74\ (R^2 = 0.923) \ldots\ldots\ldots (4.22)$$

For rice: cassava: banana of R_{70}:C_{20}:B_{10} OAI can be expressed by the linear equations

$$OAI = 0.19\ t + 1.70\ (R^2 = 0.982) \ldots\ldots\ldots (4.23)$$ at a speed of 120 rpm

whereas, variation in OAI with respect to speed (s) at temperature of 190°C is

$$OAI = 0.22\ s + 1.703\ (R^2 = 0.923) \ldots\ldots\ldots (4.24)$$

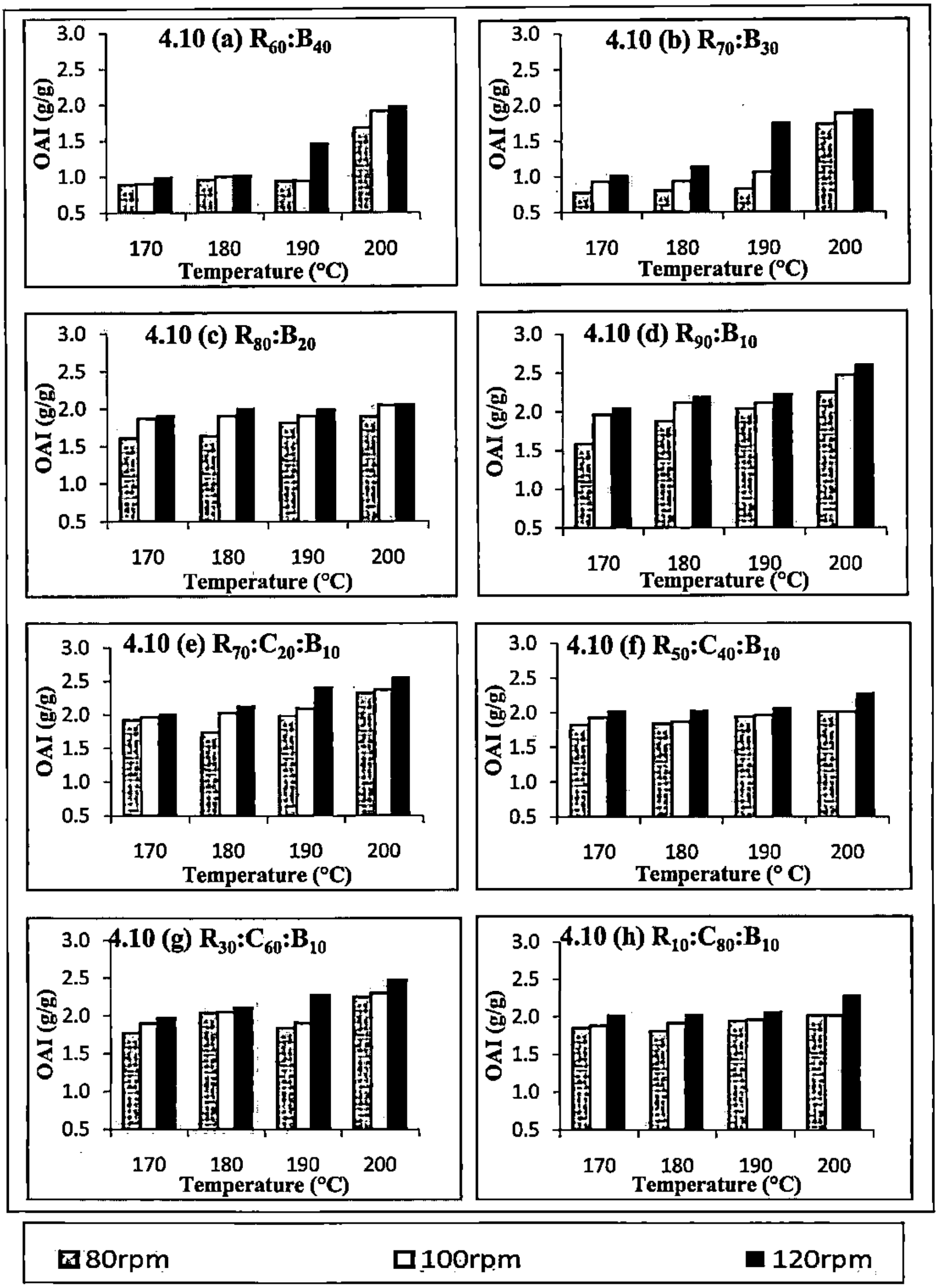

Fig. 4.10 Effect of combination, temperature and speed on OAI of extrudates

4.4 Quality of the extrudates based on textural properties

The textural properties of the extrudates were determined by measuring the peak force and breaking force by the methodologies described as per 3.8 and their results are discussed. Textural properties are discussed in terms of crispness, hardness, toughness, snap force and snap energy.

4.4.1 Peak force of the extrudates

The peak force of the extrudates for the various blends of rice: banana and rice: cassava: banana was evaluated as per the properties *viz.* crispness, hardness and toughness. The crispness of the extruded product increased with the number of the peaks displayed by the texture analyser.

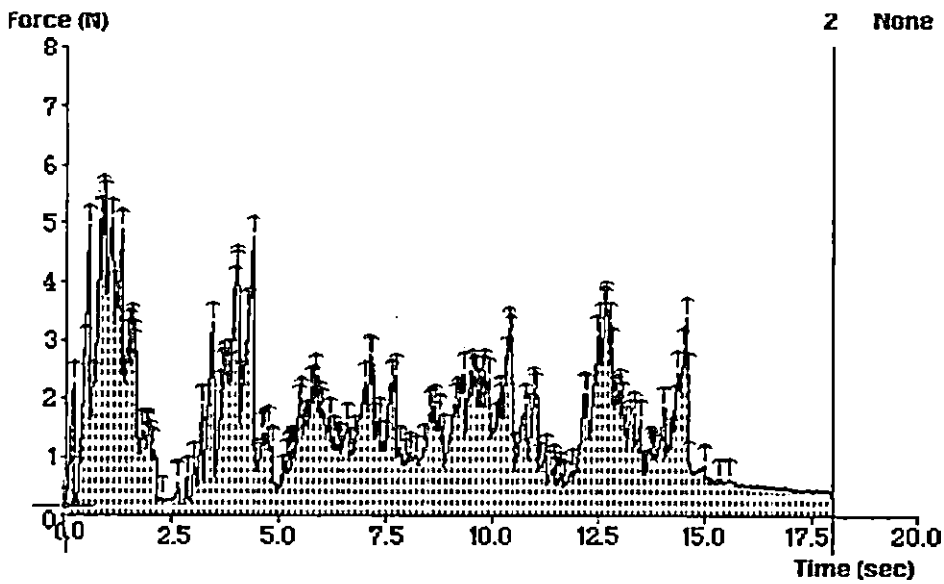

Fig. 4.11 Texture Profile Analysis (TPA) of the extrudates

The crispness (number of peaks) of the extrudates for rice: banana combination ranged from 3.3 to 7.9 and 3.3 to 8.1 for rice: cassava: banana extrudates (Appendix A3). Out of these, R_{90}:B_{10} of rice: banana combinations and R_{10}:C_{80}:B_{10} combinations of the rice: cassava: banana combinations showed high brittleness due to the high elastic property associated with these snacks (Linko *et al.*, 1982).

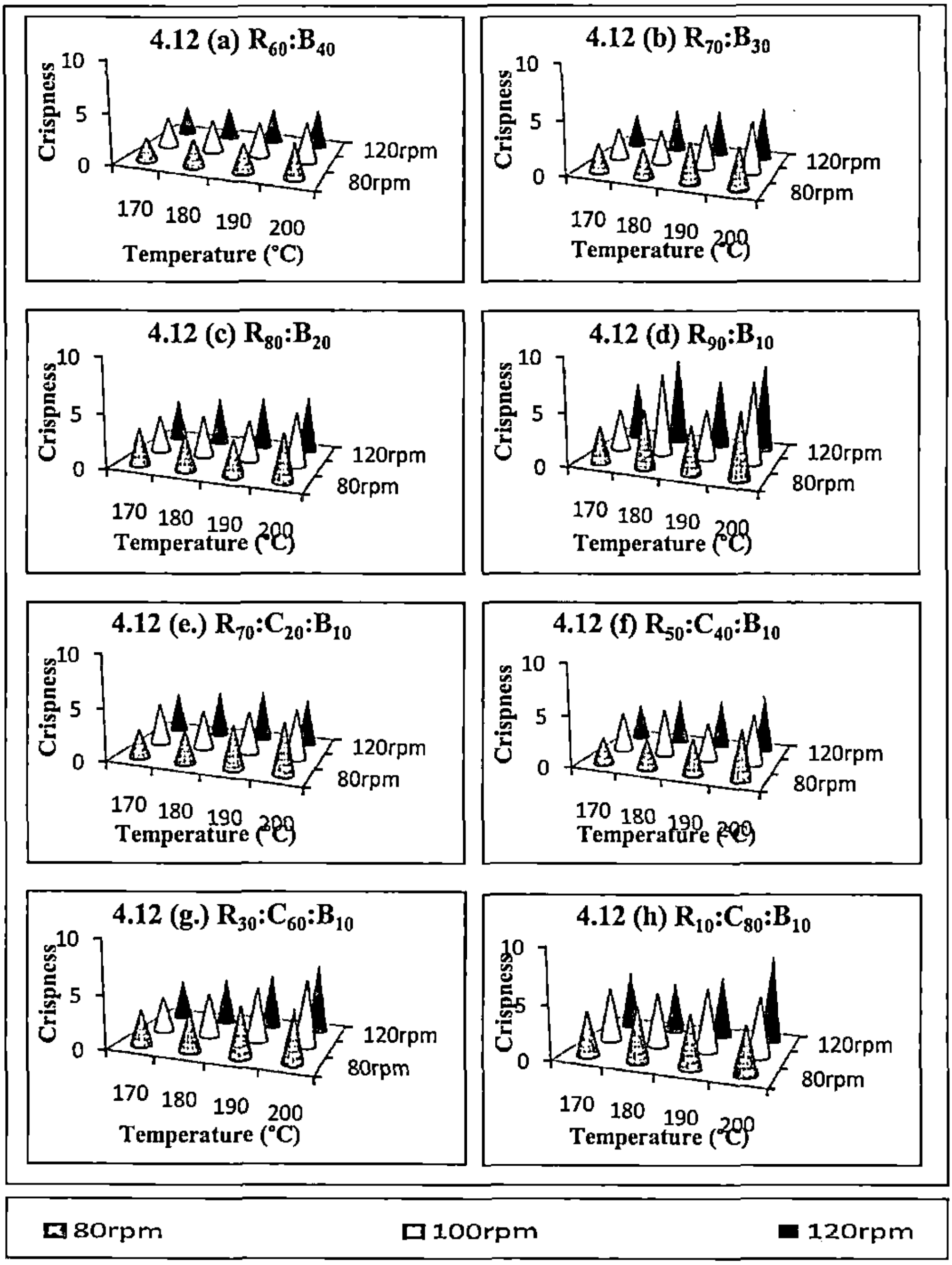

Fig. 4.12 Effect of combination, temperature and speed on crispness of extrudates

Fig. 4.12 indicates the crispness exhibited by different proportions of rice: banana and rice: cassava: banana combinations with respect to different process parameters. 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).

Crispness exhibited by these proportions varied in the range as

$$P8 > P4 > P7 > P6 > P5 = P3 > P2 > P1$$

Higher crispness was found in case of cassava extrudates due to the higher amount of starch content compared with rice and banana. At elevated temperatures extrudates showed maximum expansion with high crisp factor. The crispness in terms of different process parameters are appended in Appendix (B3). The crispness of the extruded product was related to the hardness and toughness of the extruded product (Singh *et al.,* 1994a). Analysis of variance (Appendix H) indicated that the effect of the various flour blends on the crispness of the extrudates were highly significant ($p<0.01$). There was elevated significance with the effect of temperature speeds with sample configuration whereas there was no significant difference with the effect of speed when taking the variation along with sample temperature alone.

Hardness (N) and toughness (N-s) exhibited by the rice: banana composition ranged from 20.22 to 42.46 N and 7.44 to 20.45 N-s. For rice: cassava: banana combinations these varied in the range of 13.44 to 35.21 N and 3.79 to 14.30 N-s. These properties had a negative correlation in terms of expansion. Higher values for hardness and toughness indicated the higher amount of mechanical strength which has to be applied for the product to shear. Screw speed and screw conFig.uration also had significant effect with less harder products at these parameters.

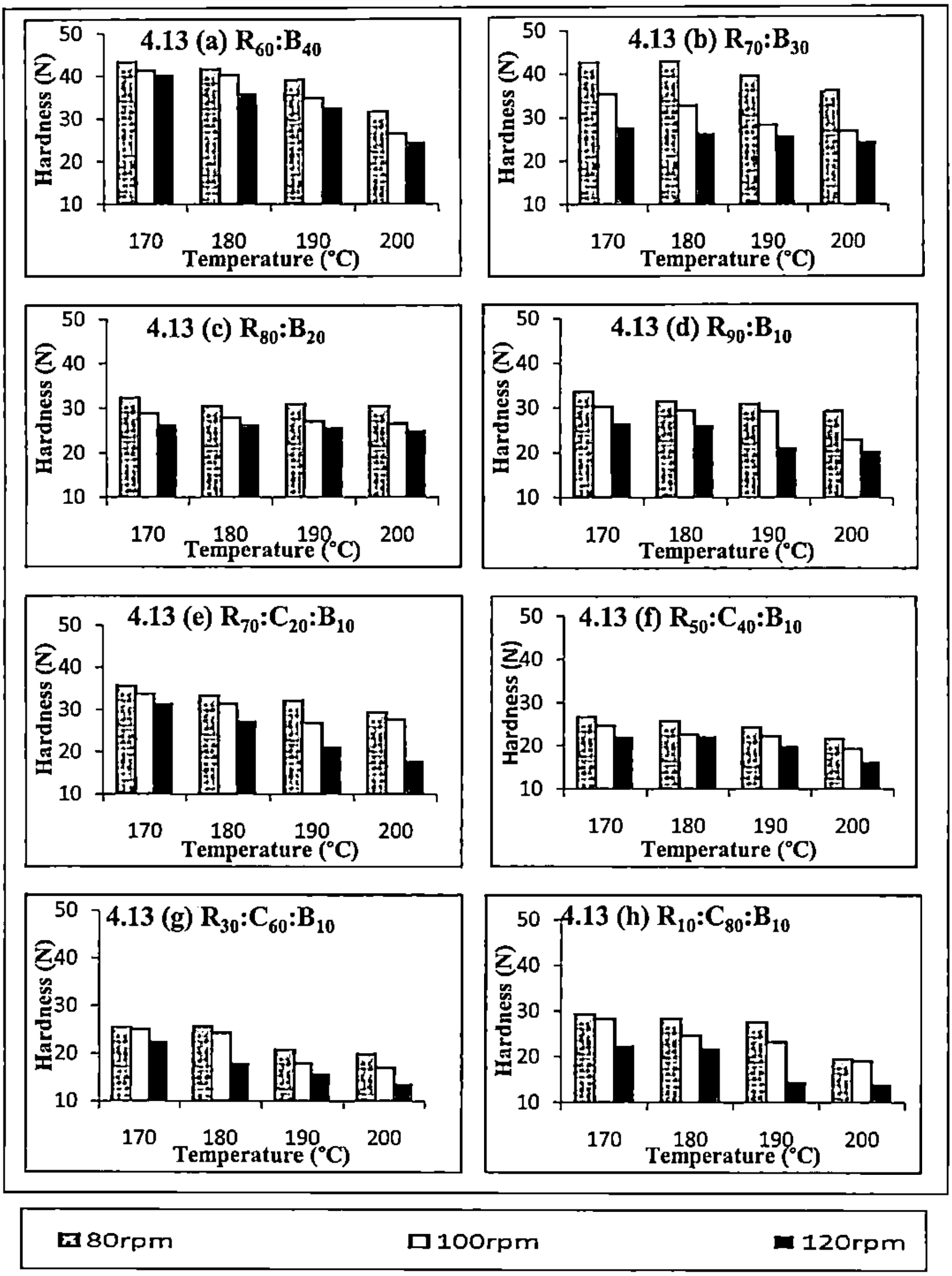

Fig. 4.13 Effect of combination, temperature and speed on hardness of extrudates

Table 4.12 Interaction of temperature and combination on hardnesss of extrudates

Temperature (°C)	Hardness (N) of extrudates at various combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	42.44.	42.11	41.19	40.80	32.11	31.99	31.74	29.06	43.09
180	41.40	40.23	39.33	38.92	26.76	30.53	28.80	24.00	37.58
190	35.13	38.09	37.81	33.17	25.78	27.89	25.70	20.28	31.04
200	34.29	27.33	35.31	27.85	23.93	20.22	19.45	16.67	28.18
Mean	45.39	41.11	40.67	39.09	37.58	27.14	26.43	22.51	
CD_B = 0.2.6	CD_{AB} = 0.7.4								

A – combination B – temperature AB – combination temperature interaction

Table 4.12, indicates the mean values of hardness with respect to the two combinations. It clearly signified that decrease in die temperature decreases the expansion of extrudates resulting in increase in density and hardness. This was in authentication to the results of Chaiyakul *et al.* (2009). A tougher product obtained due to the denser structure which was found as a result of higher density and thicker cell wall (Badrie and Mellowes, 1991). The linear equation exhibited with respect to hardness can be expressed as

For rice: banana combination of R_{60}:B_{40}, the variation of hardness with process temperature (t) at a speed of 80 rpm is given by

Hardness = -3.86 t + 48.24 (R^2 = 0.892) .... (4.25)

whereas, variation in hardness with respect to speed at a temperature of 170°C is expressed as

Hardness = -1.51 s + 44.56 (R^2 = 0.965) .... (4.26)

For R_{30}:C_{60}:B_{10}, variation in hardness can be expressed by the linear equations,

Hardness = -3.08 t + 28.55 (R^2 = 0.899) .... (4.27) at a speed of 100 rpm whereas, variation in hardness with respect to speed (s) at temperature of 200°C is given by

$$Hardness = -3.06\ s + 22.69\ (R^2 = 0.992) \ldots\ldots (4.28)$$

The interaction with respect to crispness and toughness with temperature, speed and combinations are shown in Appendix (B3).

4.4.2 Breaking force of the extrudates

The breaking force of the extrudates for the various blends of rice: banana and rice: cassava: banana was evaluated as per the procedures described in 3.8. The snap force (N) and snap energy (N-s) of the extrudates from respective combinations were found using snap test. Snap force exhibited by rice: banana varied from 5.15 to 14.77 N and that of rice: cassava: banana from 5.8 to 12.44 N whereas the snap energy varied from 0.98 to 5.66 N-s for rice: banana combinations and 0.86 to 4.55 N-s in case of rice: cassava: banana combinations. Snap force showed a positive correlation with hardness and bulk density. Snap energy which indicated the breaking strength also correlated positively with bulk density. This in turn represents the negative correlation between expansion index and breaking strength which means that decreased breaking strength of extrudates was associated with high expansion index and low bulk density. This was in concordance with the results obtained by Choudhury and Gautam, (1998), Aylin *et al.* (2008).

Table 4.13 Interaction of temperature and speed on snap force of extrudates

Speed (rpm)	**Snap force (N) of extrudates at various temperatures**				
	T1	T2	T3	T4	Mean
80	13.36	12.53	10.85	10.07	11.45
100	12.73	12.30	10.50	9.59	11.32
120	12.17	11.15	10.36	9.37	10.97
Mean	12.40	12.34	10.57	9.68	
$CD_C = 0.56$	$CD_{BC} = 1.12$				

C – Speed BC – Temperature speed interaction

Table 4.13 indicates that higher temperature requires less breaking force was less (Kaur *et al.*, 2002). Screw speed also had significant effect on snap force which shows the influence on less bulk density and expansion. Increased starch also resulted in less hardness of extrudates. This is in consistent with the results of Jhoe *et al.* (2009).

Linear equation of these extrudates in terms of snap energy can be expressesed as

For R_{60}:B_{40} combination, the variation of snap energy with process temperatures (t) at a speed of 80 rpm is given by

Snap energy = -0.82 t + 6.58 (R^2 = 0.984) .... (4.29)

whereas, variation in snap energy with respect to speed (s) at a temperature of 170°C is expressed as

Snap energy = -1.30 s + 7.07 (R^2 = 0.992)............ (4.30)

For R_{70}:C_{20}:B_{10} snap energy can be expressed by the linear equations,

Snap energy = -0.59 t + 4.82 (R^2 = 0.954) .... (4.31) at a speed of 80 rpm

whereas, variation in snap energy with respect to speed (s) at temperature of 170°C is given by

Snap energy = -1.22 s + 5.60 (R^2 = 0.949)............ (4.32)

The snap energy exhibited by all the extrudates are presented in the model data in the Fig. 4.13,(a – d) for rice : banana combinations and (e – h) for rice: cassava: banana combination. The results focused that brittleness is inversely associated to the maximum force required to break the sample (Katz and Labuza, 1981; Vickers, 1988).

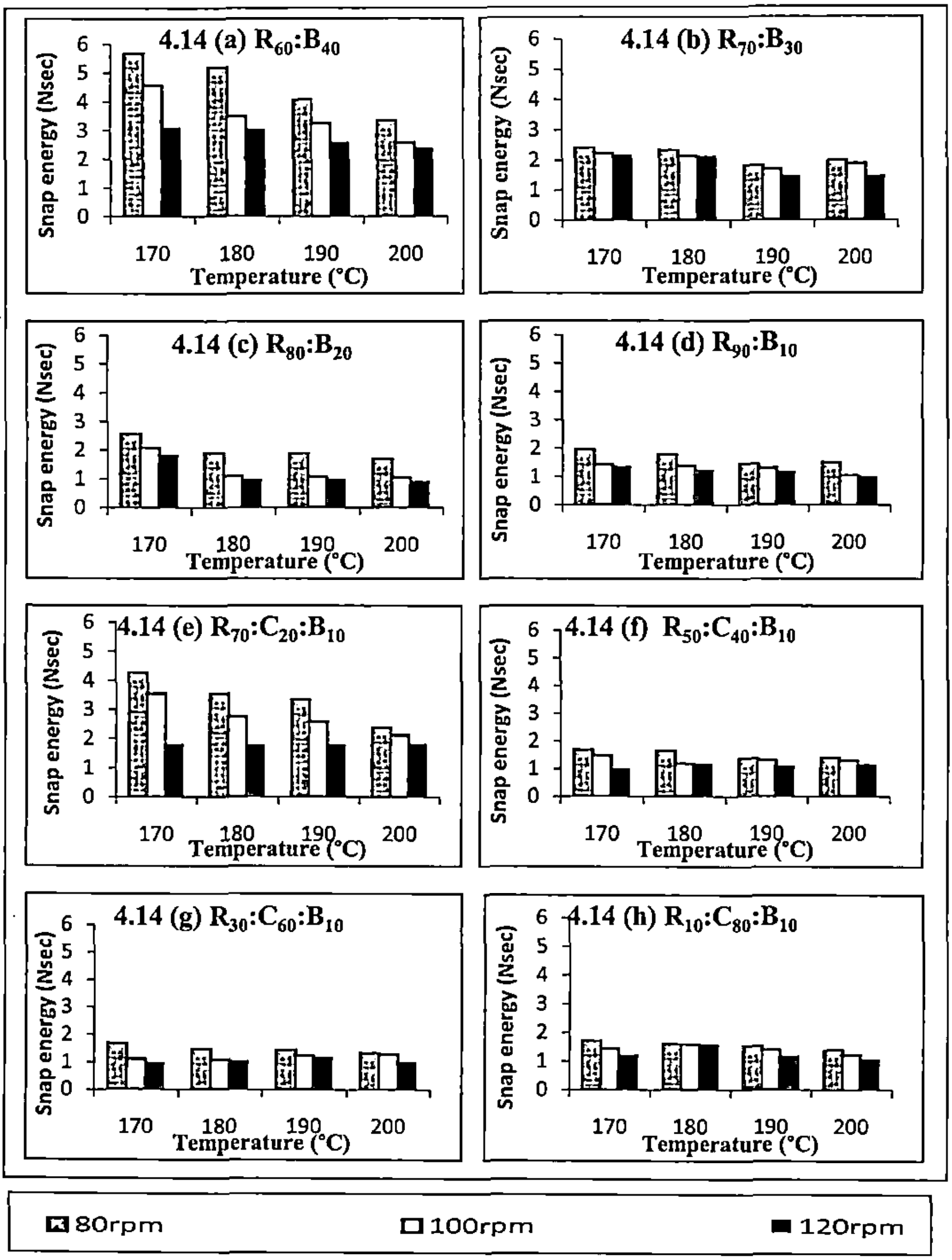

Fig. 4.14 Effect of combination, temperature and speed on snap energy of extrudates

4.5 Quality of the extrudates based on colour properties

The tristimulus colour values as well as total colour change (ΔE) and the browning index were calculated as per the methodologies and formulas explained in 3.9. Significant variation was noticed as regards L, a, b, ΔE and browning index (BI) for the combinations under concern.

