DEVELOPMENT OF EXTRUDED SNACKS UTILIZING BROKEN RICE AND MUNG BEAN

Thesis

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**MASTER OF SCIENCE
in
FOOD TECHNOLOGY
(Minor Subject: Biochemistry)**

By

**Chetan Sharma
(L-2010-A-42-M)**

**Department of Food Science and Technology
College of Agriculture**

LUDHIANA-141004

2012

CERTIFICATE – 1

This is to certify that the thesis entitled, "**DEVELOPMENT OF EXTRUDED SNACKS UTILIZING BROKEN RICE AND MUNG BEAN**" submitted for the degree of M.Sc., in the subject of Food Technology (Minor subject: Biochemistry) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Mr. Chetan Sharma (L-2010-A-42-M)** under my supervision and that no part of this thesis/ dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

Major Advisor
(Dr. Baljit Singh)
Baking Technology
Department of Food Science
and Technology
Punjab Agricultural University
Ludhiana – 141004

CERTIFICATE – II

This is to certify that the thesis report entitled, "**DEVELOPMENT OF EXTRUDED SNACKS UTILIZING BROKEN RICE AND MUNG BEAN**" submitted by **Mr. Chetan Sharma (**Admn No. **L-2010-A-42-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfilment of the requirements for the degree of M.Sc., in the subject of **Food Technology** (Minor subject: Biochemistry) has been approved by the Student's Advisory Committee along with Head of the Department after an oral examination on the same.

____
Head of the Department
(Dr. K.S. Minhas)

____
Major Advisor
(Dr. Baljit Singh)

____
Dean Postgraduate Studies
(Dr. Gursharan Singh)

ACKNOWLEDGEMENT

Fore mostly, I bow my head with reverence to 'Almighty Lord' who showed the blessings on me during the course of this investigation and brought it to a logical end.

I express my profound gratitude, indebtedness and appreciation to my Major Advisor ***Dr. Baljit Singh,*** *Baking Technologist, Department of Food Science and Technologist, Department of Food Science and Technology, PAU, Ludhiana, for his valuable guidance, indispensable suggestions and constructive criticism and persistence, which led to the successful completion of this work. I owe a great to him. I consider myself fortunate.*

I am thankful to all the members of my Advisory Committee ***Dr. Savita Sharma*** *(Senior Dough Rheologist), Department of Food Science and Technology* ***Dr. Surekha Bhatia*** *(Assistant Biochemist) Department of Processing and Food Engineering and* ***Dr. Amarjeet Kaur*** *(Senior Milling Technologist) Department of Food Science and Technology for their valuable suggestions and expert guidance on various issues related to this research work.*

I am thankful to ***Dr. K. S. Minhas****, Head, Department of Food Science and Technology for providing necessary departmental facilities for the conduct of this investigation.*

I wish to express my deepest sense of gratitude to my reverted parents, ***Sh. Jaspal Sharma*** *and* ***Smt. Geeta Sharma,*** *my brother* ***Neeraj*** *and sister* ***Piyanka*** *for their unconditional love, support and sacrifices, which can never be forgotten and whose ever willing help has a great role in my life. I cannot weigh my feelings with words for my dearest cousins* ***Gayatri, Navjeet, Navneet, Swaraj*** *and Bhabhi ji* ***Manju*** *and loving niece* ***Jazzu*** *and nephew* ***Laksh****, for their everlasting love and affection and support.*

I have been fortunate to come across my funny and good friends without whom life would be bleak. I am happy to acknowledge the shadow support and moral upliftment showered upon me by ***Shiveta, Preety (husk), Kanchan, Shivani, Sarbjit, Sukhchain, Jassa, Parminder, Pankaj, and Sameer.***

I fully acknowledge the help and cooperation rendered by the laboratory staff especially Sarbjit Singh, Samar and Balkrishan during experiment. Lastly, but not the least, I am grateful to the unmentioned ones.