Table 4.14 Interaction effect of combination and temperature on lightness of extrudates

Temperature (°C)	Lightness (L) of extrudates at various combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	84.77	84.55	89.73	94.76	89.52	89.10	87.42	87.42	87.81
180	84.42	83.97	87.52	92.04	89.42	87.55	86.62	86.62	86.60
190	80.58	81.27	87.51	91.79	88.39	87.16	84.28	84.28	85.57
200	79.31	80.08	86.96	91.31	88.10	86.96	83.49	83.49	85.31
Mean	82.27	82.47	87.93	92.48	87.81	86.60	85.57	83.43	
$CD_A = 0.049$	$CD_{AB} = 0.099$								

A – combination B – temperature AB – combination temperature interaction

Table 4.14, clearly indicates that extrusion process significantly affected the colour. The extrudates made out of the rice: banana combinations result in a light dark spectrum varying (Fig. 4.14) from (76 ± 0.56) to (95 ± 0.08) and for rice: cassava: banana combinations it ranged from (79 ± 0.17) to (90 ± 0.03) respectively (Appendix B4).

With increase in temperature 'L' value of extrudates decreased (Plate 4.1 and 4.2). These changes in colour intensity are caused by the maillard reaction between reducing sugars (dextrinised starch) and amino groups from proteins (Wen *et al.*, 1990). The colour intensity in extruded products also increased due to the starch concentration as a result of reduced sugars generated by starch dextrinisation, especially at higher die temperatures. This was in confirmation with the results of Fernández *et al.* (2004).

R_{60}:B_{40}

170°C 180°C 190°C 200°C

Plate 4.1 Variation in colour of R_{60}:B_{40} combination at 100 rpm at varying die temperature

190°C

80 rpm 100 rpm 120 rpm

R_{70}:C_{20}:B_{10}

Plate 4.2 Variation in colour for R_{70}:C_{20}:B_{10} combination at 190°C at varying speed

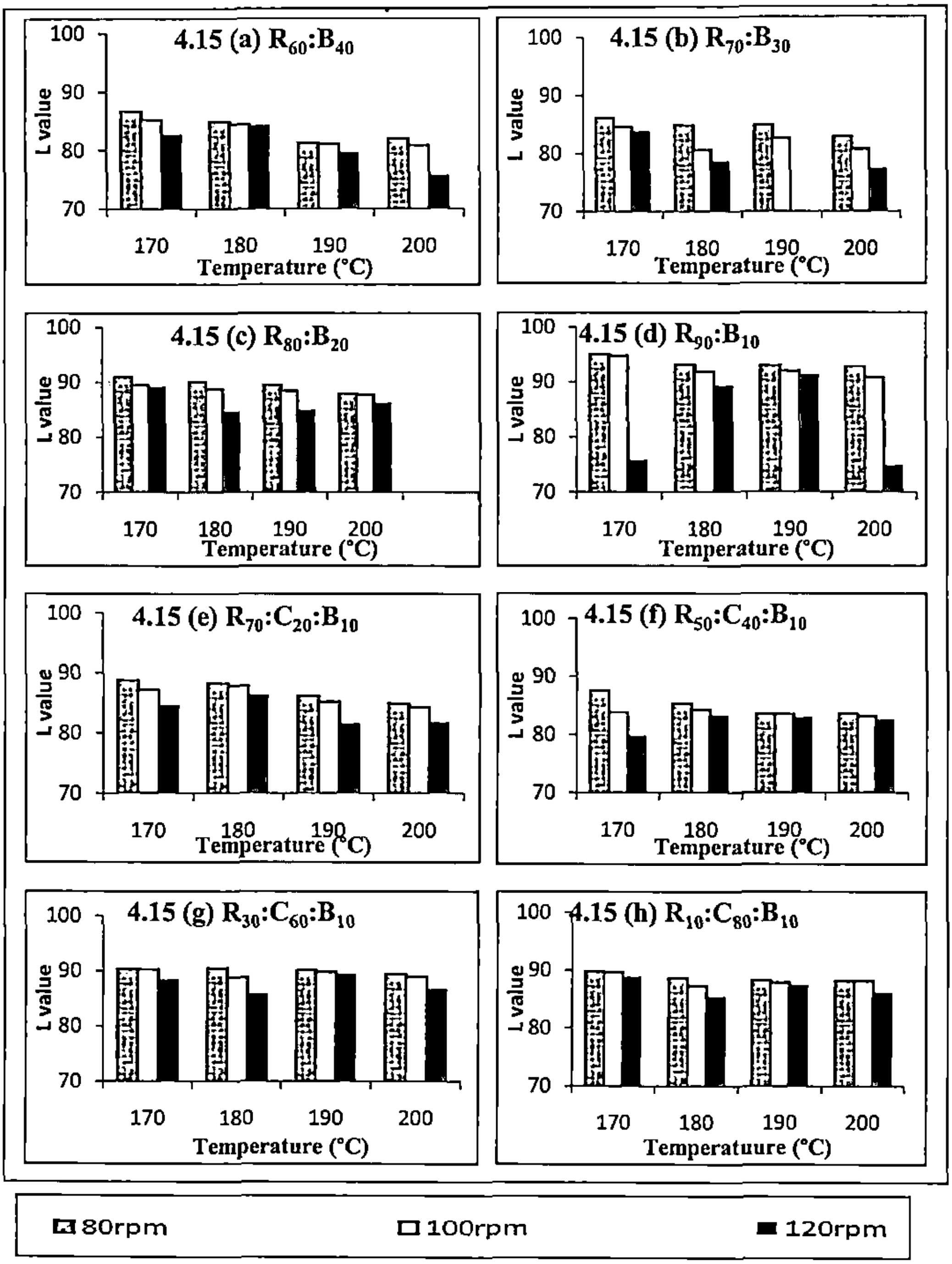

Fig. 4.15 Effect of combination, temperature, speed on lightness of extrudates

The lightness ('L') of the extrudates can be described in terms of linear equations as given below:

For R_{60}:B_{40} combination, the variation of lightness with process temperature (t) at a speed of 100 rpm is given by

$$L = -1.69\,t + 87.00\ (R^2 = 0.896) \ldots\ldots\ (4.33)$$

whereas, variation in lightness with respect to speed (s) of 170°C is expressed as

$$L = -2.00\,s + 88.76\ (R^2 = 0.979) \ldots\ldots\ (4.34)$$

For R_{10}:C_{80}:B_{10} lightness can be expressed by the linear equations,

$$L = -0.53\,t + 89.75\ (R^2 = 0.914) \ldots\ldots (4.35)$$ at a speed of 80 rpm

whereas, variation in lightness with respect to speed (s) at 170°C is

$$L = -0.4\,s + 89.90\ (R^2 = 0.842) \ldots\ldots (4.36)$$

The redness of the product varied from (2.5 ± 0.03) to (7.6 ± 0.11) for cereal based combinations and (3.7 ± 0.02) to (7.4 ± 0.71) for cassava based extrudates. The yellowness to these products varied in the range of (14 ± 0.09) to (26 ± 0.10) for the rice: banana combination and (20 ± 0.03) to (28 ± 0.23) for the rice: cassava: banana combination. Fig. 4.15 (a – h) clears that most of the extrudates have higher 'a' values which shows that the products were slight reddish. This redness appeared in the cassava products was due to the presence of beta carotene pigment in the variety (Sreevijaya) choosen for extrusion. Variation of the rice: banana combinations and rice: cassava: banana combinations at constant die temperatures are displayed in Plate 4.3 and 4.4.

R_{70}:C_{20}:B_{10} R_{50}:C_{40}:B_{10} R_{30}:C_{60}:B_{10} R_{10}:C_{80}:B_{10}

Plate 4.3 Variation of rice: cassava: banana combination at die temperature 190°C

R_{90}:B_{10} R_{80}:B_{20} R_{70}:B_{30} R_{60}:B_{40}

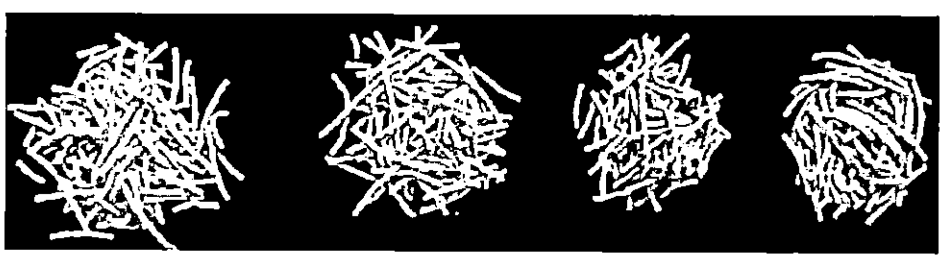

Plate 4.4 Variation of rice: banana combination at die temperature 180°C

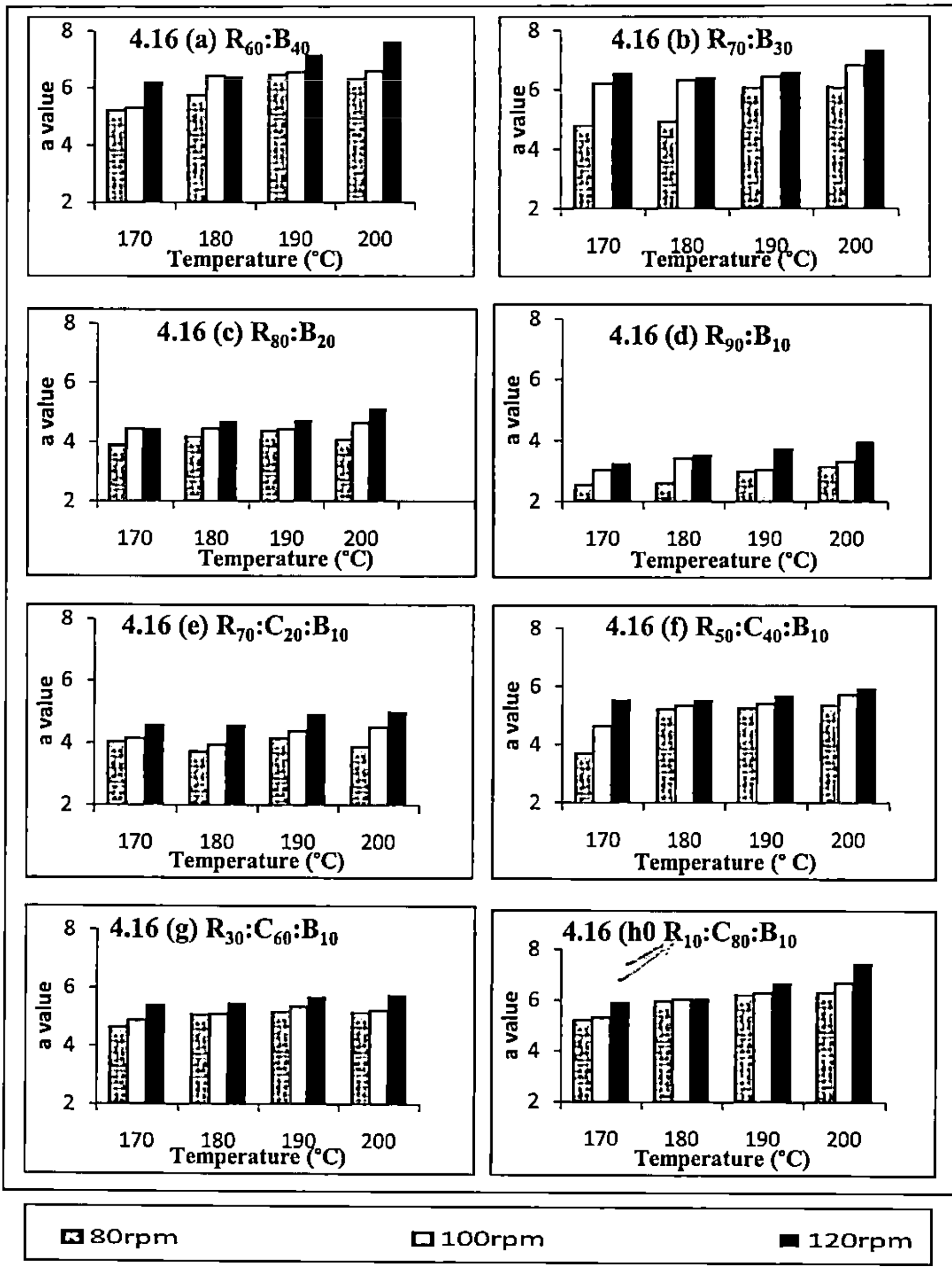

Fig. 4.16 Effect of combination, temperature, speed on redness ('a') of extrudates

Figure 4.16 (a to h) explains the variation in yellowness ('b') of the extrudates. The values indicated that the products showed a slight yellowness as the amount of cassava flour increased. On the other hand, products with higher "a" values were darker and had lower "L" values which is similar to previous reports (Altan *et al.*, 2008; Ilo and Berghofer, 1999). It was seen that increasing the temperature from 170 to 200°C increased the "a" (redness) and "b" (yellowness) values suggesting that the degradation of pigments was accelerated at the high temperature (Altan *et al.*, 2008, 2009; Ilo and Berghofer, 1999, Ali *et al.*, 2008). Generally with increases in temperature, the products had lower "L" values with higher 'a' and 'b' values.

Lightness can be expressed in terms of linear equation as given below:

For R_{70}:B_{30} combination, the variation of lightness with process temperatures (t) at a constant speed of 100 rpm is given by

$$L = 0.645\ t + 5.905\ (R^2 = 0.916) \ldots\ldots\ldots\ldots (4.39)$$

whereas, variation in lightness with respect to speed (s) at a temperature of 200°C is expressed as

$$L = 0.645\ s + 5.425\ (R^2 = 0.989) \quad \ldots\ldots\ldots\ldots \quad (4.40)$$

For, R_{70}:C_{20}:B_{10} lightness can be expressed by the linear equations,

$L = 0.172\ t + 4.325\ (R^2 = 0.869) \ldots\ldots\ldots\ldots (4.41)$ at a speed of 120 rpm

whereas, variation in lightness with respect to speed at temperature of 170°C is given by

$$L = 0.28\ s + 3.646\ (R^2 = 0.901) \ldots\ldots\ldots\ldots (4.42)$$

The interactions for all extrudates in terms of combination, temperature and speed are tabulated in Appendix (B4) for all the 96 treatments.

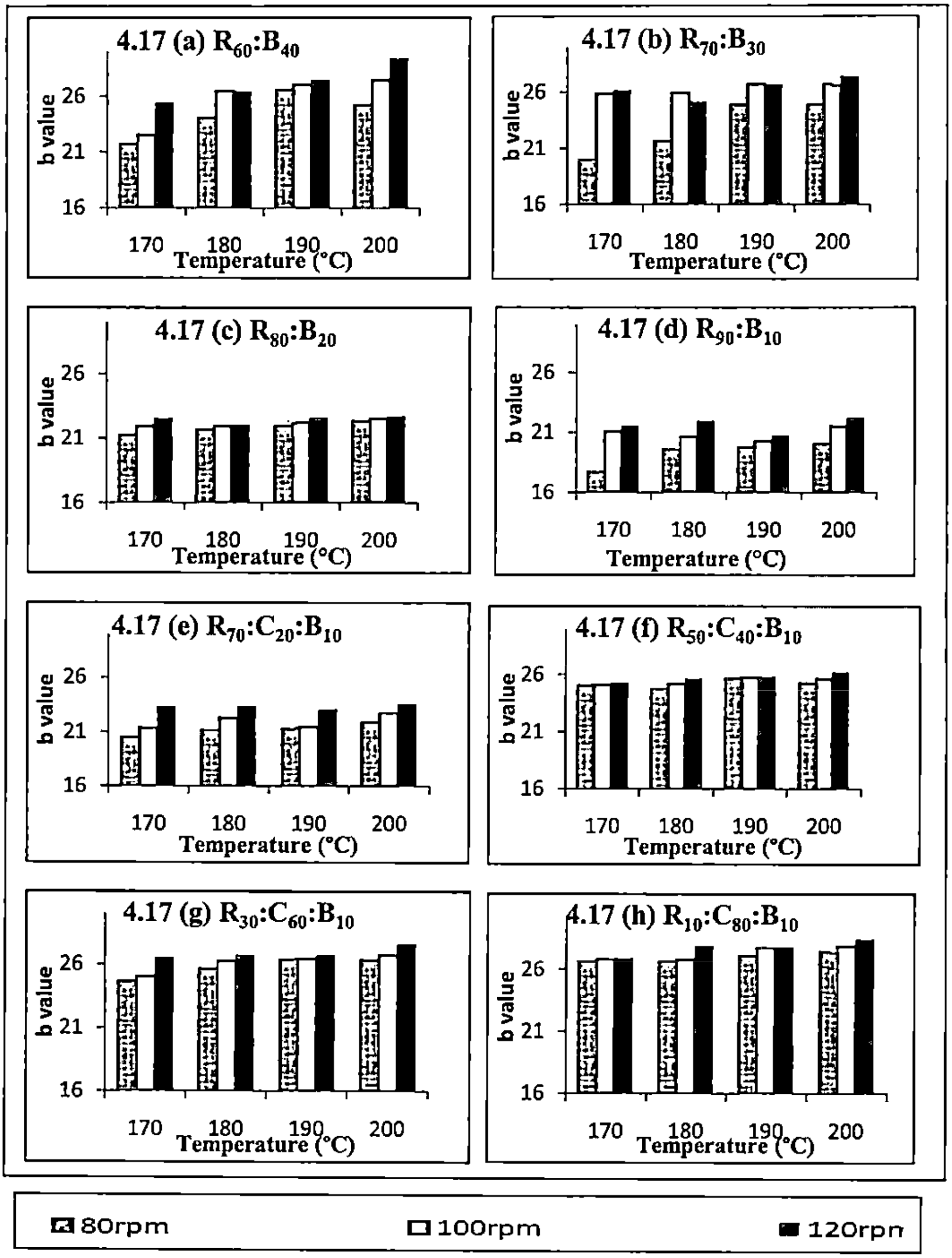

Fig. 4.17 (a-h) Effect of combination, temperature and speed on yellowness ('b') of extrudates

4.5.2 Total colour change of extrudates

The total colour change (ΔE) increased from (21 ± 0.93) to (29 ± 0.90) for rice: banana combination and (21 ± 0.02) to (30 ± 0.19) for the rice: cassava: banana combination. There was a gradual increase in ΔE with increase in process temperature. This implies that with increase in temperature, the degradation rate of colour becomes faster as a result of high energy transferred to the inside of food material (Ali *et al.,* 2008, Cemalettin and Mustafa, 2010). This could also be due to the chemical interactions such as caramelisation of carbohydrates. Significant variation was noticed in total colour change irrespective of treatments and combinations. The linear equation can be expressed as

For rice: banana combination of R_{70}:B_{30} combination, the variation of total colour change with process temperatures (t) at a speed of 100 rpm is given by

$$\Delta E = 0.62\ t + 24.05\ (R^2 = 0.989) \ldots\ldots\ldots\ldots\ldots (4.43)$$

whereas, variation in total colour change with respect to speed (s) at a temperature of 200°C can be expressed as

$$\Delta E = 1.16\ s + 23.95\ (R^2 = 0.969) \ldots\ldots\ldots\ldots\ldots (4.44)$$

For R_{50}:C_{40}:B_{10}, ΔE can be expressed by the linear equations,

$$\Delta E = 1.45\ t + 20.95\ (R^2 = 0.873) \ldots\ldots\ldots\ldots\ldots (4.45)$$ at a speed of 80 rpm

whereas, variation in ΔE with respect to speed (s) at temperature of 170°C can be expressed as

$$\Delta E = 2.05\ s + 20.86\ (R^2 = 0.990) \ldots\ldots\ldots\ldots\ldots (4.46)$$

The interactions for all extrudates in terms of combination, temperature and speed are tabulated in Appendix (B4) for all the 96 treatments. Figure 4.17 (a –h) shows the total colour change of the extrudates exhibited by the two combinations under study.

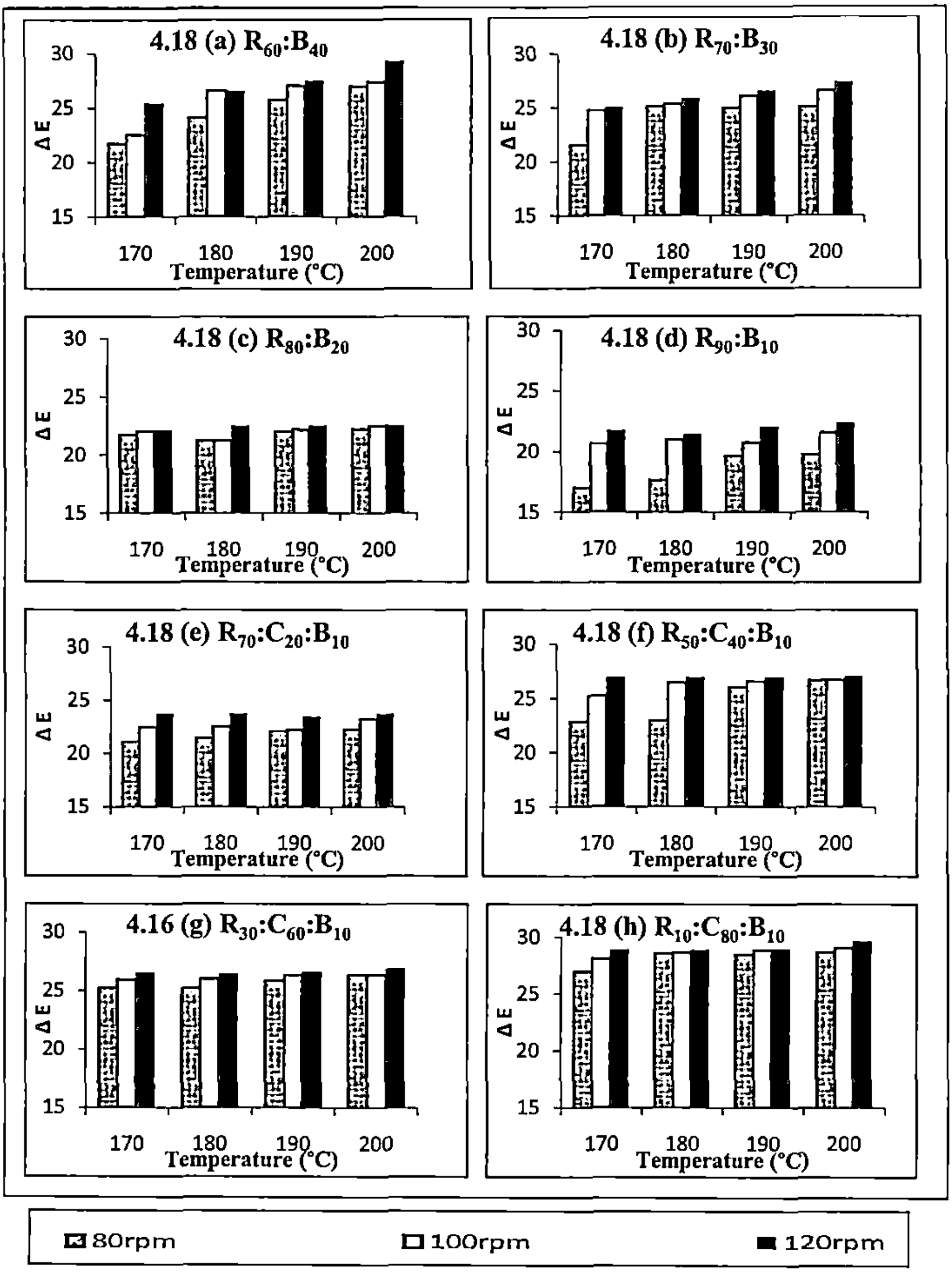

Fig.4.18 Effect of combination, temperature, speed on ΔE of extrudates

4.5.3 Browning index (BI) of extrudates

The browning index of extrudates increased with increase in die temperature. The results obtained were in agreement with the studies published by (Fernando and Cisneros, 2007). The Browning index (BI) varied from (19 ± 0.06) to (47 ± 0.77) for rice based extrudates and (30 ± 0.69) to (45 ± 0.42) for cassava based extrudates.

Table 4.15 Interaction of combination and speed on BI of extrudates

Speed (rpm)	BI of extrudates at various combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	42.53	42.33	31.32	24.77	34.00	43.57	42.52	38.36	36.76
100	42.21	41.38	30.54	24.16	32.85	40.52	41.40	37.68	36.53
120	39.75	36.75	29.72	24.14	32.41	39.79	39.83	37.41	35.45
Mean	41.50	40.15	30.53	24.36	41.29	41.25	37.82	33.09	
CD_C= 0.071	CD_{AC}= 0.201								

A – combination C – Speed AC – Combination speed interaction

Table 4.15, shows that higher rates achieved at low speed and all others were on par with each others. For rice banana combinations, BI was found less for R_{90}:B_{10} at high process conditions (190, 200°C at 120 rpm). The values of browning index showed that at higher temperatures, (Appendix B4) the products results in more brown compounds and the result was supported by the increase in 'a' value (Cemalettin and Mustafa, 2010). It also revealed that increase in screw speed and die temperature increased the browning index.

4.6 Variation in machine parameters of extrudates

The machine variables were determined by the methodologies explained as per 3.10.

4.6.1 Feed rate

The feed rate obtained for the eight compositions are indicated in Fig. 4.19 (a & b). The increased amount of rice resulted with increased feed rate (2.2 kg/h) in rice: banana combination whereas increased amount of cassava in the rice: cassava: banana resulted with decrease in feed rate (Ding *et al.* 2005).The reason for was due to high particle size of the rice compared with that of the cassava flour. So it will result in extrudates with low density and high expansion (Fan, 1996).

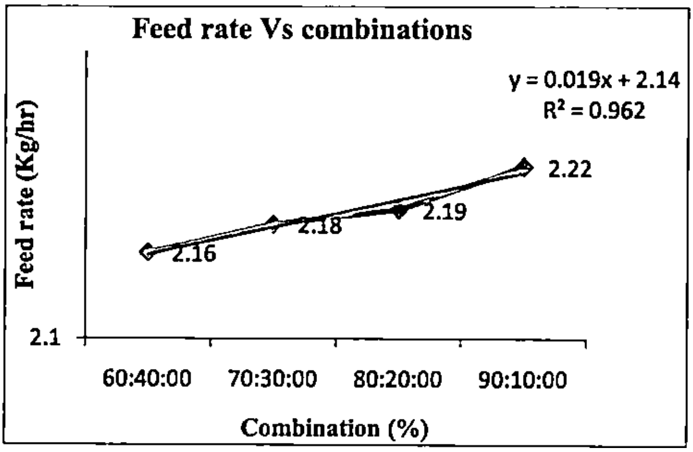

Fig. 4.19 (a) Variation of feed rate for rice: banana combinations

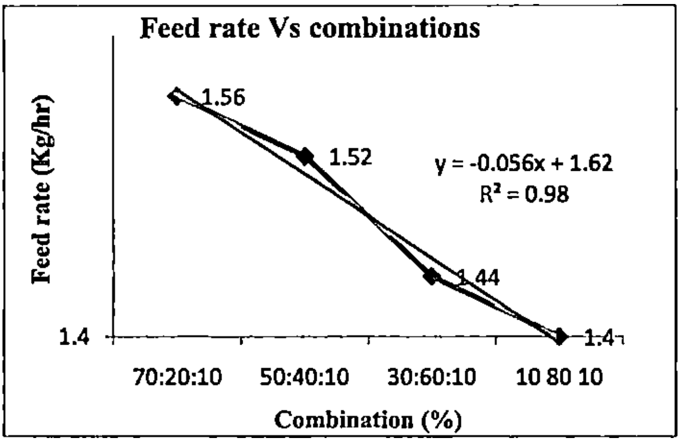

Fig. 4.19 (b) Variation of feed rate for rice: cassava: banana combinations

In case of cassava extrudates, the decreased amount of feed rate resulted in products with high expansion indicating the greater starch gelatinisation of cassava extrudates.

The variation of feed rate with respect to rice: banana combinations can be expressed by the linear equation

$$y = 0.02\,x + 2.14\ (R^2 = 0.962) \ldots\ldots\ (4.47)$$

For the rice : cassava : banana combinations, it can be expressed as

$$y = -0.06\,x + 1.62\ (R^2 = 0.98) \ldots\ldots\ (4.48)$$

where 'y' represents the feed rate of the flours and 'x' shows the different combinations of the two combinations.

4.6.2 Mass flow rate of the extrudates

The mass flow rate of the rice banana combination varied between 1.3 to 1.7 kg/h for the rice banana combination and 0.7 to 2.4 kg/h for the cassava extrudates. (The values for all treatments are appended in Appendix C1). With increase in temperature the mass flow rate of the extrudates decreased. Lower amount were achieved for cassava combination due to less density of the major component (cassava). This property had also significant relation with respect to screw speed since high screw speed resulted with less mass flow rate. The variations in the mass flow rate of extrudate samples were very less, due to constant maintenance of barrel temperature (Fig. 4.20) as well as moisture content in the feed mixtures (Deshpande and Poshadri, 2011).

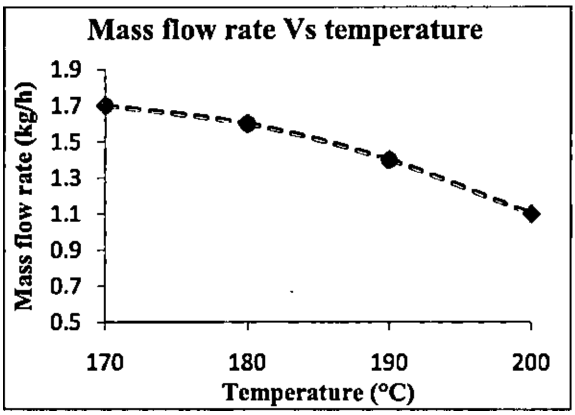

Fig. 4.20 Variation in mass flow rate with die temperature

4.6.3 Volumetric flow rate

When rice powder is incorporated at a higher proportion it resulted with higher volumetric flow from 1536 to 4120 m^3/hr in R_{90}:B_{10} and with increase in temperature a decrease in flow was noted. For rice: cassava: banana combinations it varied from 2755 to 6388 m^3/h (Appendix C2). The reason for this is due to high particle size and density (0.14 - 0.16 g/cm^3) of blends with increased amount of rice powder.

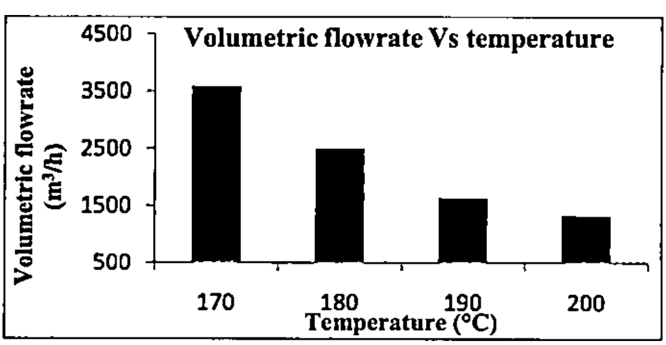

Fig. 4.21 Effect of volumetric flow with change in die temperature

4.6.4 Torque

The results for torque obtained varied from 45 to 60 N-m for both rice: banana and rice: cassava: banana combinations (Appendix C3). Increased amount of rice resulted with increase in torque which indicated that coarse textured materials required higher amount of mechanical shear (Karunanithy and Muthukumarappan, 2011).

4.6.5 Specific mechanical energy (SME)

The calculated SME of extrudates ranged from 136.4 to 454.4 kWh/kg for rice: banana and for rice: cassava: banana it varied between 217.2 to 632.3 kWh/kg (Appendix C4). The increased amount of rice flour resulted with higher fuel consumption. These findings show that SME input was significantly affected by the particle average size. The increasing particle size decreased the SME input. Similar results were also reported by Altan *et al.* (2009). Large particles have less contact area in relation to particle and consequently, are less affected by barrel temperature than finer particles as reported by Desrumaux *et al.* (1998).

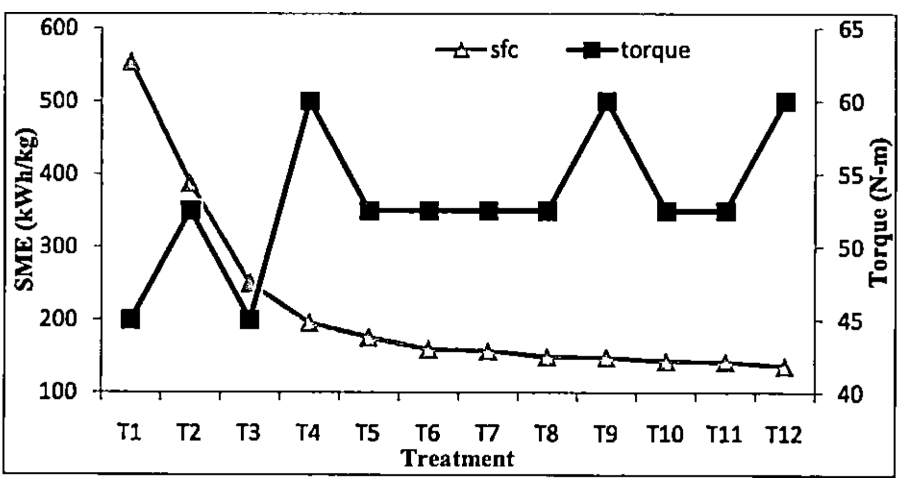

Fig. 4.22 Effect of SME and torque for R_{60}:B_{40} with die temperature and screw speed

Fig. 4.22 shows the variation of temperature, SME, torque and moisture conrent. With increase in temperature, SME was decreased (Onwulata and Konstance, 2006). The finer particles would heat more rapidly and reach the melt transition temperature faster than coarser particles resulting in lower viscosity and hence reduce SME. Also, energy expended to reduce the size of the particles in the extruder may not be available for starch conversion. Torque and moisture content had not much variation with increase in process temperature.

4.7 Packing and storage studies

The MAP stored extrudates for three month (Plate 4.5) were taken for quality analysis. Shelf life study of selected extrudates were commenced with textural and biochemical analysis. Selection of the extrudate was done with expansion ratio above 3.1 and bulk density upto 0.14 g/cm^3 (Pawar *et al.*, 2009). Based on this, seventeen treatments were choosen as the best samples and further analysis was performed. The selected extrudates are presented in Table 4.16.

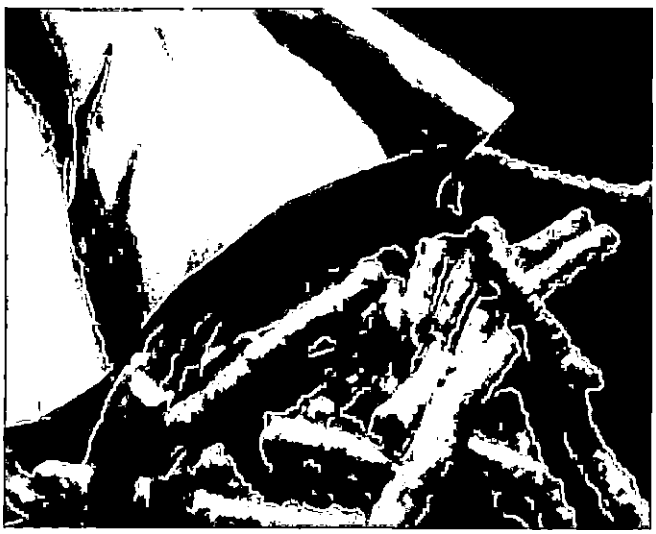

Plate 4.5 The extrudates after three month storage

Table 4.16 Selected extrudates after three month storage

Treatment	Combination (%)	Temperature-speed	ER1	BD (g/cm^3)
T1	R_{70}:B_{30}	200°C – 120 rpm	3.05	0.14
T2	R_{10}:C_{80}:B_{10}	190°C – 80 rpm	3.40	0.14
T3	R_{10}:C_{80}:B_{10}	190°C – 100 rpm	3.50	0.13
T4	R_{10}:C_{80}:B_{10}	190°C – 120 rpm	3.50	0.13
T5	R_{10}:C_{80}:B_{10}	200°C – 80 rpm	3.40	0.13
T6	R_{10}:C_{80}:B_{10}	200°C – 100 rpm	3.60	0.12
T7	R_{10}:C_{80}:B_{10}	200°C – 120 rpm	3.80	0.12
T8	R_{30}:C_{60}:B_{10}	180°C – 100 rpm	3.25	0.14
T9	R_{30}:C_{60}:B_{10}	180°C – 120 rpm	3.30	0.14
T10	R_{30}:C_{60}:B_{10}	190°C – 80 rpm	3.10	0.12
T11	R_{30}:C_{60}:B_{10}	190°C – 100 rpm	3.20	0.12
T12	R_{30}:C_{60}:B_{10}	190°C – 120 rpm	3.70	0.12
T13	R_{30}:C_{60}:B_{10}	200°C – 80 rpm	3.20	0.13
T14	R_{30}:C_{60}:B_{10}	200°C – 100 rpm	3.60	0.13
T15	R_{30}:C_{60}:B_{10}	200°C – 120 rpm	3.60	0.13
T16	R_{50}:C_{40}:B_{10}	200°C – 120rpm	3.10	0.14
T17	R_{70}:C_{20}:B_{10}	200°C – 120rpm	3.30	0.14

4.7.1 Textural analysis of selected extrudates

Texture analysis was done as per the methodologies explained under 3.8. Duncans multiple range test at 1% significance level showed variations for all characters under study. The results for these textural properties are tabulated in Table 4.17.

Table 4.17 Duncan test for texture analysis

Treatments	Crispness	Toughness (N-s)	Hardness (N)	Snap force (N)	Snap energy (N-s)
T1	8.0^{abcd}	8.77^{bc}	18.4^{abcde}	11.59^{ab}	4.78^{ab}
T2	9.4^{a}	11.95^{ab}	18.04^{abcdef}	8.98^{bcdef}	3.54^{ab}
T3	7.1^{abcd}	11.24^{abc}	24.3^{a}	12.38^{a}	1.63^{ab}
T4	8.0^{abcd}	12.63^{ab}	23.5^{ab}	11.09^{abc}	2.27^{ab}
T5	9.5^{a}	18.5^{abcde}	18.5^{abcde}	9.23^{bcdef}	4.01^{ab}
T6	5.3^{d}	6.4^{c}	13.3^{ef}	11.61^{ab}	5.72^{ab}
T7	8.7^{ab}	11.18^{abc}	17.3^{bcdef}	10.11^{abcd}	5.56^{ab}
T8	8.3^{abcd}	9.35^{abc}	19.2^{abcde}	10.12^{abcd}	1.33^{b}
T9	5.9^{bcd}	8.05^{bc}	18.4^{abcdef}	9.51^{abcde}	2.22^{ab}
T10	7.3^{abcd}	7.78^{bc}	14.8^{def}	6.45^{f}	1.74^{ab}
T11	8.0^{abcd}	8.5^{bc}	20.6^{abcd}	7.98^{def}	1.93^{ab}
T12	8.1^{abcd}	8.53^{bc}	17.6^{bcdef}	8.53^{cdef}	2.1^{ab}
T13	8.5^{abc}	14.34^{a}	18.5^{abcde}	7.5^{def}	4.43^{ab}
T14	7.4^{abcd}	10.08^{abc}	16.1^{cdef}	8.634^{bcdef}	5.85^{a}
T15	5.5^{cd}	6.67^{c}	12.01^{f}	6.84^{ef}	1.56^{ab}
T16	8.9^{ab}	12.47^{ab}	22.3^{abc}	9.87^{abcd}	4.85^{ab}
T17	6.7^{abcd}	11.25^{abc}	19.3^{abcde}	11.07^{abc}	2.16^{ab}

Sample means with the different superscript letter in columns or subscript letter in rows are significantly different ($p < 0.01$)

Table 4.17, clearly indicated the significant difference with respect to each and every treatments under study for the textural properties. All seventeen treatments after 3 month storage resulted in improved quality in terms of crispness with less hardness. Fig. 4.21 indicates the change in crispness with respect to initial and final shelf life of extrudates.

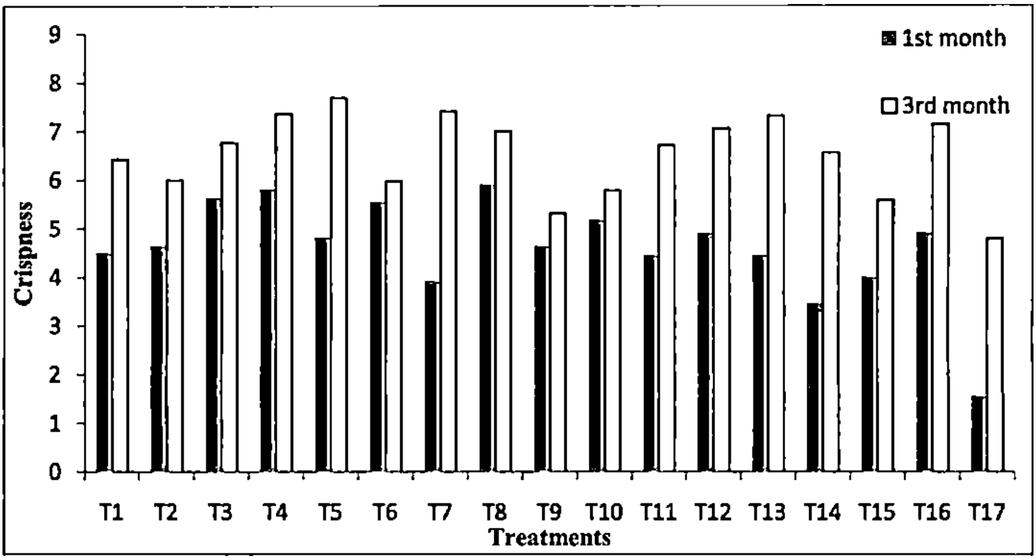

Fig. 4.23 Crispness of selected extrudates after storage

Crispness (Fig. 4.23) was found to be high for R_{10}:C_{80}:B_{10} (200°C at 80 rpm) and all others had not much significant differences with each other which resulted in less harder product. The harder products (Fig. 4.24) out of these selected samples were R_{10}:C_{80}:B_{10} (190°C at 100 rpm) and showed significant variation with the others. Toughness was found with similar results for hardness. Snap force required was low for R_{30}:C_{60}:B_{10} (190°C at 80 rpm) and high with respect to R_{10}:C_{80}:B_{10} (190°C at 100 rpm) whereas energy was found to have maximum with R_{30}:C_{60}:B_{10} (200°C at 100 rpm) and minimum for R_{30}:C_{60}:B_{10} (180°C at 100 rpm). There was not much significant variation with respect to the snap results or the breaking force required for the extrudates under consideration. The textural properties concluded that products out of R_{10}:C_{80}:B_{10} and R_{30}:C_{60}:B_{10} produced maximum expansion with higher crispness (Appendix D).

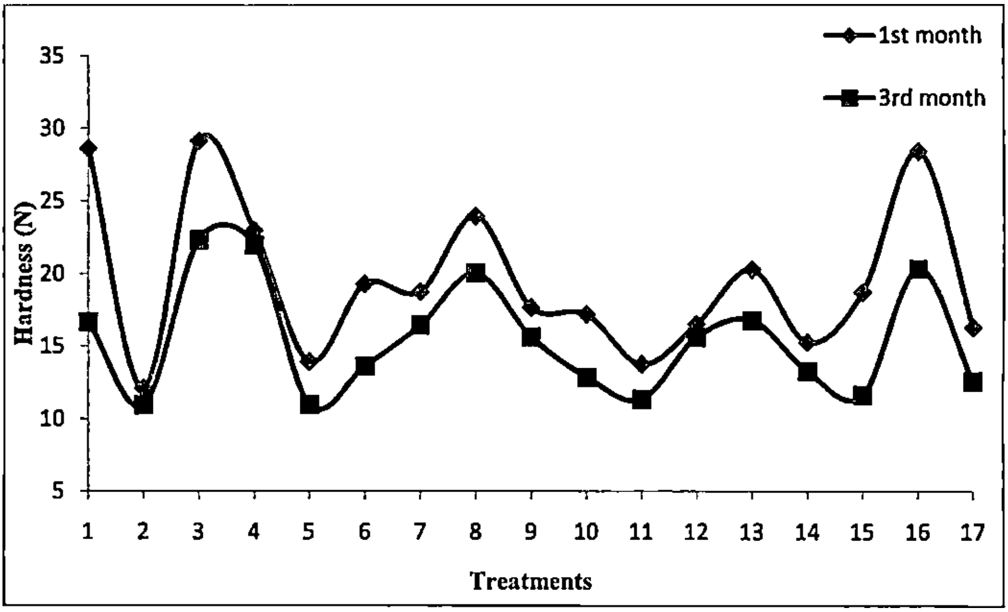

Fig. 4.24 Hardness of selected extrudates after storage

4.7.2 Proximate analysis of screened extrudates

Proximate composition of these treatments was calculated by the standard procedures mentioned as per 3.12. These proximate components including moisture content, starch, total sugar, protein, fat and total energy was calculated as described above. The duncan multiple range test resulted with significant variations for all properties under concern (Table 4.18).