Chetan Sharma
Dept. of Food Science and Technology
PAU, Ludhiana

Title of the Thesis	**:**	Development of Extruded Snacks Utilizing Broken Rice and Mung Bean
Name of the student and Admission No.	**:**	Chetan Sharma L-2010-A-42-M
Major Subject	**:**	Food Technology
Minor Subject	**:**	Biochemistry
Name and Designation of major Advisor	**:**	Dr. Baljit Singh Baking Technologist
Degree to be awarded	**:**	Master of Science
Year of award of Degree	**:**	2012
Total Pages in Thesis	**:**	50 + VITA
Name of University	**:**	Punjab Agricultural University, Ludhiana

ABSTRACT

A study was carried out to develop extruded snacks from broken rice (70 parts) and mung bean (30 parts) using twin screw intermeshing extruder. Response surface methodology (RSM) was used to study the effects of feed moisture content, screw speed and barrel temperature on response variables. Central Composite Rotatable Design (CCRD) with moisture (14-18%), screw speed (400-550 rpm) and die temperature (130-170 °C) as independent variables produced 20 different combinations that were used to investigate the effect of these variables on specific mechanical energy (SME), bulk density (BD), water absorption index (WAI), water solubility index (WSI), and hardness. The response contour plots were plotted as a function of two variables to show the effect of process variables on the physical and functional properties of the extruded snacks. Significant regression models were established with the coefficient of correlation (R^2) greater than 0.95. An optimization of process variables was attempted for maximum desirability. Increasing feed moisture caused increase in density and hardness whereas lowers SME, WAI and WSI. Increasing screw speed resulted in increase in SME and WSI and decrease in WAI of the extrudates. Higher barrel temperature reduced SME, density and hardness but increased the WSI of the extrudates. Optimized conditions for preparation of snacks were 14% moisture, 549 rpm screw speed, 148° C. the moisture, protein, fat, fiber, ash and carbohydrates content of snacks were 5.9, 12.7, 0.6, 2.5, 2.9 and 75.1 per cent respectively.

Keywords: Extruded snacks, response surface methodology, optimization, specific mechanical energy, bulk density, water absorption index, water solubility index, hardness, nutritional and organoleptic qualities

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Signature of Major Advisor Signature of the Student

ਖੋਜ ਗ੍ਰੰਥ ਦਾ ਸਿਰਲੇਖ	:	ਟੁਕੜਾ ਚਾਵਲ ਅਤੇ ਮੂੰਗੀ ਤੋਂ ਐਕਸਟਰੂਡਿਡ ਸਨੈਕਸ ਬਨਾਉਣਾ
ਵਿਦਿਆਰਥੀ ਦਾ ਨਾਮ ਅਤੇ ਪ੍ਰਵੇਸ਼ ਨੰ.	:	ਚੇਤਨ ਸ਼ਰਮਾ (L-2010-A-42-M)
ਪ੍ਰਮੁੱਖ ਵਿਸ਼ਾ	:	ਫੂਡ ਟੈਕਨਾਲੋਜੀ
ਸਹਿਯੋਗੀ ਵਿਸ਼ਾ	:	ਬਾਇਓ-ਕੈਮਿਸਟ੍ਰੀ
ਪ੍ਰਮੁੱਖ ਸਲਾਹਕਾਰ ਦਾ ਨਾਮ ਅਤੇ ਅਹੁਦਾ	:	ਡਾ. ਬਲਜੀਤ ਸਿੰਘ ਬੇਕਿੰਗ ਟੈਕਨੋਲੋਜਿਸਟ
ਡਿਗਰੀ	:	ਐਮ.ਐਸ.ਸੀ.
ਡਿਗਰੀ ਨਾਲ ਸਨਮਾਨਿਤ ਕਰਨ ਦਾ ਸਾਲ	:	2012
ਖੋਜ ਗ੍ਰੰਥ ਵਿੱਚ ਕੁੱਲ ਪੰਨੇ	:	50 + ਵੀਟਾ
ਯੂਨੀਵਰਸਿਟੀ ਦਾ ਨਾਮ	:	ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ

ਨਿਚੋੜ

ਮੌਜੂਦ ਅਧਿਐਨ ਵਿੱਚ ਟੁਕੜਾ ਚਾਵਲ ਅਤੇ ਮੂੰਗੀ ਦੀ ਵਰਤੋਂ ਨਾਲ ਐਕਸਟਰੂਡਿਡ ਸਨੈਕਸ ਬਨਾਉਣ ਲਈ ਟਵਿਨ ਸਕਰਿਉ ਐਕਸਟਰੂਡਰ ਦੀ ਵਰਤੋਂ ਰਿਸਪੋਂਸ ਸਰਫਸ ਮੈਥੋਡੋਲੋਜੀ (RSM) ਦੀ ਵਰਤੋਂ ਨਾਲ ਫੀਡ ਨਮੀ, ਸਕਰਿਉ ਦੀ ਰਫਤਾਰ ਅਤੇ ਤਾਪਮਾਨ ਦੇ ਪ੍ਰਭਾਵਾਂ ਦਾ ਲਗਾਤਾਰ ਗਤੀਸ਼ੀਲ ਨਿਰੰਤਰਾਂ ਉੱਤੇ ਵਿਸ਼ਲੇਸ਼ਣ ਕੀਤਾ ਗਿਆ। ਸੈਂਟਰਲ ਕੰਪੋਜ਼ਿਟ ਰੋਟੇਟੇਬਲ ਡਿਜ਼ਾਇਨ (CCRD) ਅਤੇ ਫੀਡ ਨਮੀ 14-18%, ਸਕਰੀਉ (400-500 RPM) ਦੀ ਰਫਤਾਰ ਅਤੇ ਤਾਪਮਾਨ (130-170 ਡਿਗਰੀ ਸੈਲਸੀਅਸ) ਦੀ ਵਰਤੋਂ ਨਾਲ ਅਜ਼ਾਦ ਵੈਰੀਅਬਲ ਦੇ ਤੌਰ ਤੇ 20 ਜੋੜ ਦੀ ਵਰਤੋਂ ਕਰਕੇ ਉਹਨਾਂ ਦੇ ਪ੍ਰਭਾਵਾਂ ਦਾ ਵਿਸ਼ੇਸ਼ ਯਾਂਤ੍ਰਿਕ ਊਰਜਾ (SME), ਘਣਤਕ ਥੋਕ, ਪਾਣੀ ਅਵਸ਼ੇਸ਼ਨ ਸੂਚਕਾਂਕ (WAI), ਪਾਣੀ ਵਿਲੇਇਤਾ ਸੂਚਕਾਂਕ (WSI) ਅਤੇ ਕਠੋਰਤਾ ਉਪਰ ਵਿਸ਼ਲੇਸ਼ਣ ਕੀਤਾ ਗਿਆ। ਭੌਤਿਕ ਅਤੇ ਕਾਰਜਕਾਰੀ ਗੁਣਾਂ ਨੂੰ ਦਿਖਾਉਣ ਲਈ ਪ੍ਰਤਾਵਾ ਰੂਪ ਰੇਖਾ ਸਕੀਮ (ਰਿਸਪੋਂਸ ਕਰੂਵਰ ਪਲਾਟਸ) ਦੀ ਵਰਤੋਂ ਕੀਤੀ। ਮਹੱਤਵਪੂਰਨ ਪ੍ਰਤੀਗਮ ਮਾਡਲ ਸਹਿਸੰਬੰਧ ਗੁਣਾਂਕ (R^2) 0.95 ਤੋਂ ਵਧੇਰੇ ਹਨ। ਪ੍ਰਕਿਰਿਆ ਚਰ ਦੇ ਅਨੁਕੂਲਨ ਅਧੀਕਤਮ ਵਾਂਛਨੀਇਤਾ ਲਈ ਕੋਸ਼ਿਸ਼ ਕੀਤੀ ਗਈ ਸੀ। ਫੀਡ ਨਮੀ ਵਾਧੇ ਨਾਲ ਵੱਧ density ਤੇ ਕਠੋਰਤਾ ਅਤੇ SME, WAI ਅਤੇ WSI ਦਾ ਘਾਟਾ ਹੋਇਆ। ਸਕਰਿਊ ਦੀ ਰਫਤਾਰ ਵਧਾਉਣ ਨਾਲ SME ਅਤੇ WSI ਦਾ ਵਾਧਾ ਅਤੇ WAI ਦਾ ਘਾਟਾ ਹੋਇਆ। ਉੱਚ ਬੈਰਲ ਤਾਪਮਾਨ ਨਾਲ SME, density ਅਤੇ ਕਠੋਰਤਾ ਦਾ ਘਾਟਾ ਜਦੋਂਕਿ WSI ਦਾ ਵਾਧਾ ਹੋਇਆ। ਸਨੈਕਸ ਦੀ ਤਿਆਰੀ ਲਈ ਵਾਂਛਨੀਇਤਾ ਹਲਾਤ - ਫੀਡ ਨਮੀ 14%, 549 RPM ਸਕਰਿਊ ਰਫਤਾਰ ਅਤੇ 148 ਡਿਗਰੀ ਸੈਲਸੀਅਸ ਤਾਪਮਾਨ ਸਨ। ਸਨੈਕਸ ਵਿੱਚ ਨਮੀ 5.9, ਪ੍ਰੋਟੀਨ 12.7, ਚਰਬੀ 0.6, ਕੱਚੇ ਫਾਇਬਰ 2.5, ਭਸਮ 2.9 ਅਤੇ ਕਾਰਬੋਹਾਈਡ੍ਰੇਟ 75 ਫੀਸਦੀ ਮਾਤਰਾ ਵਿੱਚ ਸਨ।