Table 4.18 Duncan test for proximate analysis

Treatment	M.C (%)	Starch (%)	Sugar (%)	Protein (%)	Fat (%)	Total energy (KJ/100g)
T1	9.62^{ab}	63.35^{ij}	3.3363^{e}	7.7274^{b}	0.134^{e}	1266.79^{g}
T2	10.33^{ab}	58.39^{l}	3.9688^{b}	3.0406^{k}	0.5833^{b}	1130.11^{i}
T3	7.25^{b}	69.69^{d}	3.5042^{d}	2.9109^{kl}	0.2033^{ed}	1298.07^{ef}
T4	7.64^{ab}	75.69^{b}	3.7453^{c}	2.8816^{l}	0.42^{c}	1411.69^{b}
T5	8.1^{ab}	73.22^{c}	4.4407^{a}	2.837^{l}	0.55^{b}	1384.96^{c}
T6	8.83^{ab}	61.21^{k}	3.7204^{c}	5.8904^{d}	0.39^{c}	1215.05^{h}
T7	10.98^{a}	68.97^{de}	4.5247^{a}	2.8389^{l}	0.57^{b}	1314.81^{de}
T8	8.84^{ab}	66.94^{f}	3.5289^{d}	4.7921^{h}	0.2833^{d}	1286.72^{fg}
T9	9.18^{ab}	74.73^{b}	3.38^{de}	4.7685^{hi}	0.5667^{b}	1420.79^{b}
T10	9.13^{ab}	73.23^{c}	4.3926^{a}	4.6245^{i}	0.45^{c}	1410.98^{b}
T11	9.77^{ab}	62.58^{jk}	3.5395^{d}	5.1778^{f}	0.4033^{c}	1230.12^{h}
T12	8.05^{ab}	64.28^{hi}	4.4174^{a}	4.9748^{g}	0.42^{c}	1263.98^{g}
T13	9.09^{ab}	79.22^{a}	3.8678^{bc}	4.4788^{j}	1.0133^{a}	1263.98^{g}
T14	10.2^{ab}	68.13^{ef}	4.5163^{a}	4.8496^{gh}	0.5967^{b}	1335.67^{d}
T15	7.68^{ab}	62.46^{jk}	4.4657^{a}	5.347^{e}	0.2867^{d}	1235.10^{h}
T16	7.93^{ab}	66.77^{fg}	2.85^{g}	6.8832^{c}	0.4533^{c}	1314.82^{de}
T17	9.71^{ab}	65.42^{gh}	3.053^{f}	8.0335^{a}	0.28^{d}	1308.18^{ef}

The moisture content was calculated for all extrudates (96) during the initial month and resulted within a range of 6 to 11% (Fig. 4.25). Significant variation was noticed as regards moisture content for the eight combinations under consideration (Appendix E). Temperature also had a significant effect and the different response of the combinations with respect to the different temperatures was noticed. Speed doesn't have significant influence on moisture content.

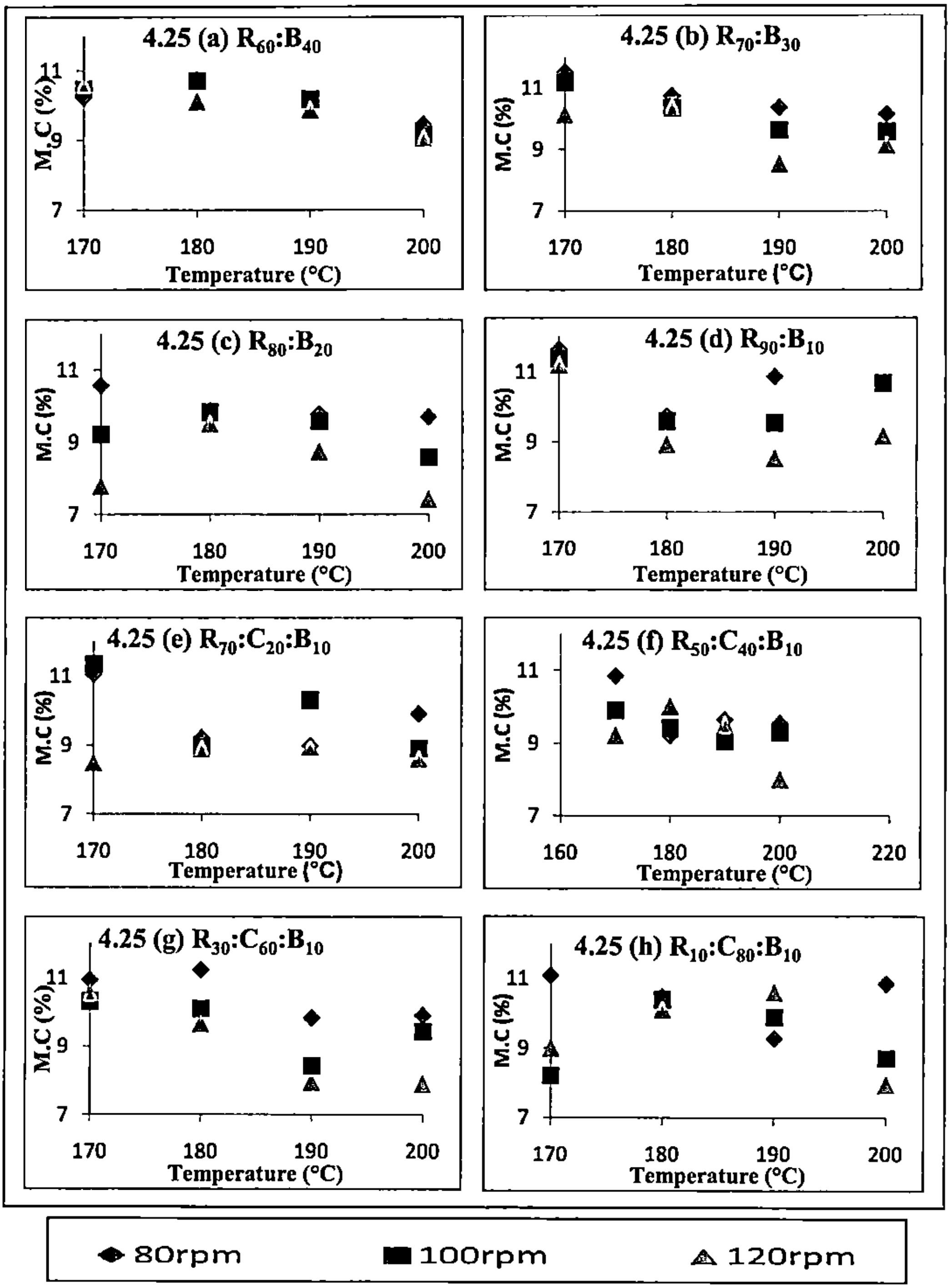

Fig. 4.25 Effect of combination, temperature and speed on M.C of extrudates

From Fig. 4.25 it was observed that the moisture content was minimum for R_{90}:B_{10} in case of rice: banana and for rice: cassava: banana combinations it was R_{10}:C_{80}:B_{10} followed by R_{30}:C_{60}:B_{10} and all other were on par to these combinations. This controlled effect on the moisture content demonstrated the beneficial effect of homogeneity in particle size on quality attributes such as expansion ratio, porosity and breaking strength (Anton and Luciano, 2007).

Starch content was found maximum for R_{30}:C_{60}:B_{10} (200°C at 80 rpm) and low for R_{10}:C_{80}:B_{10} (190°C at 80 rpm). There was significant variation as regards starch content with regard to different combinations. Higher amount of sugar was found with respect to R_{10}:C_{80}:B_{10} (200°C at 100 rpm) and low for R_{50}:C_{40}:B_{10} (200°C at 120 rpm). There was not much significant variation as regard with this and all the treatments except R_{10}:C_{80}:B_{10} (200°C at 100 rpm) and R_{50}:C_{40}:B_{10} (200°C at 120 rpm) which was on par with each other. This increase in nutrients could be because of the balancing of nutrients amoung the raw materials *viz.* rice, cassava and banana. This carbohydrate content was high in cereal based composition which also contributed good solubility index due to starch content. This was in confirmation to the results of Pawar *et al.* (2009).

Protein was seen less in case of R_{10}:C_{80}:B_{10} (200°C at 80 rpm) and high for R_{70}:C_{20}:B_{10} (200°C at 120 rpm). The results showed significant variation with respect to each selected samples. The extrudates hardness was found to be strongly influenced by the protein content. Increased protein content produced a less expanded and more rigid network resulting in higher resistance to shear (Chaiyakul *et al.*, 2009). It also confirmed that extrusion resulted in the regularity of nitrogen reduction by facilitating high process temperatures. Low amount of protein was 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).

Fat was found maximum in the case of $R_{30}:C_{60}:B_{10}$ (200°C at 80 rpm) and minimum in case of $R_{70}:B_{30}$ (200°C at 80 rpm). This variation in fat content during extrusion is caused by the formation of starch-lipid and protein-lipid complexes (Bhatnagar and Hanna, 1994 (a), 1994 (b), Singh *et al.*, 2007, Kasprzak and Rzedzicki, 2008).

From these proximate compositions, the total energy achieved by each samples was calculated with Atwater formula and found higher for $R_{30}:C_{60}:B_{10}$ (200°C at 80 rpm). The energy exhibited by these selected extrudates is displayed in Fig.4.26 and the values for all treatments are appended in Appendix (E).

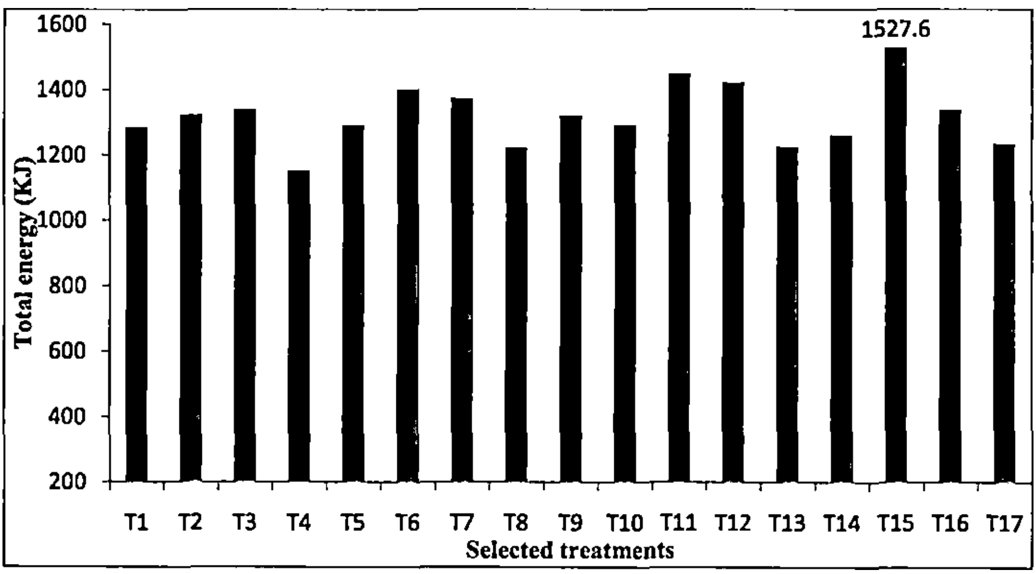

Fig. 4.26 Energy supplied by the selected extrudates

4.8 Sensory evaluation of selected extrudates

The success or failure of a new expanded food product is directly related to sensory attributes, where texture plays a major role (Iwe, 2000, Anton and Luciano, 2007). The extruded snacks that ranked first in the selected seventeen extrudates with control was subjected to sensory evaluation by a panel of 12 semi trained members by

9 – point hedonic scale. Two sets of sensory evaluation were carried out using spice and sugar coating. Stastical analysis for the sensory (Sumathi *et al.*, 2007) was carried out for each attributes using Kendall's coeffecient of concordance test (Statistical values appended in Appendix F1). The average score recorded by judges for spice coated and sugar coated extrudates are presented and discussed in Table 4.19 and Table 4.20.

Table 4.19 Sensory analysis of spice coated extrudates

Treatments	Appearance	Flavor	Taste	Texture	Overall acceptability
T60	6.8	6.5	7.0	6.7	6.9
T78	6.6	6.6	6.7	6.7	6.7
T81	8.0	7.9	8.4	8.1	8.1
T82	7.5	7.0	7.3	7.3	7.2
T83	7.6	7.3	7.3	7.0	7.5
T91	7.3	7.3	7.0	6.8	7.2
T93	7.2	7.2	6.8	6.7	7.1
T94	7.3	7.3	7.3	7.2	7.3
T96	7.3	7.3	7.4	7.6	7.5
CONTROL	7.8	7.4	7.7	7.0	7.7
Kendall's W	**.180****	**.232****	**.233****	**.204****	**.190****

Kendall's W was found significant for all characters under study. Hence the mean rank score could be taken as an indicator to access the differential preferences of the judges towards the different products. From Table 4.19 it could be read that the treatment T81 *i.e.*, the combination of rice: cassava: banana (R_{30}:C_{60}:B_{10}) under 190°C with 120 rpm had the maximum score for all the characters *viz.* appearance, flavour, taste, texture, overall acceptability (Fig. 4.27).

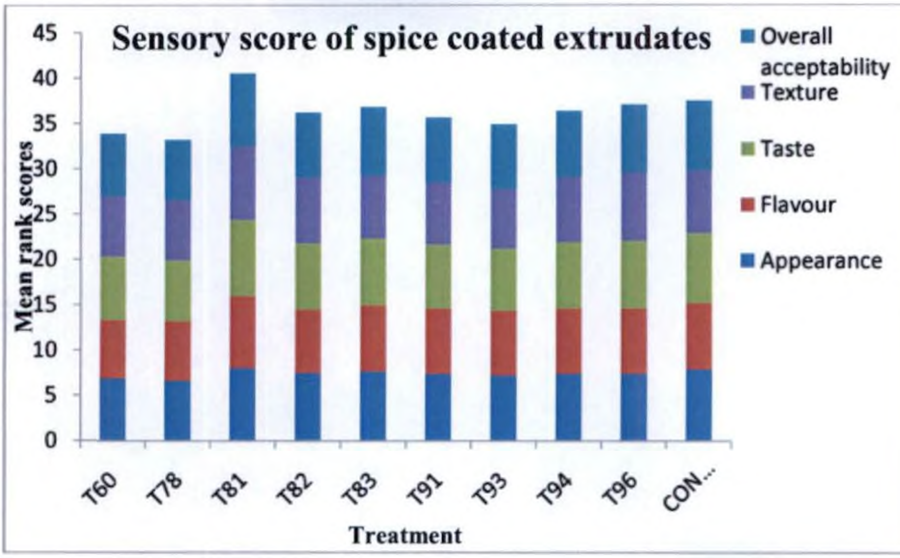

Fig. 4.27 Sensory score of spice coated extrudates

Table 4.20 Sensory analysis of sugar coated extrudates

Treatments	Appearance	Flavor	Taste	Texture	Overall acceptability
T60	6.6	6.4	6.0	5.7	6.8
T78	6.8	6.8	6.3	6.3	6.9
T81	6.8	6.8	7.0	7.1	6.9
T82	7.0	6.7	6.8	7.0	7.0
T83	7.2	7.0	6.8	7.2	7.1
T91	7.0	7.1	6.9	7.2	7.2
T93	7.5	6.8	6.8	6.6	6.9
T94	8.1	8.0	8.4	8.3	8.2
T96	7.8	7.7	8.2	7.9	7.9
Kendall'W	**.284****	**.365****	**.449****	**.452****	**.582****

With respect to sugar coating also the Kendall's W was found significant for all the characters under study (Appendix F2). Hence the mean rank score could be taken as an indicator to access the differential preferences of the judges towards the different products. From the Table 4.20 it could be read that the treatment T94 *i.e.*, the rice: cassava: banana combination (R_{10}:C_{80}:B_{10}) under 200°C with 80 rpm had the maximum score for all the characters namely appearance, flavor, taste, texture, overall acceptability under concern (Fig. 4.28).

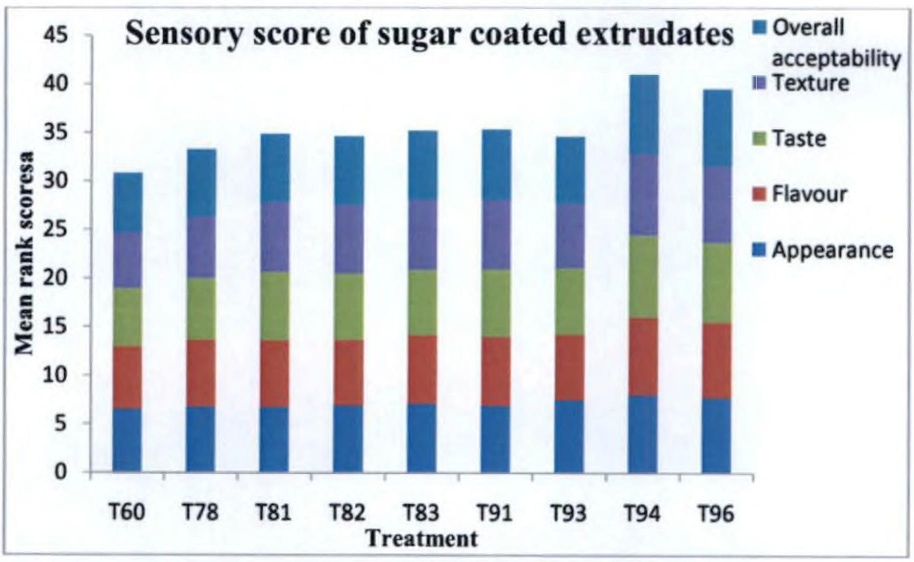

Fig. 4.28 Sensory score of sugar coated extrudates

The spice coated and sugar coated expanded snacks for the sensory evaluation are displayed in Plate 4.6.

Plate 4.6 Spice and sugar coated extrudates

4. 9 Optimisation and standardisation

On the basis of product quality, process parameters with temperature above 180°C and screw speeds (80, 100 and 120 rpm) were found as optimum (Pawar *et al.*, 2009). The study concluded that rice :cassava : banana combination of R_{10}:C_{80}:B_{10} (Plate 4.7) with extrusion temperatures of 180°C – 200°C at higher screw speed (120 rpm) that showed better physical parameters such as expansion ratio (ER), bulk density (BD), crispness was standardised as the best composition out of all combinations under concern.

4.10 Economic feasibility of proposed product technology

The economic analysis was performed for the standardised rice: cassava: banana combination of R_{10}:C_{80}:B_{10}. The project cost for the proposed project was estimated and the details are appended in Appendix A. The economic feasibility of this extruder based food industry was found feasible with a positive NPV (₹ 5611725/-) and an IRR of 37%. The BCR for this project was 1.14 with BEP of 2.15 years. The approximate production cost for this nutritional snack food works out to be about ₹ 150/ Kg at the prevailing market prices. And the calculated unit cost of this standardised expanded snack was ₹ 3/- per 20 g pack which will be a reasonable cost for the consumers.

190^{0}C **200^{0}C**

80 rpm

100 rpm

120 rpm

R_{10}:C_{80}:B_{10}

Plate 4.7 Colour variation of standardised composition at acceptable process conditions

Summary and Conclusion

SUMMARY AND CONCLUSION

The production and consumption of expanded ready-to-eat (RTE) products through extrusion cooking is notably increasing worldwide. Extrusion cooking is a high-temperature short-time (HTST) processing technology in which raw materials are exposed to a combination of moisture, pressure, temperature, and mechanical shear resulting in stable products which have gained an unquestionable acceptance in global food market. Extrusion cooking is used for the production of expanded snack foods, modified starch ready-to- eat cereals, baby foods and pasta. This technology has many distinct advantages like versatility, low cost, better product quality and lack of process effluents. These snack foods contribute an important part of daily nutrient and calorie intake for many consumers.

A ready to eat cereal based extruded product was developed by blending rice, nendran banana and cassava powder in 2 different combinations namely, rice: banana and rice: cassava: banana 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}. The moisture content of blend was standardised to 16% with water. Each blend was extruded at four different die temperatures from 170°C to 200°C with a 10°C interval at screw speeds of 80, 100 and 120 rpm.

Quality evaluation of the developed 96 extrudates along with control was done for standard engineering properties including physical, functional, textural and machine parameters. MAP of the extrudates were carried out in 400 gauge aluminum bags and kept for 3 months period for shelf life studies. Based on puffing characteristics, 17 samples were selected as best products at the end of storage studies, the quality evaluation of these extrudates in terms of physical, functional, textural and organoleptic properties were analysed. The sensory examination of the top nine samples among the selected 17 extrudates, along with control was carried out. The results of the study can be summarised as follow.

Increase in process temperature resulted in the enhancement of expansion ratio (2.6 -3.8) for both combinations irrespective of speed. The bulk density of the extrudates was found to have a considerable decrease at higher temperature and speed (0.12-0.16g/cm^3). Product density and apparent density showed a gradual decrease with increase in process parameters. Increase in porosity (46%) of the extrudates achieved at higher temperature speed combinations with increased amount of rice and cassava combinations (say R_{90}:B_{10}, R_{10}:C_{80}:B_{10}). The a_w of all combinations made out from the eight blends ranged from 0.5 to 0.7. The result indicates that at elevated temperatures the water activity will be less which signifies the safe range of the products for consumption.

Water Absorption Index of extrudates prepared out of rice: banana and rice: cassava: banana showed a gradual decrease with increase in temperature from 170°C to 200°C. The highest WAI was determined in triticale extrudate (37.8 g/g) along with lowest WAI in rice extrudate (9.5 g/g). The magnitude of WSI of these extrudates increased perceptibly with increase in process temperature of extrusion. The OAI increased with increase in temperature of the die. Higher expansion achieved by the extrudates due to elevated temperatures and speed increased the air pockets that resulted in increased oil absorption characteristics of the extrudates.

The crispness of the extrudates from these combinations ranged from 3.2 to 8.1. Out of these, extrudates from R_{10}:C_{80}:B_{10} followed by R_{30}:C_{60}:B_{10} at elevated temperature had good crispness .The crispness of the extruded product was inversely related to hardness and toughness property. Hardness (N) and toughness (N-s) exhibited by the rice: banana composition ranged from 16.44 to 48.09 N and 7.44 to 20.45 N-s. For rice: cassava: banana combinations these varied in the range of 13.27 to 44.67 N and 3.79 to 14.30 N-s. These properties had a negative correlation in terms of expansion. Snap force exhibited by rice: banana varied from 7.34 to 20.45 N and that of rice: cassava: banana from 5.8 to 17.33 N. Snap force showed a positive correlation with hardness and bulk density. Snap energy which indicated the breaking strength also correlated positively with bulk density.

Extrusion process significantly affected the colour. The extrudates made out of the rice: banana combinations resulted in a light dark spectrum varying from (76 ± 0.56) to (95 ± 0.08) and for rice: cassava: banana combinations it ranged from (79 ± 0.17) to (90 ± 0.03) respectively. With increase in temperature, 'L' value of extrudates decreased. The green-red spectrum contribution to the product varied from (2.5 ± 0.03) to (7.6 ± 0.11) for cereal based combinations and (3.7 ± 0.02) to (7.4 ± 0.71) for cassava based extrudates. The blue-yellow spectrum contribution to these products varied in the range of (14 ± 0.09) to (26 ± 0.10) for the first combination and (20 ± 0.03) to (28 ± 0.23) for the second combination. Increasing the temperature from 170 to 200°C increased the 'a' (redness) and 'b' (yellowness) values resulting in the degradation of pigments at higher temperature. The total colour change showed a gradual increase with increase in process temperature. The rates of browning increased with increase in die temperature.

The increased amount of rice resulted in increased feed rate (2.2 kg/h) which increased the extrudates expansion. Rice powder incorporated at higher proportions resulted with higher volumetric flow from 1536 to 4120 m^3/h 2755 to 6388 m^3/h. Mass flow was less for cassava combination due to high starch content of the major component (cassava powder). The results obtained for the torque varied from 45 to 60 Nm for almost all rice banana and rice cassava banana combinations. It did not have much variation with respect to die temperatures or speed. The SME of extrusion range from 136.4 to 454.4 kWh/kg for rice banana and for later it varied between 217.2 to 632.3 kWh/kg. With increase in temperature SME decreased

The selected seventeen treatments, after 3 month storage resulted in improved quality, in terms of crispness with less hardness. The moisture content for all extrudates during the initial and final month ranged of 6 to 11% without showing much variation. The textural analyses revealed that products out of R_{10}:C_{80}:B_{10} and

R_{30}:C_{60}:B_{10} produced maximum expansion with higher crispness. From these selected samples the proximate compositions including starch, sugar, protein and fat were determined. The total energy content of each sample was calculated with Atwater formula and was found higher for the combination R_{30}:C_{60}:B_{10} at a temperature of 200°C and speed of 80 rpm.

The extruded snacks that ranked first in the selected seventeen extrudates with control was subjected to sensory evaluation by a panel of 12 semi trained members by 9 – point Hedonic scale. Two sets of sensory evaluation were carried out using spice and sugar coating. The assessment indicated in an overall acceptability for (R_{30}:C_{60}:B_{10}) processed under 190°C with 120 rpm for spice coated and (R_{10}:C_{80}:B_{10}) under 200^{0}C with 80rpm for sugar coated extrudates. On the basis of product quality, process parameters with temperature above (180°C, 190°C, and 200°C) with screw speeds of (100 and 120 rpm) were acceptable for the production of extrudates. The study concluded that rice :cassava : banana combination of R_{10}:C_{80}:B_{10} at elevated temperatures of 180°C – 200°C with screw speed (120 rpm) which showed good expansion ratio (ER), low bulk density (BD), high crispness was standardised as the best composition out of different combinations under study.

The economic analysis was performed for the standardised rice: cassava: banana combination of R_{10}:C_{80}:B_{10}. The economic feasibility of this extruder based food industry was found feasible with a positive NPV and IRR of 37%. The BCR for this project was 1.14 with a BEP of 2.15 years. The calculated unit cost of this standardised expanded snack was ₹ 3/- per 20g pack. The commercialisation of this product can yield high profits for an entrepreneur within two to three years after the installation of the plant. This food (or a snack) would undoubtedly become an integral part of the diet of a modern consumer, with fewer additives, high nutritional quality, less thermal damage and reasonable cost.

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Appendices

APPENDIX A

ECONOMIC FEASIBILITY OF THE PROPOSED PROJECT

The project feasibility for the standardized product from Rice: cassava: banana (R_{10}:C_{80}:B_{10}) was under concern.

Assumptions :-

Area of plant building	= 186 m^2
Cost of plant building	= ₹ 16129/m^2
Total output of the plant	= 150 t/yr
Total run of the plant	= 8 h/300 days

Capital cost of the project

a. Land and building	= 30,00,000/-
b. Machineries	
Cleaner cum grader	= 60,000/-
Peeler cum slicer	= 40,000/-
Drier with extra sieves	= 6, 00,000/-
Mini hammer milling machine	= 1, 50,000/-
Extruder	= 20, 00,000/-
Electrostatic coater	= 1, 00,000/-
Packing machine with gas cylinders	= 3, 00,000/-
c. Quality control	= 20,00,000/-

f. Pre-operative expenses = 50,000/-

g. Fixtures and furniture = 45,000/-

h. Miscellaneous items = 50,000/-

Capital cost = 49, 05,000/-

Annual expenses incurred by the plant

		Quantity (kg)	Rate (₹/kg)	Amount (₹)
a.	Raw materials			
	Rice	15000	25	3, 75,000
	Cassava	3, 00,000	12	36, 00,000
	Banana	1, 50,000	30	45, 00,000
	Sugar & spices			25,000
b.	Electricity	39600	5.5	217,800
c.	Water requirement	500	16	8,000
d.	Labours			
	Unskilled labours	8	7000	56,000
	Skilled labours	4	9000	36,000
	Quality checker	1	10000	10,000
	Plant manager	1	12000	12,000
	Supervisor	1	10000	10,000
	Accountant	1	9000	9,000
	Office assistant	1	7000	7,000
e.	Packing cost			5,00,000
f.	Stationary items			50,000
g.	Marketting cost			10,00,000

Production cost = 1, 04, 15,800/-

Total cost of the project = 1, 53, 20,800/-

Cost of production of the product

The product may be marketed as per the market condition in 15g or 20 g packets with Rs 5 to Rs 7 respectively (by including profit margin).

The product will be sold in 20g packets with ₹ 3/- each and the benefit incurred by the plant will be 45000000 for the first year with an assumption that the selling of the products was initiated from second year onwards.

Assumptions:-

Annual growth rate of costs and benefits is 3 percent

The costs and benefits are discounted at 12%

NPV of the project

Here it is assumed 100% sales as cash and no credit with a steady market demand for the product).

NPV at 12% discount rate = Cash flow x Discount factor

The total NPV for a period of 6 years was calculated and found with a positive value which implies that the project was feasible.

Year	Total cost (₹)	Benefits (₹)	Discount factor	Cash flow	Net present value (₹)
1	15320800	0	0.893	-15320800	-13679286
2	8719444	13905000	0.797	5185556	4133893
3	9618202	16222500	0.712	6604298	4700809
4	10516959	18540000	0.636	8023041	5098787
5	11415717	208575500	0.567	9441783	5357521
6	12314474	23175000	0.507	10860526	5502280
Total	52372921	125508810		13933878	5611725

IRR of the project

The internal rate of return can be defined as that rate of discount at which the present value of cash inflow is equal to present value of cash outflow.

Trial and Error method was used to estimate the IRR of the project. It is assumed that the project will yield an annual cash flow of Rs. 30,000,000.

The IRR was found at 37% with high benefit

Befit Cost Ratio (BCR)

Year	Total cost (₹)	Benefits
1	136792286	0
2	6951088	11084981
3	6846046	11546855
4	6683718	11782505
5	6477584	11835106
6	6238896	11741176
Total	38374051	46249447

BCR = Benefits / Total cost (in terms of present worth)

BCR = 1.14

Break Even Point

The B-E of a firm is that point when there is neither loss nor profit. During the time period incurred for break even, the fixed cost invested by a firm will be recovered. The breakeven point of this project was within 2.15 years.

ECONOMIC ANALYSIS OF AN EXTRUDER PLANT

ASSUMPTIONS

1. Expected life of the system is 6 years
2. Annual growth rate of costs and benefits is 3 per cent
3. Salvage value will be nil
5. The costs and benefits are discounted at 12%

Year	Captital Cost (₹)	Production Cost (₹)	O & M	Total Cost (₹)	Benefits (₹)	Discount Factor	Present Worths					Cah Flow (₹)	Net Present Worth (NPW) (₹)
							Costs				Benefits		
							Capital Cost (₹)	O & M	Production Cost	Total Costs (₹)			
1	4905000	10415800	0	15320800	0	0.893	4379464	9299821	0	13679286	0	-15320800	-13679286
2	0	8719444	0	8719444	13905000	0.797	0	6951088	0	6951088	11084981	5185556	4133893
3	0	9618202	0	9618202	16222500	0.712	0	6846046	0	6846046	11546855	6604298	4700809
4	0	10516959	0	10516959	18540000	0.636	0	6683718	0	6683718	11782505	8023041	5098787
5	0	11415717	0	11415717	20857500	0.567	0	6477584	0	6477584	11835106	9441783	5357521
6	0	12314474	0	12314474	23175000	0.507	0	6238896	0	6238896	11741176	10860526	5502280
TOTAL	4905000	50686122	0	67905596	69525000		4379464	36258257	0	40637721	46249447	13933878	5611725

Discount Rate	0.12
NPW	5611725
IRR	37%
B-C ratio	1.14

APPENDIX B1

Table B1.1 Interaction of combination, temperature and speed on ER1of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C)				
		T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	2.60	2.63	2.82	2.84	
	S2	2.71	2.68	2.90	2.85	2.76
	S3	2.79	2.82	2.93	2.98	
P2 (R_{70}:B_{30})	S1	2.60	2.76	2.71	3.01	
	S2	2.64	2.89	2.84	3.05	2.81
	S3	2.85	2.95	3.06	3.07	
P3 (R_{80}:B_{20})	S1	2.45	2.45	2.80	2.64	
	S2	2.50	2.61	2.83	2.86	2.87
	S3	2.58	2.73	2.90	3.09	
P4 (R_{90}:B_{10})	S1	2.90	2.89	2.95	3.04	
	S2	2.88	2.97	2.97	3.17	2.98
	S3	2.90	3.03	3.07	3.20	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	3.03	3.03	3.13	3.20	
	S2	3.16	3.19	3.17	3.31	3.20
	S3	3.19	3.20	3.25	3.44	
P6 (R_{50}:C_{40}:B_{10})	S1	3.10	3.17	3.23	3.30	
	S2	3.11	3.17	3.26	3.40	3.25
	S3	3.16	3.17	3.32	3.42	
P7 (R_{30}:C_{60}:B_{10})	S1	3.04	3.19	3.22	3.34	
	S2	3.06	3.21	3.26	3.44	3.25
	S3	3.11	3.26	3.40	3.50	
P8 (R_{10}:C_{80}:B_{10})	S1	3.32	3.32	3.52	3.69	3.55
	S2	3.46	3.47	3.62	3.72	
CD_{ABC} = 0.102	S3	3.49	3.55	3.64	3.78	**CD_A= 0.029**

Table B1.2 Interaction of combination and speed on ER1 of extrudates

Speed (rpm)	ER1 of various combinations								
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**Mean**
80	2.88	2.76	2.62	2.76	3.11	3.20	3.18	3.48	2.30
100	2.99	2.88	2.81	2.82	3.21	3.24	3.26	3.57	3.10
120	3.08	2.98	2.85	2.85	3.29	3.31	3.30	3.62	3.16
Mean	2.76	2.81	2.87	2.98	3.20	3.25	3.25	3.55	
CD_C = 0.018	CD_{AC} = 0.051								

Table B1.3 Interaction of temperature and speed on ER1 of extrudates

Speed (rpm)	ER1 at different temperatures				
	T1	T2	T3	T4	**Mean**
80	2.87	3.00	3.03	3.09	2.30
100	2.30	3.08	3.13	3.18	3.10
120	3.06	3.19	3.17	3.22	3.16
Mean	2.98	3.09	3.11	3.16	
CD_C =0.018	CD_{BC} = 0.036				

Table B1.4 Interaction of combination and speed on ER2 of extrudates

Speed (rpm)	ER2 Combinations								
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**Mean**
80	8.27	7.66	6.89	7.62	10.09	10.19	10.16	12.21	9.14
100	9.58	8.33	7.92	7.96	10.39	10.60	10.71	12.62	9.76
120	10.52	8.87	8.13	8.12	11.40	10.60	11.17	13.52	10.33
Mean	7.65	7.90	8.29	9.46	10.58	10.62	10.68	12.78	
CD_C = 0.123	CD_{AC} = 0.349								

Table B1.5 Interaction of combination, temperature and speed on ER2 of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C)				
		T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	6.60	7.34	7.62	9.08	7.65
	S2	6.98	8.09	8.79	9.30	
	S3	8.14	9.35	8.96	9.45	
P2 (R_{70}:B_{30})	S1	7.10	7.49	8.00	8.04	7.90
	S2	7.31	7.61	8.63	8.14	
	S3	7.70	7.93	8.14	8.71	
P3 (R_{80}:B_{20})	S1	6.20	6.53	8.06	6.98	8.29
	S2	7.28	7.07	8.15	8.16	
	S3	8.14	7.12	8.41	9.52	
P4 (R_{90}:B_{10})	S1	7.10	8.92	9.20	9.90	9.46
	S2	8.36	9.14	10.32	11.82	
	S3	8.61	10.56	11.18	13.31	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	9.70	9.78	10.28	10.58	10.56
	S2	10.00	10.08	10.32	11.14	
	S3	10.46	11.34	10.63	13.15	
P6 (R_{50}:C_{40}:B_{10})	S1	9.19	10.36	10.21	10.99	10.62
	S2	9.27	10.44	10.51	11.96	
	S3	9.33	11.55	10.77	12.14	
P7 (R_{30}:C_{60}:B_{10})	S1	9.52	9.91	10.58	10.65	10.68
	S2	10.00	10.18	10.97	11.71	
	S3	10.88	10.92	11.14	11.73	
P8 (R_{10}:C_{80}:B_{10})	S1	11.47	11.88	12.06	13.41	12.78
	S2	12.11	12.01	12.40	13.97	
CD_{ABC} = 0.697	S3	12.62	13.16	13.47	14.82	**CD_A = 0.202**

Table B1.6 Interaction of temperature and speed on ER2 of extrudates

Speed (rpm)	ER2 at different temperature				
	T1	T2	T3	T4	Mean
80	8.45	9.05	9.30	9.74	9.74
100	9.36	9.47	9.82	10.40	10.40
120	9.99	10.37	10.19	10.79	10.79
Mean	9.26	9.63	9.77	10.31	
$CD_C = 0.123$	$CD_{BC} = 0.247$				

Table B1.7 Interaction of temperature and speed on BD of extrudates

Speed (rpm)	BD (g/cm^3) at different temperature				
	T1	T2	T3	T4	Mean
80	0.26	0.23	0.21	0.16	0.22
100	0.23	0.22	0.20	0.15	0.22
120	0.23	0.21	0.19	0.15	0.20
Mean	0.24	0.22	0.19	0.16	

Table B1.8 Interaction of combination and speed on PD of extrudates

Temperature (°C)	PD (g/cm^3) of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	1.32	1.17	0.87	0.74	0.59	0.43	0.42	0.37	0.72
180	1.19	1.03	0.81	0.58	0.59	0.42	0.41	0.31	0.65
190	1.11	0.94	0.78	0.47	0.53	0.35	0.35	0.23	0.60
200	0.83	0.60	0.67	0.36	0.46	0.33	0.33	0.21	0.50
Mean	1.11	0.93	0.78	0.66	0.54	0.38	0.37	0.28	
$CD_B = 0.016$	$CD_{AB} = 0.044$								

Table B1.9 Interaction of combination, temperature and speed on BD (g/cm^3) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	0.33	0.31	0.24	0.19	
	S2	0.32	0.27	0.22	0.16	0.28
	S3	0.30	0.25	0.18	0.15	
P2 (R_{70}:B_{30})	S1	0.30	0.23	0.20	0.19	
	S2	0.22	0.23	0.19	0.18	0.25
	S3	0.19	0.20	0.19	0.18	
P3 (R_{80}:B_{20})	S1	0.25	0.23	0.20	0.19	
	S2	0.21	0.23	0.19	0.19	0.24
	S3	0.19	0.20	0.19	0.18	
P4 (R_{90}:B_{10})	S1	0.34	0.30	0.23	0.16	
	S2	0.33	0.27	0.21	0.15	0.21
	S3	0.32	0.27	0.20	0.15	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	0.22	0.22	0.21	0.18	
	S2	0.19	0.19	0.20	0.17	0.20
	S3	0.18	0.18	0.18	0.16	
P6 (R_{50}:C_{40}:B_{10})	S1	0.23	0.21	0.20	0.17	
	S2	0.23	0.21	0.19	0.16	0.19
	S3	0.23	0.21	0.18	0.15	
P7 (R_{30}:C_{60}:B_{10})	S1	0.21	0.16	0.13	0.13	
	S2	0.19	0.16	0.13	0.12	0.16
	S3	0.19	0.14	0.12	0.11	
P8 (R_{10}:C_{80}:B_{10})	S1	0.18	0.17	0.14	0.13	
	S2	0.18	0.17	0.14	0.12	0.15
	S3	0.17	0.17	0.13	0.12	

Table B1.10 Interaction of combination, temperature, and speed on PD (g/cm³) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C)				
		T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	1.49	1.31	1.16	0.93	
	S2	1.27	1.15	1.12	0.82	1.11
	S3	1.98	1.10	1.06	0.73	
P2 (R_{70}:B_{30})	S1	1.36	1.08	0.67	0.66	
	S2	1.12	1.04	0.63	0.60	0.93
	S3	1.08	0.97	0.59	0.47	
P3 (R_{80}:B_{20})	S1	0.90	0.80	0.70	0.60	
	S2	0.80	0.70	0.50	0.52	0.78
	S3	0.70	0.60	0.45	0.41	
P4 (R_{90}:B_{10})	S1	0.85	0.64	0.52	0.42	
	S2	0.73	0.55	0.45	0.36	0.66
	S3	0.63	0.54	0.43	0.31	
Rice: cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	0.68	0.63	0.55	0.53	
	S2	0.65	0.58	0.53	0.44	0.54
	S3	0.43	0.58	0.51	0.42	
P6 (R_{50}:C_{40}:B_{10})	S1	0.46	0.44	0.36	0.33	
	S2	0.42	0.42	0.31	0.31	0.38
	S3	0.36	0.38	0.31	0.31	
P7 (R_{30}:C_{60}:B_{10})	S1	0.50	0.44	0.38	0.35	
	S2	0.41	0.42	0.35	0.34	0.37
	S3	0.41	0.39	0.31	0.30	
P8 (R_{10}:C_{80}:B_{10})	S1	0.37	0.33	0.25	0.22	0.28
	S2	0.36	0.30	0.22	0.21	
CD_{ABC} = 0.076	S3	0.36	0.30	0.22	0.20	**CD_A = 0.022**

Table B1.11 Interaction of combination, temperature and speed on AD (g/cm^3) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	30.00	31.44	27.48	21.64	
	S2	29.28	28.50	25.25	20.89	26.08
	S3	28.17	26.92	22.91	18.92	
P2 (R_{70}:B_{30})	S1	25.00	22.41	18.24	18.57	
	S2	22.67	20.92	15.97	17.94	21.99
	S3	19.47	18.67	15.61	12.80	
P3 (R_{80}:B_{20})	S1	25.00	23.66	21.66	18.77	
	S2	22.67	22.15	21.50	18.21	19.45
	S3	21.88	21.78	19.55	17.66	
P4 (R_{90}:B_{10})	S1	23.00	22.44	21.11	17.55	
	S2	21.45	22.12	21.00	17.32	18.77
	S3	20.99	22.09	18.45	16.22	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	22.00	19.88	18.11	16.89	
	S2	20.90	18.56	17.95	16.44	18.79
	S3	19.88	18.44	17.34	15.61	
P6 (R_{50}:C_{40}:B_{10})	S1	15.20	11.56	9.15	9.09	
	S2	13.32	10.01	8.78	7.53	9.97
	S3	11.86	9.55	8.32	5.85	
P7 (R_{30}:C_{60}:B_{10})	S1	11.00	10.19	6.38	6.34	
	S2	9.68	8.97	5.60	5.16	7.92
	S3	8.76	5.77	4.14	5.10	
P8 (R_{10}:C_{80}:B_{10})	S1	10.00	9.56	7.13	6.35	7.32
	S2	9.56	8.43	7.00	6.45	
CD_{ABC} = 2.594	S3	8.35	6.79	5.90	5.90	**CD_A= 0.749**

Table B1.12. Interaction of combination and temperature on AD (g/cm^3) of extrudates

Temperature (°C)	AD (g/cm^3) of various combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	30.00	31.44	27.48	23.78	22.00	19.66	18.66	14.67	20.29
180	29.67	28.50	25.25	22.66	20.90	14.99	13.44	11.88	19.09
190	28.17	26.22	22.91	21.67	19.88	11.86	12.33	10.88	17.68
200	19.47	19.44	18.78	18.56	18.78	10.99	7.77	5.90	14.36
Mean	26.08	21.99	19.45	18.77	18.79	9.97	7.92	7.32	
CD_B = 0.529	**CD_{AB} = 0.1.497**								

Table B1. 13. Interaction of combination and speed on AD of extrudates

Speed (rpm)	AD (g/cm^3) of various combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	30.00	28.65	27.20	22.77	19.67	18.67	18.66	14.67	19.44
100	28.67	26.95	25.98	21.85	14.55	13.44	13.44	10.78	17.72
120	18.99	26.52	22.31	19.49	10.91	12.33	12.33	8.78	16.40
Mean	26.08	21.99	19.45	18.77	18.79	9.97	7.92	7.32	
CD_C = 0.458	**CD_{AC} = 0.1.297**								

Table B1. 14 Interaction of temperature and speed on AD of extrudates

Speed	AD (g/cm^3) at different temperatures				
	T1	T2	T3	T4	Mean
80	21.75	21.30	18.94	15.78	19.44
100	20.57	18.78	17.40	14.15	17.72
120	18.55	17.20	16.70	13.15	16.40
Mean	20.29	19.09	17.68	14.36	
CD_C = 0.165	**CD_{BC} = 0.917**				

Table B1. 15. Interaction of combination, temperature and speed on Porosity of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	2.89	9.79	11.79	13.90	
	S2	5.91	10.19	12.48	14.22	10.35
	S3	7.26	11.04	13.14	15.16	
P2 (R_{70}:B_{30})	S1	4.28	8.52	10.41	13.34	
	S2	7.45	9.63	11.17	13.61	10.65
	S3	8.71	10.17	12.47	14.44	
P3 (R_{80}:B_{20})	S1	5.23	9.58	9.21	10.46	
	S2	7.82	9.68	13.62	17.18	14.16
	S3	10.16	10.34	15.87	19.80	
P4 (R_{90}:B_{10})	S1	6.61	11.90	13.89	21.69	
	S2	9.92	13.09	19.66	22.09	16.16
	S3	10.11	19.92	20.46	24.62	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	15.49	18.63	19.73	19.23	
	S2	16.46	19.12	21.82	22.12	20.14
	S3	18.72	22.68	23.18	24.51	
P6 (R_{50}:C_{40}:B_{10})	S1	18.58	22.69	27.13	28.97	
	S2	21.49	26.03	29.23	37.39	27.86
	S3	22.37	27.99	32.32	40.16	
P7 (R_{30}:C_{60}:B_{10})	S1	20.75	26.48	26.59	32.14	
	S2	21.92	28.71	28.13	36.18	30.31
	S3	23.36	29.13	29.85	44.49	
P8 (R_{10}:C_{80}:B_{10})	S1	24.12	26.81	34.73	36.97	33.86
	S2	25.08	31.00	36.15	40.18	
CD_{ABC} = 1.948	S3	31.89	32.38	40.26	46.78	CD_A= 0.562

Table B1.16. Interaction of combination and temperature on porosity of extrudates

Temperature (°C)	Porosity (%) of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	6.81	5.35	13.65	8.88	16.89	20.81	22.01	27.03	15.18
180	9.44	10.35	13.28	14.97	20.14	25.57	28.11	30.06	18.99
190	11.35	12.47	13.80	18.00	21.57	29.56	30.03	37.04	21.73
200	13.80	14.43	15.90	22.80	21.96	35.51	41.10	41.33	25.85
Mean	10.35	10.65	14.16	16.16	20.14	27.86	30.31	33.87	
CD_B = 0.397	**CD_{AB} = 1.124**								

Table B1.17. Interaction of combination and speed on porosity of extrudates

Speed (rpm)	Porosity (%) of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	9.14	9.60	12.44	13.52	18.27	24.34	27.88	30.68	18.23
100	10.47	10.70	15.04	16.19	19.88	28.54	30.78	33.10	20.59
120	11.45	11.65	15.00	18.78	22.28	30.71	32.28	37.83	22.50
Mean	10.35	10.65	14.16	16.16	20.14	27.86	30.31	33.87	
CD_C = 0.344	**CD_{AC} = 0.974**								

Table B1.18 Interaction of temperature and speed on PD of extrudates

Speed (rpm)	PD (g/cm^3) at different temperatures				
	T1	T2	T3	T4	Mean
80	0.82	0.71	0.63	0.56	0.68
100	0.71	0.64	0.59	0.50	0.61
120	0.63	0.60	0.56	0.44	0.55
Mean	0.72	0.65	0.60	0.50	
CD_C =0.014	**CD_{BC} = 0.027**				

Table B1. 19. Interaction of combination and speed on water activity of extrudates

Speed (rpm)	**Water activity of different combinations**								
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**Mean**
80	0.60	0.66	0.59	0.62	0.64	0.63	0.60	0.60	0.62
100	0.58	0.66	0.60	0.60	0.62	0.64	0.62	0.59	0.61
120	0.56	0.66	0.58	0.60	0.59	0.62	0.59	0.62	0.61
Mean	0.56	0.66	0.61	0.59	0.63	0.61	0.62	0.60	
CD_C = 0.0011	**CD_{AC} = 0.0031**								

Table B1.20. Interaction of temperature and speed on water activity of extrudates

Speed (rpm)	**Water activity at different temperatures**				
	T1	**T2**	**T3**	**T4**	**Mean**
80	0.63	0.61	0.60	0.61	0.62
100	0.62	0.62	0.62	0.60	0.61
120	0.62	0.62	0.61	0.61	0.61
Mean	0.62	0.61	0.61	0.61	
CD_C = 0.0011	**CD_{BC} = 0.0022**				

Table B1.21. Interaction of combination, temperature and speed on water activity of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	0.60	0.55	0.55	0.51	
	S2	0.58	0.53	0.52	0.47	0.56
	S3	0.54	0.52	0.51	0.46	
P2 (R_{70}:B_{30})	S1	0.69	0.67	0.65	0.64	
	S2	0.68	0.66	0.63	0.63	0.66
	S3	0.66	0.65	0.64	0.62	
P3 (R_{80}:B_{20})	S1	0.63	0.61	0.61	0.61	
	S2	0.62	0.61	0.60	0.61	0.61
	S3	0.62	0.61	0.61	0.57	
P4 (R_{90}:B_{10})	S1	0.62	0.61	0.59	0.57	
	S2	0.61	0.60	0.58	0.56	0.59
	S3	0.61	0.59	0.58	0.53	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	0.66	0.66	0.65	0.65	
	S2	0.65	0.65	0.63	0.64	0.63
	S3	0.65	0.64	0.62	0.61	
P6 (R_{50}:C_{40}:B_{10})	S1	0.65	0.63	0.62	0.62	
	S2	0.64	0.63	0.61	0.61	0.61
	S3	0.64	0.62	0.61	0.59	
P7 (R_{30}:C_{60}:B_{10})	S1	0.63	0.62	0.60	0.59	
	S2	0.63	0.61	0.60	0.58	0.62
	S3	0.63	0.60	0.59	0.57	
P8 (R_{10}:C_{80}:B_{10})	S1	0.62	0.61	0.59	0.58	0.60
	S2	0.62	0.60	0.58	0.57	**CD_A=**
CD_{ABC} = 0.00222	S3	0.61	0.59	0.58	0.56	**0.0017**

APPENDIX B2

Table B2. 1 Interaction of combination, temperature and speed on WAI (g/g) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C)				
		T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	18.44	17.67	16.46	15.23	
	S2	17.23	16.33	15.70	13.89	15.88
	S3	16.23	12.80	14.26	12.80	
P2 (R_{70}:B_{30})	S1	14.66	11.80	11.73	11.04	
	S2	12.77	11.04	11.08	10.98	11.57
	S3	10.99	10.91	11.02	10.77	
P3 (R_{80}:B_{20})	S1	13.33	13.06	12.85	12.17	
	S2	12.91	12.12	12.71	10.89	11.38
	S3	12.83	11.71	12.12	8.86	
P4 (R_{90}:B_{10})	S1	14.04	12.30	12.01	11.34	
	S2	12.14	11.21	10.25	11.28	11.33
	S3	10.44	11.07	9.50	11.01	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	37.81	26.80	26.97	27.18	
	S2	27.42	24.67	23.63	26.90	27.11
	S3	24.56	24.48	23.63	23.20	
P6 (R_{50}:C_{40}:B_{10})	S1	33.80	27.04	30.27	27.30	
	S2	28.36	25.62	25.68	26.92	26.44
	S3	26.75	23.82	23.56	26.15	
P7 (R_{30}:C_{60}:B_{10})	S1	26.81	27.75	26.94	26.06	
	S2	24.48	24.94	24.81	25.15	25.24
	S3	24.20	23.66	23.29	24.75	
P8 (R_{10}:C_{80}:B_{10})	S1	29.00	25.34	26.36	22.45	22.22
	S2	26.34	25.06	25.08	21.11	
CD_{ABC} = 0.761	S3	25.27	22.33	23.87	19.56	**CD_A= 2.64**

Table B2. 2 Interaction of combination and speed on WAI of extrudates

Speed (rpm)	WAI (g/g) of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	15.39	12.55	12.22	13.12	37.81	33.80	26.88	25.45	20.17
100	12.91	14.87	11.25	11.51	26.89	26.77	28.97	28.44	19.98
120	11.94	11.66	11.51	11.33	26.88	25.60	25.26	27.11	19.96
Mean	15.88	11.57	11.38	11.33	27.11	26.44	25.24	22.22	
CD_C = 0.47	**CD_{AC} = 1.3**								

Table B2. 3. Interaction of temperature and speed on WAI of extrudates

Speed (rpm)	WAI (g/g) at different temperatures				
	T1	T2	T3	T4	Mean
80	19.01	20.34	20.60	20.99	20.17
100	18.22	20.13	20.21	21.58	19.98
120	17.94	20.12	19.95	21.59	19.96
Mean	21.31	20.25	20.19	18.39	
CD_C = 0.47	**CD_{BC} = 0.93**				

Table B2. 4. Interaction of temperature and speed on WSI of extrudates

Speed (rpm)	WSI (%) at different temperatures				
	T1	T2	T3	T4	Mean
80	8.50	10.80	11.44	15.66	10.96
100	9.22	11.47	12.33	16.31	11.19
120	10.80	12.58	13.87	18.22	18.78
Mean	10.30	11.50	12.29	18.66	
CD_C = 1.34	**CD_{BC} = 2.7**				

Table B2.5. Interaction of combination, temperature and speed on WSI of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C)				
		T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	2.20	5.22	2.58	7.30	
	S2	2.40	6.30	6.67	8.09	5.58
	S3	4.97	7.09	8.81	10.68	
P2 (R_{70}:B_{30})	S1	2.44	3.64	7.65	6.72	
	S2	5.41	6.12	7.74	8.81	6.85
	S3	6.20	8.54	8.54	10.44	
P3 (R_{80}:B_{20})	S1	4.90	4.63	4.93	8.75	
	S2	7.82	6.05	9.98	16.28	9.92
	S3	8.55	11.46	12.57	17.79	
P4 (R_{90}:B_{10})	S1	8.58	11.31	14.34	14.35	
	S2	10.85	14.55	16.70	17.46	13.90
	S3	12.94	15.56	17.11	18.99	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	3.48	9.38	8.57	10.77	
	S2	5.09	11.14	11.13	13.42	9.98
	S3	7.08	12.16	13.16	13.62	
P6 (R_{50}:C_{40}:B_{10})	S1	4.45	5.50	5.70	9.77	
	S2	8.13	6.10	9.28	10.47	11.22
	S3	10.68	6.13	11.30	12.16	
P7 (R_{30}:C_{60}:B_{10})	S1	9.21	9.91	10.99	16.47	
	S2	10.27	11.38	14.06	18.91	15.44
	S3	13.26	15.22	22.04	23.51	
P8 (R_{10}:C_{80}:B_{10})	S1	10.26	11.95	13.84	17.13	18.82
	S2	12.35	15.20	16.96	18.07	
CD_{ABC} = 7.16	S3	15.01	15.72	19.72	22.56	**CD_A= 2.2**

Table B2.6. Interaction of combination and speed on WSI of extrudates

Speed (rpm)	WSI (%) of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	6.72	7.30	8.75	14.35	9.77	10.77	10.99	17.13	10.96
100	8.81	8.09	16.28	17.46	10.47	13.42	14.06	18.07	11.19
120	10.44	10.68	17.79	18.99	12.16	13.62	22.04	22.56	18.78
Mean	5.58	6.85	9.92	13.90	9.98	11.22	15.44	18.82	
CD_C = 1.35	**CD_{AC} = 0.038**								

Table B2.7. Interaction of combination and speed on OAI of extrudates

Speed (rpm)	OAI (g/g) of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	1.11	1.09	1.85	1.94	1.93	2.04	2.09	2.15	1.87
100	1.21	1.12	1.91	2.17	1.95	2.05	2.14	2.26	1.87
120	1.48	1.57	2.00	2.22	2.06	2.08	2.23	2.31	1.88
Mean	1.26	1.26	1.92	2.11	1.98	2.06	2.15	2.24	
CD_C = 0.05	**CD_{AC} = 0.141**								

Table B2.8. Interaction of temperature and speed on OAI of extrudates

Speed (rpm)	OAI (g/g) at different temperatures				
	T1	T2	T3	T4	Mean
80	1.69	1.77	1.81	1.98	1.87
100	1.76	1.89	1.87	2.04	1.87
120	1.81	1.91	1.87	2.08	1.88
Mean	1.75	1.85	1.86	2.03	
CD_C = 0.05	**CD_{BC} = 0.09**				

Table B2. 9. Interaction of combination, temperature and speed on OAI (g/g) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	0.90	0.93	0.92	1.67	
	S2	0.89	0.98	0.93	1.90	1.26
	S3	0.98	1.01	1.45	1.98	
P2 (R_{70}:B_{30})	S1	0.80	0.79	0.82	1.72	
	S2	0.92	0.92	1.06	1.87	1.26
	S3	1.02	1.13	1.75	1.92	
P3 (R_{80}:B_{20})	S1	1.61	1.63	1.80	1.88	
	S2	1.86	1.90	1.90	2.03	1.92
	S3	1.91	2.01	2.00	2.05	
P4 (R_{90}:B_{10})	S1	1.60	1.87	2.02	2.24	
	S2	1.94	2.11	2.09	2.46	2.11
	S3	2.03	2.19	2.21	2.60	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	1.99	1.73	1.96	2.30	
	S2	1.94	2.02	2.07	2.35	1.98
	S3	1.99	2.13	2.40	2.54	
P6 (R_{50}:C_{40}:B_{10})	S1	1.80	1.83	1.92	2.01	
	S2	1.91	1.86	1.94	2.01	2.06
	S3	2.01	2.03	2.05	2.28	
P7 (R_{30}:C_{60}:B_{10})	S1	1.80	2.03	1.82	2.23	
	S2	1.88	2.04	1.89	2.28	2.15
	S3	1.95	2.10	2.25	2.45	
P8 (R_{10}:C_{80}:B_{10})	S1	1.80	1.80	1.92	2.01	2.24
	S2	1.86	1.91	1.94	2.01	
CD_{ABC} = 0.28	S3	2.01	2.03	2.05	2.28	CD_A = 0.08

APPENDIX B3

Table B3. 1. Interaction of combination, temperature and speed on crispness of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C)				
		T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	2.10	2.50	2.60	3.20	
	S2	2.80	3.00	3.20	3.70	3.70
	S3	2.90	3.20	3.50	3.90	
P2 (R_{70}:B_{30})	S1	2.50	2.50	3.50	3.50	
	S2	2.70	3.00	3.90	4.50	3.86
	S3	3.10	4.00	4.30	4.80	
P3 (R_{80}:B_{20})	S1	3.30	3.20	3.20	4.20	
	S2	3.30	3.70	3.60	4.80	4.37
	S3	3.90	4.50	4.90	5.30	
P4 (R_{90}:B_{10})	S1	3.30	5.20	4.20	5.80	
	S2	3.70	7.40	4.50	7.40	5.87
	S3	5.30	7.90	6.20	7.90	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	2.50	2.90	3.90	4.60	
	S2	3.80	3.60	3.90	4.60	4.37
	S3	4.00	4.50	4.90	4.60	
P6 (R_{50}:C_{40}:B_{10})	S1	2.40	2.80	3.30	4.60	
	S2	3.70	4.50	3.50	4.80	4.68
	S3	3.70	4.60	4.90	5.50	
P7 (R_{30}:C_{60}:B_{10})	S1	3.20	3.50	4.50	4.60	
	S2	3.20	4.00	4.90	5.90	5.23
	S3	3.90	4.50	5.20	6.50	
P8 (R_{10}:C_{80}:B_{10})	S1	3.90	4.80	4.60	4.10	6.03
	S2	4.80	4.80	5.60	5.30	
CD_{ABC} = 1.62	S3	5.50	4.90	5.80	8.10	CD_A= 0.47

Table B3.2. Interaction of combination and temperature on crispness of extrudates

Temperature (°C)	Crispness of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	3.9	3.0	3.4	4.5	3.9	4.1	4.5	5.6	4.4
180	4.2	3.7	3.4	5.4	4.0	4.5	4.7	6.0	4.7
190	4.4	4.2	3.8	6.0	4.6	4.9	5.2	6.9	4.9
200	5.0	4.6	4.2	7.9	5.1	5.2	6.5	8.1	5.6
Mean	3.7	3.9	4.4	5.9	4.4	4.7	5.2	6.0	
CD_B = 0.33	**CD_{AB} = 0.94**								

Table B3.3. Interaction of combination and speed on crispness of extrudates

Speed (rpm)	Crispness of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	3.5	3.5	3.7	5.6	4.0	4.3	5.2	5.8	4.6
100	3.7	3.8	4.4	5.8	4.3	4.6	5.8	6.0	4.8
120	3.9	4.2	5.1	6.3	4.8	5.2	5.9	6.2	5.5
Mean	4.6	3.9	4.4	5.9	4.4	4.7	5.2	6.0	
CD_C = 0.29	**CD_{AC} = 0.81**								

Table B3.4 Interaction of combination, temperature and speed on hardness (N) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	42.46	42.64	39.18	25.52	41.39
	S2	27.44	35.26	39.15	47.52	
	S3	25.91	32.18	28.00	38.18	
P2 (R_{70}:B_{30})	S1	42.42	42.64	39.15	35.66	41.11
	S2	35.22	32.55	28.00	26.45	
	S3	27.65	26.21	25.52	24.11	
P3 (R_{80}:B_{20})	S1	32.21	30.11	30.60	30.11	29.77
	S2	28.77	27.55	26.77	26.22	
	S3	26.33	26.11	25.44	24.78	
P4 (R_{90}:B_{10})	S1	33.44	31.33	30.44	28.87	28.78
	S2	30.22	29.33	28.89	22.67	
	S3	26.44	26.00	20.99	20.22	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	35.21	33.21	31.76	29.22	31.58
	S2	33.45	31.21	26.57	27.57	
	S3	31.21	27.24	20.97	17.80	
P6 (R_{50}:C_{40}:B_{10})	S1	28.55	27.32	24.11	21.53	22.14
	S2	24.55	22.33	22.15	19.22	
	S3	22.05	21.90	21.90	16.27	
P7 (R_{30}:C_{60}:B_{10})	S1	25.99	24.22	23.19	19.28	21.43
	S2	27.88	24.55	22.95	18.74	
	S3	22.19	21.78	14.33	13.93	
P8 (R_{10}:C_{80}:B_{10})	S1	25.33	25.32	20.66	19.55	20.99
	S2	24.97	23.94	17.77	16.77	
CD_{ABC} = 9.8	S3	22.43	17.68	15.66	13.44	**CD_A= 3.7**

Table B3.5 Interaction of combination and speed on hardness of extrudates

Speed (rpm)	Hardness (N) of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	42.11	42.49	39.87	39.66	37.33	28.96	26.01	27.86	37.16
100	41.17	41.26	37.77	40.33	29.44	27.89	20.69	26.70	35.46
120	35.66	36.33	36.88	37.71	23.77	24.58	20.81	24.72	32.31
Mean	41.33	41.11	38.88	37.67	37.58	27.14	26.43	22.51	
CD_C = 2.3	**CD_{AC} = 6.41**								

Table B3.6 Interaction of temperature and speed on hardness of extrudates

Speed (rpm)	Hardness (N) at different temperatures				
	T1	T2	T3	T4	Mean
80	42.66	42.33	32.62	28.64	37.15
100	38.78	36.97	31.05	28.09	35.46
120	38.51	33.45	29.47	27.81	32.31
Mean	42.22	37.55	31.04	28.18	
CD_C = 2.3	**CD_{BC} = 4.53**				

Table B3.7 Interaction of temperature and speed on crispness of extrudates

Speed (rpm)	Crispness of different temperatures				
	T1	T2	T3	T4	Mean
80	4.10	4.73	4.51	4.88	4.62
100	4.51	4.86	4.55	5.05	4.82
120	4.53	4.98	5.09	5.36	4.85
Mean	4.4	4.7	4.9	5.1	
CD_C = 0.29	**CD_{BC} = 0.57**				

Table B3.8 Interaction of combination, temperature and speed on toughness (N-s) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	20.45	15.67	12.17	12.12	
	S2	17.42	14.58	12.09	7.44	13.87
	S3	14.67	12.42	11.01	8.14	
P2 (R_{70}:B_{30})	S1	15.99	12.35	11.78	13.23	
	S2	12.50	9.37	11.53	12.33	12.99
	S3	10.98	7.41	8.35	10.73	
P3 (R_{80}:B_{20})	S1	14.56	15.66	11.93	14.74	
	S2	13.64	13.58	11.36	8.29	10.39
	S3	12.23	8.22	5.75	7.77	
P4 (R_{90}:B_{10})	S1	15.94	16.31	18.16	18.00	
	S2	15.35	15.81	16.39	17.52	9.59
	S3	9.41	15.17	14.70	12.45	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	13.60	12.53	13.66	11.19	
	S2	12.62	10.98	12.55	9.17	17.18
	S3	6.54	10.29	5.94	6.87	
P6 (R_{50}:C_{40}:B_{10})	S1	14.14	14.30	13.23	12.74	
	S2	9.93	10.78	10.37	11.88	15.82
	S3	9.39	8.21	8.81	8.90	
P7 (R_{30}:C_{60}:B_{10})	S1	12.29	8.87	10.48	8.75	
	S2	10.38	8.31	8.56	8.55	14.16
	S3	7.32	6.40	7.21	6.04	
P8 (R_{10}:C_{80}:B_{10})	S1	11.77	9.10	9.34	7.38	
	S2	11.20	7.66	7.40	7.06	14.03
CD_{ABC} = 5.9	S3	10.92	6.51	5.24	3,79	CD_A= 1.7

Table B3.9. Interaction of combination and temperature on toughness of extrudates

Temperature (°C)	Toughness (N-s) at different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	20.50	19.38	18.31	18.06	14.87	15.60	14.62	11.98	14.27
180	16.39	12.78	17.92	14.26	14.61	12.68	14.20	10.84	13.53
190	15.87	12.49	16.65	12.32	13.88	12.55	11.77	10.29	13.34
200	10.53	10.82	15.85	11.11	11.41	11.88	11.41	8.43	12.88
Mean	13.87	12.99	10.39	9.59	17.18	15.82	14.16	14.03	
$CD_B = 1.2$	**$CD_{AB} = 3.4$**								

Table B3.10 Interaction of combination and speed on toughness of extrudates

Speed (rpm)	Toughness (N-s) at different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	19.27	16.40	16.44	15.65	13.49	13.11	12.77	12.67	14.49
100	18.09	15.55	15.14	14.14	13.16	13.45	12.34	9.67	13.35
120	14.19	15.52	14.11	12.12	12.34	12.22	11.66	8.81	12.67
Mean	13.87	12.99	10.39	9.59	17.18	15.82	14.16	14.03	
$CD_C = 1.04$	**$CD_{AC} = 2.94$**								

Table B3.11 Interaction of temperature and speed on toughness of extrudates

Speed (rpm)	Toughness (N-s) at different temperatures				
	T1	T2	T3	T4	Mean
80	18.44	14.71	14.05	13.85	14.44
100	12.40	13.85	12.38	13.45	13.35
120	11.96	12.03	12.21	12.09	12.66
Mean	14.27	13.53	13.34	12.88	
$CD_C = 1.04$	**$CD_{BC} = 2.08$**				

Table B3.12. Interaction of combination, temperature and speed on snap force (N) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	17.33	14.72	12.44	12.16	
	S2	16.88	14.59	11.26	11.18	14.22
	S3	15.67	13.55	11.06	10.77	
P2 (R_{70}:B_{30})	S1	12.03	11.64	10.65	9.41	
	S2	10.06	11.37	8.68	8.82	11.42
	S3	9.22	10.71	7.89	8.52	
P3 (R_{80}:B_{20})	S1	13.99	11.98	9.37	8.30	
	S2	13.96	11.45	9.31	8.08	10.16
	S3	11.42	9.62	8.63	7.33	
P4 (R_{90}:B_{10})	S1	10.80	8.72	7.48	6.18	
	S2	9.12	8.49	6.93	6.07	8.63
	S3	9.07	7.65	5.80	5.87	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	12.44	12.81	12.31	9.23	
	S2	10.35	11.77	10.51	8.59	12.11
	S3	9.81	10.34	8.65	8.05	
P6 (R_{50}:C_{40}:B_{10})	S1	11.58	11.16	11.78	8.65	
	S2	10.35	19.75	8.08	7.66	11.66
	S3	9.81	9.62	7.65	7.34	
P7 (R_{30}:C_{60}:B_{10})	S1	11.14	11.21	10.20	9.04	
	S2	11.09	11.13	8.82	8.88	10.90
	S3	10.91	9.49	7.77	8.87	
P8 (R_{10}:C_{80}:B_{10})	S1	10.11	8.87	9.46	7.21	8.45
	S2	9.41	8.54	8.69	6.64	
CD_{ABC} = 3.2	S3	8.03	7.45	6.95	5.15	**CD_A=0.92**

Table B3.13. Interaction of combination and speed on snap force of extrudates

Temperature (°C)	Snap force (N) at different combinations								
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**Mean**
170	14.22	12.76	11.75	9.91	12.44	11.99	11.56	10.77	12.75
180	12.98	11.98	10.83	9.88	12.12	11.59	12.22	10.71	12.34
190	11.55	10.66	9.75	8.37	11.66	11.29	11.66	9.56	10.57
200	12.22	10.55	9.34	8.16	10.11	10.99	11.15	8.93	9.68
Mean	12.45	10.42	10.16	8.63	11.89	11.66	10.90	8.45	
CD_B =0.65	**CD_{AB} =1.84**								

Table B3.14. Interaction of combination and speed on snap force of extrudates

Speed (rpm)	Snap force (N) at different combinations								
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**Mean**
80	14.24	11.66	11.21	10.56	12.44	11.78	11.32	9.34	11.45
100	11.45	11.33	10.33	9.56	11.89	11.21	10.66	8.65	11.32
120	11.56	10.98	10.09	8.65	11.56	10.71	10.23	8.91	10.97
Mean	12.45	10.42	10.16	8.63	11.89	11.66	10.90	8.45	
CD_C =0.56	**CD_{AC} = 1.6**								

Table B3.15. Interaction of combination, temperature and speed on snap energy (N-s) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : Banana combinations						
P1 (R_{60}:B_{40})	S1	5.66	3.52	3.28	2.32	4.03
	S2	3.50	2.74	2.54	2.07	
	S3	1.79	1.78	1.25	1.78	
P2 (R_{70}:B_{30})	S1	1.62	1.59	1.36	1.35	2.03
	S2	1.43	1.15	1.30	1.24	
	S3	0.98	1.15	1.09	1.12	
P3 (R_{80}:B_{20})	S1	1.62	1.42	1.43	1.32	1.63
	S2	1.07	1.04	1.24	1.28	
	S3	0.95	1.00	1.18	0.99	
P4 (R_{90}:B_{10})	S1	1.58	1.69	1.34	1.47	1.50
	S2	1.57	1.42	1.16	1.36	
	S3	1.54	1.17	1.00	1.11	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	4.55	4.22	4.02	3.29	2.70
	S2	4.22	3.53	3.20	2.53	
	S3	2.31	2.54	3.01	2.35	
P6 (R_{50}:C_{40}:B_{10})	S1	2.54	1.87	1.83	1.64	1.78
	S2	2.06	0.87	1.04	1.51	
	S3	1.83	0.86	0.95	1.29	
P7 (R_{30}:C_{60}:B_{10})	S1	2.36	2.27	1.80	1.92	1.39
	S2	2.18	2.18	1.67	1.83	
	S3	2.12	2.12	1.46	1.45	
P8 (R_{10}:C_{80}:B_{10})	S1	1.89	1.76	1.25	1.39	1.29
	S2	1.38	1.37	1.14	1.03	
CD_{ABC} = 1.47	S3	1.34	1.34	1.49	1.00	**CD_A= 0.42**

Table B3.16 Interaction of combination and speed on snap energy of extrudates

Temperature (°C)	Snap energy (N-s) of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	5.66	3.06	1.90	1.33	4.55	2.30	2.04	1.77	2.14
180	4.05	2.80	1.62	1.32	2.24	1.90	1.60	1.51	2.09
190	3.83	2.75	1.31	1.31	1.78	1.62	1.50	1.43	2.09
200	3.40	2.19	1.29	1.19	1.68	1.31	1.37	1.30	1.86
Mean	4.03	2.03	1.63	1.50	2.70	1.78	1.39	1.29	
CD_B = 0.29	**CD_{AB} = 0.85**								

Table B3.17 Interaction of combination and speed on snap energy of extrudates

Speed (rpm)	Snap energy (N-s) of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	4.66	2.96	2.11	2.20	1.67	2.08	1.44	1.41	2.07
100	3.83	2.77	2.01	1.76	1.52	1.64	1.42	1.36	2.06
120	3.59	2.37	1.98	1.38	1.31	1.17	1.32	1.11	2.00
Mean	4.03	2.03	1.63	1.50	2.70	1.78	1.39	1.29	
CD_C = 0.26	**CD_{AC} = 0.73**								

Table B3.18. Interaction of temperature and speed on snap energy of extrudates

Speed (rpm)	Snap energy (N-s) at different temperatures				
	T1	T2	T3	T4	Mean
80	2.24	2.43	2.32	2.01	2.07
100	2.12	2.01	2.19	1.80	2.06
120	2.05	1.83	1.76	1.77	2.00
Mean	2.14	2.09	2.09	1.86	
CD_C = 0.26	**CD_{BC} = 0.52**				

APPENDIX B4

Table B4.1 Interaction of combination, temperature and speed on Lightness of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : Banana combinations						
P1 (R_{60}:B_{40})	S1	84.7	86.6	81.1	81.7	
	S2	84.4	85.1	81.1	80.6	82.27
	S3	84.2	82.6	79.6	75.7	
P2 (R_{70}:B_{30})	S1	85.6	84.7	82.6	84.6	
	S2	84.3	80.5	80.5	82.3	82.47
	S3	83.6	78.6	77.3	68.0	
P3 (R_{80}:B_{20})	S1	90.8	89.7	89.4	87.5	
	S2	89.4	88.4	88.3	87.4	87.93
	S3	89.1	84.4	84.9	86.0	
P4 (R_{90}:B_{10})	S1	94.9	93.0	92.4	92.6	
	S2	94.7	91.8	90.4	91.7	92.47
	S3	80.9	89.2	81.0	91.0	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	90.2	90.0	89.9	89.9	
	S2	88.5	90.0	89.5	88.7	87.81
	S3	85.6	88.2	89.2	86.6	
P6 (R_{50}:C_{40}:B_{10})	S1	89.4	88.0	88.5	87.8	
	S2	89.3	88.0	87.1	87.6	86.60
	S3	88.6	87.1	85.3	85.9	
P7 (R_{30}:C_{60}:B_{10})	S1	88.2	88.4	86.1	84.7	
	S2	87.8	87.0	85.1	84.1	85.57
	S3	86.3	84.5	81.6	81.7	
P8 (R_{10}:C_{80}:B_{10})	S1	87.3	85.1	83.4	83.3	83.43
	S2	83.6	84.0	83.4	82.9	
CD_{ABC} =0.172	S3	80.0	83.2	82.9	82.4	**CD_A =0.049**

Table B4.2. Interaction of combination and speed on lightness of extrudates

Speed (rpm)	L value of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	82.84	84.14	88.55	92.50	88.11	87.40	85.85	82.16	86.66
100	82.07	82.30	88.33	92.49	88.46	87.49	85.63	83.77	86.21
120	81.91	80.98	86.92	92.44	90.01	88.19	84.88	84.36	86.12
Mean	82.27	82.47	87.93	92.48	87.81	86.60	85.57	83.43	
CD_C =0.031	**CD_{AC} = 0.061**								

Table B4. 3 Interaction of temperature and speed on lightness of extrudates

Speed (rpm)	L value at different temperatures				
	T1	T2	T3	T4	Mean
80	88.18	86.79	85.70	86.20	86.63
100	88.11	86.51	85.23	85.56	86.22
120	87.14	86.50	85.02	84.94	86.12
Mean	87.81	86.60	85.57	85.31	
CD_C = 0.09	**CD_{BC} = 0.061**				

Table B4.4. Interaction of combination, temperature and speed on redness ('a') of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	6.39	6.19	7.09	7.57	
	S2	6.39	5.28	6.52	6.54	6.30
	S3	5.71	5.18	6.43	6.30	
P2 (R_{70}:B_{30})	S1	6.36	6.52	6.57	7.32	
	S2	6.26	6.17	6.43	6.79	6.28
	S3	4.88	4.75	6.04	6.03	
P3 (R_{80}:B_{20})	S1	4.40	4.69	4.66	5.08	
	S2	4.38	4.60	4.40	4.38	4.41
	S3	3.84	4.04	4.12	4.32	
P4 (R_{90}:B_{10})	S1	3.21	3.92	3.75	3.53	
	S2	2.98	3.41	3.28	3.03	3.30
	S3	2.52	2.58	3.11	2.98	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	4.56	4.54	4.93	4.99	
	S2	3.92	4.10	4.47	4.36	4.29
	S3	3.70	3.98	3.85	4.12	
P6 (R_{50}:C_{40}:B_{10})	S1	5.65	5.52	5.52	5.90	
	S2	4.61	5.49	5.37	5.66	5.19
	S3	3.66	5.33	5.20	5.30	
P7 (R_{30}:C_{60}:B_{10})	S1	5.86	6.00	6.67	7.39	
	S2	5.25	5.98	6.25	6.61	5.27
	S3	5.15	5.88	6.17	6.24	
P8 (R_{10}:C_{80}:B_{10})	S1	5.29	5.41	5.62	5.71	
	S2	5.18	4.84	5.27	5.07	6.12
CD_{ABC} = 0.074	S3	5.10	4.61	5.10	5.04	**CD_A=0.021**

Table B4. 5. Interaction of combination and temperature on redness ('a') of extrudates

Temperature (°C)	'a' value of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	5.55	5.83	4.21	3.12	4.06	4.95	5.42	5.36	4.94
180	6.16	6.21	4.39	3.18	4.20	5.19	5.95	5.44	5.18
190	6.68	6.35	4.46	3.39	4.41	5.27	6.36	5.62	5.18
200	6.80	6.72	4.59	3.50	4.49	5.32	6.74	6.74	5.27
Mean	6.30	6.26	4.41	3.30	4.29	5.19	5.27	6.12	
CD_B = 0.0147	**CD_{AB} = 0.043**								

Table B4.6. Interaction of combination and speed on redness ('a') of extrudates

Speed (rpm)	'a' value of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	5.99	5.82	4.37	3.25	4.05	5.04	5.88	5.09	4.98
100	6.30	6.45	4.39	3.28	4.37	5.11	5.99	5.22	5.16
120	6.42	6.55	4.48	3.36	4.45	5.65	6.48	5.25	5.29
Mean	6.49	6.26	4.41	3.30	4.29	5.19	5.27	6.12	
CD_C = 0.013	**CD_{AC} =0.037**								

Table B4. 7. Interaction of temperature and speed on redness ('a') of extrudates

Speed (rpm)	'a' value at different temperatures				
	T1	T2	T3	T4	Mean
80	4.65	5.09	5.13	5.04	4.98
100	5.05	5.29	5.17	5.07	5.16
120	5.26	5.43	5.25	5.44	5.29
Mean	5.27	5.18	5.18	4.94	
CD_C = 0.013	**CD_{BC} = 0.026**				

Table B4.8. Interaction of combination, temperature and speed on yellowness ('b') of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	25.3	26.4	27.4	29.2	25.02
	S2	22.4	26.4	27.0	27.3	
	S3	21.6	24.0	26.9	25.1	
P2 (R_{70}:B_{30})	S1	26.0	25.0	26.5	27.3	24.60
	S2	25.7	24.7	24.7	26.5	
	S3	19.8	21.5	26.5	24.7	
P3 (R_{80}:B_{20})	S1	22.4	22.5	22.5	22.0	21.01
	S2	21.1	22.1	22.5	21.9	
	S3	21.1	21.9	22.6	21.6	
P4 (R_{90}:B_{10})	S1	21.4	22.2	20.7	21.9	18.37
	S2	21.0	21.4	20.3	20.6	
	S3	17.6	17.0	19.7	19.5	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	23.3	22.8	23.5	23.3	22.07
	S2	21.3	21.3	22.7	22.2	
	S3	20.4	21.2	21.8	21.1	
P6 (R_{50}:C_{40}:B_{10})	S1	26.6	26.6	26.5	27.5	25.33
	S2	26.1	26.3	25.0	26.6	
	S3	25.5	26.3	24.6	26.2	
P7 (R_{30}:C_{60}:B_{10})	S1	27.8	27.7	27.6	28.4	25.96
	S2	26.7	27.6	27.2	27.8	
	S3	26.5	27.0	27.1	27.3	
P8 (R_{10}:C_{80}:B_{10})	S1	25.2	25.8	25.7	26.0	27.40
	S2	25.0	25.5	25.6	25.0	
CD_{ABC} = 0.22	S3	25.0	25.1	25.5	24.6	**CD_A= 0.064**

Table B4.9. Interaction of combination and temperature on yellowness ('b') of extrudates

Temperature (°C)	'b' value of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	22.47	23.31	20.07	17.67	21.65	25.08	24.65	27.01	23.46
180	24.98	24.62	21.18	18.09	21.80	25.22	26.06	27.30	23.47
190	26.25	25.16	21.22	18.41	22.19	25.45	26.37	27.44	23.74
200	26.37	25.32	21.54	19.29	22.66	25.59	26.76	27.84	24.21
Mean		24.60	21.01	18.37	22.07	25.33	25.96	27.40	
CD_B =0.045	**CD_{AB} =0.127**								

Table B4. 10. Interaction of combination and speed on yellowness ('b') of extrudates

Speed (rpm)	'b' value of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	24.36	23.81	20.67	18.21	21.85	25.15	25.46	27.02	23.51
100	25.31	24.98	21.16	18.25	22.03	25.29	25.75	27.43	23.79
120	25.66	25.01	21.18	18.65	22.34	25.56	26.67	27.74	23.86
Mean	25.02	24.60	21.01	18.37	22.07	25.33	25.96	27.40	
CD_C =0.039	**CD_{AC} = 0.111**								

Table B4.11. Interaction of temperature and speed on yellowness ('b') of extrudates

Speed (rpm)	'b' value at different temperatures				
	T1	T2	T3	T4	Mean
80	24.04	23.37	23.38	23.22	23.51
100	24.24	23.38	23.92	23.38	23.79
120		23.62	23.93	23.80	23.86
Mean	24.21	23.74	23.47	23.46	
CD_C = 00.04	**CD_{BC} = 0.078**				

Table B4. 12. Interaction of combination, temperature and speed on total colour change of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	21.6	24.0	27.0	25.1	25.74
	S2	22.4	26.4	26.9	27.3	
	S3	25.3	26.4	27.4	29.2	
P2 (R_{70}:B_{30})	S1	19.8	24.9	24.7	24.9	25.28
	S2	26.0	25.2	26.5	25.2	
	S3	26.5	25.7	27.3	25.7	
P3 (R_{80}:B_{20})	S1	21.1	22.1	22.2	21.6	21.97
	S2	22.4	22.5	22.5	21.9	
	S3	21.5	21.1	21.9	22.0	
P4 (R_{90}:B_{10})	S1	16.6	17.9	19.7	19.5	20.96
	S2	21.0	21.4	20.2	20.6	
	S3	21.4	21.9	20.7	22.4	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	21.0	21.3	22.1	21.9	22.52
	S2	22.2	22.4	23.1	22.1	
	S3	23.6	23.6	23.8	23.3	
P6 (R_{50}:C_{40}:B_{10})	S1	22.9	26.4	26.6	26.0	26.14
	S2	25.2	26.9	26.6	26.5	
	S3	27.0	22.8	26.9	26.9	
P7 (R_{30}:C_{60}:B_{10})	S1	26.9	28.6	28.5	28.4	26.30
	S2	28.0	29.0	28.6	28.8	
	S3	28.8	29.6	28.8	28.8	
P8 (R_{10}:C_{80}:B_{10})	S1	25.2	26.3	25.8	26.9	28.56
	S2	25.9	26.3	26.3	26.2	CD_A= 0.061
CD_{ABC} = 0.211	S3	26.5	26.6	26.6	26.4	

Table B4. 13. Interaction of combination and temperature on total colour change of extrudates

Temperature (°C)	Δ E of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	23.09	23.20	21.50	20.19	22.23	25.04	27.89	25.85	24.32
180	25.57	25.30	21.85	20.61	22.42	26.46	28.64	26.18	24.64
190	27.07	25.75	22.15	21.46	22.45	26.68	28.67	26.22	24.70
200	27.20	26.20	22.37	21.57	22.98	27.04	29.06	26.28	25.08
Mean	25.74	25.28	21.97	20.96	22.52	26.13	26.30	28.56	
$CD_B = 0.043$	$CD_{AB} = 0.122$								

Table B4. 14. Interaction of combination and speed on total colour change of extrudates

Speed (rpm)	Δ E of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	24.95	24.28	21.73	20.80	22.22	25.83	26.16	28.39	24.18
100	26.05	25.69	22.01	20.86	22.46	26.03	26.31	28.49	24.83
120	26.21	25.88	22.17	21.20	22.88	27.05	26.93	28.81	24.39
Mean	25.74	25.28	21.97	20.96	22.52	26.13	26.30	28.56	
$CD_C = 0.037$	$CD_{AC} = 0.105$								

Table B4. 15. Interaction of BC on total colour change of extrudates

Speed (rpm)	Δ E at different temperature				
	T1	T2	T3	T4	Mean
80	24.03	24.81	24.22	24.52	24.39
100	24.28	25.15	24.80	24.62	24.82
120	24.64	25.28	24.90	24.96	24.83
Mean	24.08	24.32	24.64	24.70	
$CD_C = 0.061$	$CD_{BC} = 0.075$				

Table B4.16. Interaction of combination, temperature and speed on browning index of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	32.3	36.7	45.4	44.6	41.50
	S2	32.7	41.3	51.8	44.2	
	S3	40.5	41.4	40.7	46.3	
P2 (R_{70}:B_{30})	S1	29.0	30.4	39.3	37.8	40.15
	S2	41.1	40.4	44.0	39.9	
	S3	41.3	42.9	47.2	40.3	
P3 (R_{80}:B_{20})	S1	26.5	31.0	33.7	34.2	30.53
	S2	28.4	32.1	31.1	28.9	
	S3	30.1	30.4	29.6	30.5	
P4 (R_{90}:B_{10})	S1	22.6	24.0	25.2	27.4	24.36
	S2	21.9	23.4	28.6	22.8	
	S3	18.8	25.7	22.1	23.5	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	29.6	30.0	31.4	32.6	41.29
	S2	30.3	30.6	34.0	33.7	
	S3	35.6	34.1	37.4	37.8	
P6 (R_{50}:C_{40}:B_{10})	S1	42.3	39.6	42.5	32.2	41.25
	S2	41.8	42.2	41.8	38.9	
	S3	42.4	42.2	44.8	44.9	
P7 (R_{30}:C_{60}:B_{10})	S1	40.7	42.4	40.4	42.1	37.82
	S2	38.8	40.3	40.2	40.1	
	S3	41.9	41.6	42.4	44.1	
P8 (R_{10}:C_{80}:B_{10})	S1	36.4	38.0	38.8	36.4	33.09
	S2	40.4	37.9	38.3	36.9	
CD_{ABC} = 0.402	S3	36.6	39.8	37.5	36.8	CD_A =0.116

Table B4. 17. Interaction of combination and temperature on browning index of extrudates

Temperature (°C)	BI of different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
170	45.97	43.61	31.45	25.89	38.66	40.44	36.72	31.57	35.23
180	45.02	40.44	31.18	24.51	41.32	40.99	37.82	31.84	35.95
190	39.84	39.33	31.17	24.39	42.17	41.43	38.18	34.24	36.09
200	35.17	37.23	28.30	22.64	43.02	42.14	38.55	34.69	37.71
Mean	41.50	40.15	30.53	24.36	41.29	41.25	37.82	33.09	
CD_B =0.082	CD_{AB} = 0.232								

Table B4.18 Interaction of temperature and speed on browning index of extrudates

Speed (rpm)	BI at different temperature				
	T1	T2	T3	T4	Mean
80	37.03	38.23	36.42	36.30	36.76
100	36.09	37.93	36.43	34.78	36.53
120	34.74	36.98	35.46	34.62	35.45
Mean	37.82	36.09	35.95	35.23	
CD_C = 0.071	CD_{BC} = 0.142				

Table B4. 19 Interaction of combination and speed on moisture content of extrudates

Speed (rpm)	BI at different combinations								
	P1	P2	P3	P4	P5	P6	P7	P8	Mean
80	10.11	10.37	9.70	10.63	10.50	9.59	10.07	10.25	10.05
100	10.23	10.06	9.50	9.94	9.87	9.09	9.11	9.70	9.67
120	9.83	9.98	8.72	9.91	9.47	9.50	9.60	9.37	9.66
Mean	10.14	10.13	10.06	9.31	9.94	9.77	9.59	9.40	
CD_C =0.381	CD_{AC} = 0.1.079								

Table B4. 20. Interaction of combination, temperature and speed on moisture content of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C) T1	T2	T3	T4	Mean
Rice : banana combinations						
P1 (R_{60}:B_{40})	S1	10.20	10.70	10.10	9.50	10.14
	S2	10.50	10.70	10.20	9.20	
	S3	10.60	10.10	9.90	9.10	
P2 (R_{70}:B_{30})	S1	11.50	10.60	10.40	10.10	10.13
	S2	11.20	10.40	9.60	9.60	
	S3	10.10	10.40	8.50	9.10	
P3 (R_{80}:B_{20})	S1	10.60	9.90	9.80	9.70	10.06
	S2	9.20	9.80	9.60	8.60	
	S3	7.80	9.50	8.70	7.40	
P4 (R_{90}:B_{10})	S1	11.60	9.70	10.90	10.70	9.31
	S2	11.40	9.60	9.50	10.70	
	S3	11.20	8.90	8.50	9.20	
Rice : cassava : banana combinations						
P5 (R_{70}:C_{20}:B_{10})	S1	11.00	9.20	10.30	9.90	9.94
	S2	11.30	9.00	9.00	8.90	
	S3	8.50	8.90	8.90	8.60	
P6 (R_{50}:C_{40}:B_{10})	S1	10.80	10.00	9.60	9.50	9.77
	S2	9.90	9.40	9.50	9.30	
	S3	9.20	9.20	9.10	8.00	
P7 (R_{30}:C_{60}:B_{10})	S1	10.90	11.20	9.80	9.90	9.59
	S2	10.30	10.10	8.40	9.40	
	S3	10.60	9.70	8.00	7.90	
P8(R_{10}:C_{80}:B_{10})	S1	11.10	10.50	10.60	10.60	9.40
	S2	8.90	10.40	9.90	8.70	**CD_A=**
CD_{ABC} = 2.16	S3	8.20	10.10	9.30	8.00	**0.623**

Table B4. 21. Interaction of combination and temperature on moisture content of extrudates

Temperature (°C)	M.C (%) of different combinations								
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**Mean**
170	9.22	10.49	9.74	9.64	10.56	9.26	8.73	9.17	10.09
180	10.05	9.62	8.94	9.41	9.41	9.98	9.12	9.92	9.93
190	10.44	10.95	9.37	10.18	9.51	8.95	10.60	9.43	9.60
200	10.52	9.50	9.19	11.40	10.30	9.40	9.91	10.58	9.56
Mean	10.14	10.13	10.06	9.31	9.94	9.77	9.59	9.40	
CD_B = 0.44	**CD_{AB} = 1.246**								

Table B4. 22 Interaction of temperature and speed on moisture content of extrudates

Speed (rpm)	M.C (%) at different temperatures				
	T1	**T2**	**T3**	**T4**	**Mean**
80	10.19	9.87	10.15	10.19	10.05
100	9.60	9.51	10.14	10.16	9.67
120	9.01	9.29	10.00	9.45	9.60
Mean	10.09	9.92	9.60	9.56	
CD_C = 0. 38	**CD_{BC} = 0.0.76**				

APPENDIX C1

Table C1 Interaction of combination, temperature and speed on mass flow rate (Kg/hr) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C)			
		T1	T2	T3	T4
Rice : banana combinations					
P1 (R_{60}:B_{40})	S1	1.8	1.7	1.5	1.3
	S2	1.7	1.7	1.5	1.2
	S3	1.7	1.7	1.3	1.1
P2 (R_{70}:B_{30})	S1	1.7	1.7	1.5	1.3
	S2	1.7	1.6	1.5	1.2
	S3	1.7	1.6	1.4	1.1
P3 (R_{80}:B_{20})	S1	1.7	1.6	1.5	1.2
	S2	1.7	1.6	1.3	1.2
	S3	1.7	1.5	1.3	1.2
P4 (R_{90}:B_{10})	S1	1.6	1.4	1.4	1.4
	S2	1.5	1.3	1.3	1.3
	S3	1.5	1.3	1.3	1.2
Rice : cassava : banana combinations					
P5 (R_{70}:C_{20}:B_{10})	S1	2.3	2.2	1.9	1.6
	S2	2.2	2.2	1.7	1.5
	S3	2.1	2.1	1.7	1.5
P6 (R_{50}:C_{40}:B_{10})	S1	2.2	1.9	1.7	1.7
	S2	2.1	1.9	1.7	1.6
	S3	2.0	1.8	1.6	1.6
P7 (R_{30}:C_{60}:B_{10})	S1	1.5	1.4	1.4	1.3
	S2	1.4	1.3	1.3	1.1
	S3	1.3	1.3	1.3	1.0
P8 (R_{10}:C_{80}:B_{10})	S1	1.0	1.0	1.0	0.9
	S2	1.0	1.0	0.9	0.8
	S3	0.9	0.9	0.9	0.7

APPENDIX C2

Table C.2 Interaction of combination, temperature and speed on volumetric flow rate (m^3/hr) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C)			
		T1	T2	T3	T4
Rice : banana combinations					
P1 (R_{60}:B_{40})	S1	4124.8	4119.7	3683.7	3775.1
	S2	3635.9	3473.1	3126.0	2708.6
	S3	3816.1	3387.4	3006.4	2644.5
P2 (R_{70}:B_{30})	S1	2493.8	2182.2	1722.5	1629.5
	S2	2110.9	1897.2	1660.6	1624.7
	S3	1535.6	1722.5	1640.5	1549.5
P3 (R_{80}:B_{20})	S1	1793.3	1504.7	1519.1	1505.5
	S2	1536.5	1404.2	1342.2	1123.6
	S3	1314.2	1130.5	1230.7	1121.9
P4 (R_{90}:B_{10})	S1	1627.8	1641.6	1494.9	1465.8
	S2	1625.4	1534.0	1411.0	1376.4
	S3	1507.9	1514.9	1357.0	1306.3
Rice : cassava : banana combinations					
P5 (R_{70}:C_{20}:B_{10})	S1	7135.4	6150.2	4870.9	4922.2
	S2	6388.4	5214.3	4799.1	4710.4
	S3	6312.5	5148.9	4667.5	4187.2
P6 (R_{50}:C_{40}:B_{10})	S1	3961.9	3523.4	3416.4	3404.6
	S2	3715.9	3311.3	3281.7	3283.6
	S3	3283.6	3155.5	3258.8	2754.9
P7 (R_{30}:C_{60}:B_{10})	S1	3874.2	3239.3	3499.4	2711.0
	S2	3788.7	3122.1	3215.0	2670.5
	S3	3516.4	2921.3	3127.8	2434.8
P8 (R_{10}:C_{80}:B_{10})	S1	4436.7	3582.5	3620.9	2555.8
	S2	4167.9	3448.7	3275.6	2448.3
	S3	3601.1	3247.6	2976.8	2414.1

APPENDIX C3

Table C3. Interaction of combination, temperature and speed on torque (N-m) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C)			
		T1	T2	T3	T4
Rice : banana combinations					
P1 (R_{60}:B_{40})	S1	45.0	60.0	52.5	52.5
	S2	52.5	52.5	52.5	52.5
	S3	45.0	52.5	60.0	60.0
P2 (R_{70}:B_{30})	S1	45.0	45.0	52.5	45.0
	S2	45.0	45.0	52.5	45.0
	S3	45.0	52.5	52.5	45.0
P3 (R_{80}:B_{20})	S1	52.5	52.5	45.0	45.0
	S2	60.0	45.0	45.0	45.0
	S3	60.0	45.0	45.0	45.0
P4 (R_{90}:B_{10})	S1	60.0	45.0	45.0	45.0
	S2	60.0	45.0	45.0	45.0
	S3	60.0	45.0	45.0	45.0
Rice : cassava : banana combinations					
P5 (R_{70}:C_{20}:B_{10})	S1	60.0	60.0	45.0	45.0
	S2	52.5	60.0	45.0	45.0
	S3	45.0	52.5	45.0	45.0
P6 (R_{50}:C_{40}:B_{10})	S1	45.0	60.0	45.0	52.5
	S2	52.5	52.5	45.0	45.0
	S3	52.5	52.5	45.0	67.5
P7 (R_{30}:C_{60}:B_{10})	S1	45.0	45.0	52.5	45.0
	S2	45.0	52.5	52.5	45.0
	S3	45.0	45.0	45.0	45.0

APPENDIX C4

Table C4. Interaction of combination, temperature and speed on SME (kWh/kg) of extrudates

COMBINATION (%)	SPEED (rpm)	TEMPERATURE (°C)			
		T1	T2	T3	T4
Rice : banana combinations					
P1 (R_{60}:B_{40})	S1	554.4	454.5	196.1	157.6
	S2	388.2	434.9	175.7	149.2
	S3	250.1	422.1	159.7	148.3
P2 (R_{70}:B_{30})	S1	454.5	416.8	389.4	353.9
	S2	434.9	413.6	365.1	324.3
	S3	422.1	410.7	364.3	310.2
P3 (R_{80}:B_{20})	S1	288.3	207.6	195.6	155.9
	S2	268.9	201.7	167.2	141.7
	S3	219.8	197.0	160.9	132.0
P4 (R_{90}:B_{10})	S1	352.0	259.9	232.3	212.9
	S2	266.8	255.1	229.5	206.6
	S3	262.9	240.3	221.9	191.4
Rice: cassava : banana combinations					
P5 (R_{70}:C_{20}:B_{10})	S1	433.8	360.5	281.1	240.3
	S2	405.7	346.2	276.4	229.3
	S3	399.4	284.1	267.2	217.2
P6 (R_{50}:C_{40}:B_{10})	S1	543.3	436.5	378.2	290.3
	S2	515.2	389.8	373.3	287.3
	S3	467.3	385.7	318.4	269.8
P7 (R_{30}:C_{60}:B_{10})	S1	632.3	519.7	453.6	391.0
	S2	571.6	512.0	434.4	376.8
	S3	545.3	470.4	399.1	304.5
P8 (R_{10}:C_{80}:B_{10})	S1	533.0	475.6	442.0	392.0
	S2	478.8	472.5	418.3	384.7
	S3	477.2	459.6	411.7	368.6

APPENDIX D

Table D1. Textural analysis of selected extrudates

Treatment	Crispness	Hardness (N)	Toughness (N-s)	Snap force (N)	Snap energy (N-s)
T1	6.42	16.67	7.50	12.01	4.40
T2	6.00	15.45	8.25	8.98	3.54
T3	6.77	22.32	9.35	11.46	1.39
T4	7.37	22.81	10.80	9.86	1.77
T5	7.69	15.29	11.34	9.23	4.01
T6	5.28	13.59	6.72	11.11	4.60
T7	7.41	16.44	9.55	9.94	5.18
T8	7.00	20.04	8.47	10.12	1.33
T9	5.31	17.16	6.94	6.42	1.65
T10	5.79	12.86	6.09	7.98	1.93
T11	6.71	18.73	7.46	8.38	1.98
T12	7.05	16.39	7.50	9.31	2.09
T13	7.31	16.76	11.91	6.88	3.91
T14	6.56	15.35	8.81	7.92	5.38
T15	5.58	11.61	6.19	6.25	1.45
T16	7.14	20.30	10.42	8.72	3.29
T17	4.79	43.82	9.95	10.72	2.02

APPENDIX E

Table E.1 Proximate analysis of selected extrudates

Treatment	Moisture content (%)	Starch (%)	Sugar (%)	Protein (%)	Fat (%)	Energy (KJ/100g)
T1	9.60	64.30	3.40	7.70	0.15	1284.10
T2	10.30	68.20	4.00	3.00	0.50	1322.60
T3	7.20	66.20	3.60	2.90	0.30	1339.70
T4	7.60	59.70	3.80	2.90	0.60	1151.60
T5	8.10	69.20	4.50	2.80	0.20	1290.80
T6	8.80	75.00	3.80	5.80	0.40	1400.70
T7	10.90	72.30	4.60	2.80	0.60	1372.40
T8	8.80	61.60	3.70	4.70	0.40	1222.00
T9	9.20	69.20	3.40	4.70	0.55	1319.70
T10	9.10	67.10	4.60	4.60	0.25	1290.60
T11	9.80	76.40	3.60	5.10	0.40	1448.00
T12	8.00	73.80	4.50	4.90	0.40	1420.50
T13	9.10	62.30	3.90	4.40	0.60	1224.80
T14	10.20	64.30	4.60	4.70	0.35	1260.90
T15	7.70	79.40	4.50	5.30	1.05	1527.60
T16	7.90	68.40	2.80	6.80	0.55	1337.20
T17	9.70	62.50	3.00	8.10	0.25	1233.60

APPENDIX F

Table F.1 Sensory evaluation of spice coated extrudates using Kendall's coefficient of concordance test

Sample	Appearance	Flavour	Taste	Texture	Overall acceptability
T60	4.17	3.29	4.71	4.38	4.13
T78	3.42	3.54	3.71	3.96	3.50
T81	7.38	7.83	8.53	8.21	7.75
T82	5.96	4.83	5.13	5.67	5.00
T83	5.88	6.04	5.71	5.71	5.96
T91	5.38	5.88	4.96	4.38	5.46
T93	5.38	5.92	4.54	4.75	5.33
T94	5.58	5.88	5.71	6.46	5.38
T96	5.04	5.42	5.46	6.25	5.71
CONTROL	6.83	6.38	6.50	5.25	6.79
Kendall's W	**.180**	**.232**	**.233**	**.204**	**.190**

Table F.2 Sensory evaluation of sugar coated extrudates using Kendall's coefficient of concordance test

Sample	Appearance	Flavour	Taste	Texture	Overall acceptability
T60	3.46	3.17	2.58	1.88	1.75
T78	4.21	4.33	3.42	3.33	3.54
T81	3.75	4.46	4.96	4.79	4.46
T82	4.25	3.83	4.71	4.88	4.54
T83	4.63	5.21	4.21	5.67	5.29
T91	4.67	5.25	5.21	5.63	5.29
T93	6.46	4.04	4.50	4.29	4.50
T94	7.21	7.67	7.92	7.63	8.38
T96	6.38	7.04	7.50	6.92	7.25
Kendall's W	**.284**	**.365**	**.449**	**.452**	**.582**

APPENDIX G

Table D.1 Properties of the control (from market sample)

ER	BD (g/cm^3)	PD (g/cm^3)	AD (g/cm^3)	Porosity (%)	a_w	WAI (g/g)	WSI (%)	OAI (g/g)
7.098*	0.32	1.58	2.98	4.56	0.576	11.07	15.91	1.75

Crispness	Hardness (N)	Toughness (N-s)	Snap force (N)	Snap energy (N-s)
9.6	17.05	20.69	15.88	9.92

L	a	b	Δ E	B.I	Y.I
70.25	24.39	50.56	57.42	140.22	102.81

* Average diameter of the control samples

APPENDIX H

Factor A – Combination

Factor B – Temperature

Factor C – Speed

Factor AB – Sample Temperature interaction
Factor AC – Sample Speed interaction
Factor BC – Temperature Speed interaction

Probabilities having no asters are non significant (n.s)

ANOVA for different properties of extrudates

Table G.1 Moisture content

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	28.05	4.007	2.2044	0.0356*	0.22	0.62
4	Factor B	3	14.71	4.905	2.6980	0.0471*	0.16	0.44
6	AB	21	75.09	3.576	1.9669	0.0093**	0.45	1.25
8	Factor C	2	9.55	4.777	2.6276	0.0748	0.14	0.38
10	AC	14	21.34	1.525	0.8386		0.39	1.08
12	BC	6	19.94	3.324	1.8284	0.096	0.26	0.76
14	ABC	42	110.19	2.624	1.4432	0.052	0.78	2.14
-15	Error	192	349.04	1.818				
	Total	287	627.919					

Table G.2 ER1

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	18.902	2.700	666.0886	0.0000**	0.01	0.03
4	Factor B	3	1.341	0.447	110.2699	0.0000**	0.01	0.02
6	AB	21	2.060	0.098	24.1999	0.0000**	0.02	0.06
8	Factor C	2	1.240	0.620	152.9403	0.0000**	0.01	0.02
10	AC	14	0.146	0.010	2.5758	0.0020**	0.02	0.05
12	BC	6	0.057	0.010	2.3550	0.0323**	0.01	0.04
14	ABC	42	0.590	0.014	3.4674	0.0000**	0.04	0.10
-15	Error	192	0.778	0.004				
Total		287	25.116					

Table G.3 ER2

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	776.860	110.980	583.5348	0.0000**	0.07	0.20
4	Factor B	3	40.464	13.488	70.9207	0.0000**	0.05	0.14
6	AB	21	114.818	5.468	28.7483	0.0000**	0.15	0.40
8	Factor C	2	69.067	34.533	181.5767	0.0000**	0.04	0.12
10	AC	14	14.166	1.012	5.3204	0.0000**	0.13	0.35
12	BC	6	4.601	0.767	4.0320	0.0008**	0.09	0.25
14	ABC	42	38.642	0.920	4.8376	0.0000**	0.25	0.70
-15	Error	192	36.516	0.190				
Total		287	1095.133					

Table G.4 Bulk density

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	0.516	0.074	2.7260	0.0102*	0.03	0.08
4	Factor B	3	0.306	0.102	3.7750	0.0116*	0.02	0.05
6	AB	21	0.692	0.033	1.2191	0.2387	0.05	0.15
8	Factor C	2	0.022	0.011	0.4145		0.02	0.05
10	AC	14	0.376	0.027	0.9944		0.05	0.13
12	BC	6	0.153	0.026	0.9436		0.03	0.09
14	ABC	42	1.190	0.028	1.0486	0.4017	0.09	0.26
-15	Error	192	5.189	0.027				
Total		287	8.445					

Table G.5 Product density

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	21.985	3.141	1388.5947	0.0000**	0.010	0.02
4	Factor B	3	1.903	0.634	280.4280	0.0000**	0.010	0.02
6	AB	21	2.117	0.101	44.5686	0.0000**	0.020	0.04
8	Factor C	2	0.730	0.365	161.3288	0.0000**	0.004	0.01
10	AC	14	0.261	0.019	8.2390	0.0000**	0.010	0.04
12	BC	6	0.108	0.018	7.9935	0.0000**	0.010	0.03
14	ABC	42	0.158	0.004	1.6611	0.0118*	0.030	0.08
-15	Error	192	0.434	0.002				
Total		287	27.696					

Table G.6 Apparent density

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	29334.236	4190.605	1595.4282	0.0000**	0.27	0.75
4	Factor B	3	1417.207	472.402	179.8509	0.0000**	0.19	0.53
6	AB	21	1292.834	61.564	23.4382	0.0000**	0.54	1.50
8	Factor C	2	445.636	222.818	84.8302	0.0000**	0.17	0.46
10	AC	14	191.639	13.689	5.2114	0.0000**	0.47	1.30
12	BC	6	31.966	5.328	2.0283	0.0637	0.33	0.92
14	ABC	42	431.438	10.272	3.9108	0.0000**	0.94	2.59
-15	Error	192	504.314	2.627				
Total		287	33649.269					

Table G.7 Porosity

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	21179.376	3025.625	2042.2520	0.0000**	0.20	0.56
4	Factor B	3	4 372.867	1457.622	983.8734	0.0000**	0.14	0.40
6	AB	21	1275.945	60.759	41.0116	0.0000**	0.41	1.12
8	Factor C	2	875.384	437.692	295.4357	0.0000**	0.12	0.34
10	AC	14	187.632	13.402	9.0464	0.0000**	0.35	0.97
12	BC	6	14.596	2.433	1.6420	0.1376	0.25	0.69
14	ABC	42	487.686	11.612	7.8376	0.0000**	0.70	1.95
-15	Error	192	284.451	1.482				
Total		287	28677.939					

Table G.8 Water activity

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	0.274	0.039	2717.3309	0.0000**	0.00	0.002
4	Factor B	3	0.008	0.003	177.3533	0.0000**	0.00	0.001
6	AB	21	0.054	0.003	177.6597	0.0000**	0.00	0.004
8	Factor C	2	0.002	0.001	56.0066	0.0000**	0.00	0.001
10	AC	14	0.027	0.002	135.0048	0.0000**	0.00	0.003
12	BC	6	0.011	0.002	129.8181	0.0000**	0.00	0.002
14	ABC	42	0.069	0.002	113.4357	0.0000**	0.00	0.006
-15	Error	192	0.003	0.000				
Total		287	0.448					

Table G. 9 Water Absorption Index

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	13325.495	1903.642	702.0357	0.0000**	0.27	0.76
4	Factor B	3	318.282	106.094	39.1259	0.0000**	0.19	0.54
6	AB	21	1851.119	88.149	32.5079	0.0000**	0.55	1.52
8	Factor C	2	2.447	1.224	0.4513	0.0000**	0.17	0.49
10	AC	14	286.785	20.485	7.5544	0.0000**	0.48	1.32
12	BC	6	22.648	3.775	1.3921	0.2196	0.34	0.93
14	ABC	42	753.579	17.942	6.6169	0.0000**	0.95	2.64
-15	Error	192	520.628	2.712				
Total		287	17080.983					

Table G.10 Water Solubility Index

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	5211.614	744.516	32.8800	0.0000**	0.79	2.20
4	Factor B	3	204.535	68.178	3.0110	0.0314*	0.56	1.56
6	AB	21	3470.500	165.262	7.2985	0.0000**	1.59	4.40
8	Factor C	2	175.878	87.939	3.8836	0.0222*	0.49	1.35
10	AC	14	981.929	70.138	3.0975	0.0002**	1.35	3.81
12	BC	6	1171.455	195.243	8.6225	0.0000**	0.97	2.69
14	ABC	42	4835.203	115.124	5.0842	0.0000**	2.77	7.62
-15	Error	192	4347.535	22.643				
Total		287	20398.649					

Table G.11 Oil Absorption Index

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	38.304	5.472	175.9612	0.0000**	0.03	0.08
4	Factor B	3	2.952	0.984	31.6405	0.0000**	0.02	0.06
6	AB	21	15.760	0.750	24.1326	0.0000**	0.06	0.16
8	Factor C	2	0.005	0.003	0.0851	0.0000**	0.02	0.05
10	AC	14	3.655	0.261	8.3945	0.0000**	0.05	0.14
12	BC	6	0.649	0.108	3.4774	0.0028**	0.04	0.09
14	ABC	42	5.563	0.132	4.2594	0.0000**	0.10	0.28
-15	Error	192	5.971	0.031				
Total		287	72.858					

Table G.12 Crispness

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	640.932	91.562	26.7018	0.0000**	0.17	0.47
4	Factor B	3	64.453	21.484	6.2654	0.0003**	0.12	0.33
6	AB	21	332.355	15.826	4.6154	0.0000**	0.34	0.94
8	Factor C	2	10.308	5.154	1.5031	0.2230	0.10	0.29
10	AC	14	111.108	7.936	2.3144	0.0040**	0.29	0.81
12	BC	6	27.875	4.646	1.3548	0.2302	0.21	0.57
14	ABC	42	284.642	6.777	1.9764	0.0003**	0.59	1.62
-15	Error	864	2962.700	3.429				
Total		959	4434.374					

Table G.13 Hardness

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	58995.327	8427.904	39.4108	0.0000**	1.33	3.70
4	Factor B	3	32213.152	10737.717	50.2120	0.0000**	0.94	2.62
6	AB	21	35080.510	1670.500	7.8116	0.0000**	2.67	7.40
8	Factor C	2	3867.059	1933.530	9.0416	0.0001**	0.82	2.27
10	AC	14	9865.570	704.684	3.2953	0.0000**	2.31	6.41
12	BC	6	9217.145	1536.191	7.1836	0.0000**	1.64	4.53
14	ABC	42	15747.519	374.941	1.7533	0.0025**	4.62	12.82
-15	Error	864	184764.530	213.848				
Total		959	349750.813					

Table G.14 Toughness

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	5407.314	772.473	17.1806	0.0000**	0.61	1.70
4	Factor B	3	240.640	80.213	1.7840	0.1486	0.43	1.20
6	AB	21	4420.664	210.508	4.6819	0.0000**	1.22	3.39
8	Factor C	2	541.012	270.506	6.0163	0.0025**	0.37	1.04
10	AC	14	1269.654	90.690	2.0170	0.0143*	1.06	2.94
12	BC	6	2075.753	345.959	7.6945	0.0000**	0.75	2.08
14	ABC	42	5142.488	122.440	2.7232	0.0000**	2.12	5.88
-15	Error	864	38847.163	44.962				
Total		959	57944.686					

Table G.15 Snap force

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	13383.824	1911.975	145.3559	0.0000**	0.33	0.92
4	Factor B	3	1307.389	435.796	33.1310	0.0000**	0.23	0.65
6	AB	21	1606.656	76.507	5.8164	0.0000**	0.66	1.84
8	Factor C	2	39.537	19.769	1.5029	0.2231	0.20	0.56
10	AC	14	1001.330	71.524	5.4375	0.0000**	0.57	1.59
12	BC	6	204.742	34.124	2.5942	0.0169*	0.41	1.12
14	ABC	42	2113.457	50.320	3.8256	0.0000**	1.15	3.18
-15	Error	864	11364.838	13.154				
Total		959	31021.773					

Table G.16 Snap energy

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	706.201	100.886	36.1037	0.0000**	0.15	0.42
4	Factor B	3	11.463	3.821	1.3674	0.2514	0.11	0.30
6	AB	21	73.077	3.480	1.2453	0.2047	0.31	0.85
8	Factor C	2	0.942	0.471	0.1686		0.09	0.26
10	AC	14	67.469	4.819	1.7246	0.0461*	0.26	0.73
12	BC	6	32.781	5.464	1.9552	0.0695	0.19	0.52
14	ABC	42	302.840	7.210	2.5804	0.0000**	0.53	1.47
-15	Error	864	2414.307	2.794				
Total		959	3609.081					

Table G. 17 L value

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	4280.637	611.520	39536.2993	0.0000**	0.02	0.05
4	Factor B	3	370.671	123.557	7988.2738	0.0000**	0.01	0.04
6	AB	21	391.964	18.665	1206.7370	0.0000**	0.04	0.09
8	Factor C	2	18.245	9.122	589.7801	0.0000**	0.01	0.03
10	AC	14	183.761	13.126	848.6157	0.0000**	0.03	0.09
12	BC	6	38.410	6.402	413.8792	0.0000**	0.02	0.06
14	ABC	42	547.955	13.047	843.4918	0.0000**	0.06	0.17
-15	Error	288	4.455	0.015				
Total		383	5836.096					

Table G.18 a value

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	395.805	56.544	19977.9947	0.0000**	0.010	0.02
4	Factor B	3	5.976	1.992	703.7983	0.0000**	0.005	0.01
6	AB	21	33.327	1.587	560.7244	0.0000**	0.020	0.04
8	Factor C	2	6.368	3.184	1124.9193	0.0000**	0.005	0.01
10	AC	14	9.647	0.689	243.4546	0.0000**	0.013	0.04
12	BC	6	2.828	0.471	166.5559	0.0000**	0.009	0.03
14	ABC	42	29.126	0.693	245.0218	0.0000**	0.027	0.07
-15	Error	288	0.815	0.003				
Total		383	483.893					

Table G.19 b value

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	2992.904	427.558	16761.7761	0.0000**	0.02	0.06
4	Factor B	3	36.226	12.075	473.3989	0.0000**	0.02	0.05
6	AB	21	187.726	8.939	350.4542	0.0000**	0.05	0.13
8	Factor C	2	9.129	4.564	178.9409	0.0000**	0.01	0.04
10	AC	14	41.059	2.933	114.9742	0.0000**	0.04	0.11
12	BC	6	5.913	0.986	38.6372	0.0000**	0.03	0.08
14	ABC	42	183.929	4.379	171.6824	0.0000**	0.08	0.22
-15	Error	288	7.346	0.026				
Total		383	3464.232					

Table G.20 Total colour change

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	2266.102	323.729	13987.4092	0.0000**	0.02	0.06
4	Factor B	3	28.056	9.352	404.0787	0.0000**	0.02	0.04
6	AB	21	202.519	9.644	416.6795	0.0000**	0.04	0.12
8	Factor C	2	16.152	8.076	348.9469	0.0000**	0.01	0.04
10	AC	14	46.217	3.301	142.6372	0.0000**	0.04	0.11
12	BC	6	5.663	0.944	40.7838	0.0000**	0.03	0.08
14	ABC	42	170.378	4.057	175.2753	0.0000**	0.08	0.21
-15	Error	288	6.666	0.023				
Total		383	2741.755					

Table G. 21 Browning index

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob	S.D	C.D
2	Factor A	7	13433.844	1919.121	22788.1107	0.0000**	0.04	0.12
4	Factor B	3	315.900	105.300	1250.3596	0.0000**	0.03	0.08
6	AB	21	1246.420	59.353	704.7759	0.0000**	0.08	0.23
8	Factor C	2	125.319	62.660	744.0368	0.0000**	0.03	0.07
10	AC	14	474.210	33.872	402.2064	0.0000**	0.07	0.20
12	BC	6	60.997	10.166	120.7149	0.0000**	0.05	0.14
14	ABC	42	1371.123	32.646	387.6440	0.0000**	0.15	0.40
-15	Error	288	24.254	0.084				
Total		383	17052.068					

Abstract

DEVELOPMENT AND QUALITY EVALUATION OF EXTRUDED RTE SNACK FOOD FROM STARCH BASED FOOD PRODUCTS

by

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ABSTRACT OF THE THESIS

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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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 cooking has been used increasingly in the production of food and food ingredients such as breakfast cereals, baby foods, snacks, meat and cheese analogues, as well as modified starches which have a pivotal role in the food industry. With the increased demand of extruded RTE snacks in the modern food industries, an extruded product was developed and standardised with starch based food products such as rice, cassava and banana. The raw materials mixed in different proportions of rice: banana and rice:cassava:banana were extruded under various process parameters *viz.* die temperatures, extruder screw speeds, feed rates and feed moisture content. Quality evaluation of the developed 96 extrudates along with control was done for standard engineering properties including physical, functional, textural and machine parameters. MAP of the extrudates were carried out in 400 gauge aluminum bags and kept for 3 months period for shelf life studies. Based on puffing characteristics, 17 samples were selected as best products. At the end of storage studies, the quality evaluation of these extrudates in terms of textural and organoleptic properties were analysed and yielded satisfactory results. The subjective analysis with good overall acceptability was also noted. The study concluded that rice: cassava: banana combination of R_{10}:C_{80}:B_{10} with extrusion done at temperatures of 180°C to 200°C at higher screw speed (100 and 120 rpm) could be considered optimum. The proposed product technology was found feasible with 37% IRR with a calculated unit cost of ₹ 3/- per 20g pack. So this product will be a snack cum breakfast kit for the consumers with a balanced mix of proteins, carbohydrates, vitamins and minerals which will ensure nutritional security and food safety.