ਸ਼ਬਦ ਕੁੰਜੀ: ਐਸਕਟਰੂਜ਼ਨ, ਰਿਸਪੋਂਸ ਸਰਫਸ ਮੈਥੋਡੋਲੋਜੀ, ਵਾਂਛਨੀਇਤਾ, ਵਿਸ਼ੇਸ਼ ਯਾਂਤ੍ਰਿਕ ਊਰਜਾ, ਘਣਤਕ ਥੋਕ, ਪਾਣੀ ਅਵਸ਼ੇਸ਼ਨ ਸੂਚਕਾਂਕ, ਪਾਣੀ ਵਿਲੇਇਤਾ ਸੂਚਕਾਂਕ, ਕਠੋਰਤਾ, ਪੌਸ਼ਟਿਕ ਅਤੇ ਔਰਗੈਨੋਲੇਪਟਿਕ ਗੁਣਵਤਾ

ਪ੍ਰਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ	ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ

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CHAPTER – I

INTRODUCTION

Snacks food, which acts as a hunger quencher, is something away from main meal like breakfast either lunch or dinner. These are mainly consumed between meals either for enjoyment of its taste or brief supply of energy. They are convenient because they are quick and easy to eat. The snack foods industry is a vibrant sector and future for the industry looks promising and bright. Global snack foods market is forecast to reach US $ 334 billion and 48.519 thousand tons in volume terms, by the year 2015. The Indian snacks market is worth around US$ 3 billion and has an annual growth rate of 15-20 per cent (MOFPI, India, 2005). In most countries people from all income groups consume snack food products. Snack foods add variety to the diet which partially explains their popularity. They may also play a cultural role on special occasions or when offered to visitors (Fellows and Hampton, 1992). Snack foods have become an integral part of the daily food intake of the majority of the world's population. Basically, they are prepared from natural ingredients or components according to predesigned plans to produce products with specified quality (Limsangouan *et al* 2010).

Rice (*Oryza sativa* L) is one of the leading food crops of the world, the staple food of over half of world's population. India produces nearly 95.98 million tonnes including kharif 80.69 and rabi 15.29 million tonnes during the year 2010-11. Broken rice is the by product of rice milling industry and rice flour prepared out of broken rice can be used as important ingredient for many ready - to - eat breakfast cereals and snacks. In the milling industry the broken rice percentage is considerably high in India as most of the millers still rely on obsolete equipment to mill paddy. In whole rice grains the content of broken rice is between 22-30 per cent. The miller incurs 45 to 50 per cent of loss due to broken rice (Rao S, 2008).

India is the largest producer of pulses in the world. It produced 14.5 MT of pulses out of which mung bean contributes 8 per cent of the total production (Mula and Saxena, 2010). During 2010-11, India produced 1.80 thousand tonnes of mung bean including kharif 1.53 and rabi 0.27 thousand tonnes. Mung bean [*Vigna radiata* (L.) Wilczek], subgenus *Ceratotrpis*, is an indigenous vegetable legume, rich in starch, protein, vitamins, and the starch contains 35-45 per cent amylase (Hoover *et al* 1997). Rich in easily digestible protein (24 per cent), mung bean adds much-needed diversity to the cereal-based diets of the poor (Thirumaran and Seralathan, 1988). Pulses provide energy, dietary fiber, protein, minerals and vitamins required for human health. Research studies suggest that consumption of pulses may have potential health benefits including reduced risk of cardiovascular disease, cancer, diabetes, osteoporosis, hypertension, gastrointestinal disorders, adrenal disease and reduction of LDL cholesterol (Hu, 2003; Jacobs and Gallaher, 2004; Philanto and Korhonen, 2003; Tharanathan and Mahadevamma, 2003). Cereals and legumes, in general, play an important role in human nutrition. Recent studies have shown that cereals and beans contain constituents that have health benefits for humans, such as antioxidants and anti-disease factors (Ragaee *et al* 2006). Mung bean, being high in protein and easily digestible, constitutes a balanced diet in combination with cereals.

Extrusion cooking technology is a high-temperature, short-time, versatile and modern food operation that converts agricultural commodities, usually in a granular or powdered form, into fully cooked, shelf-stable food products with enhanced textural attributes and flavour. Due to the processing flexibility offered by extrusion cooking technology, it has become a cornerstone of the food industry, primarily in the cereal, dairy, bakery, confectionery and pet food industries (Berrios *et al* 2010; Patil *et al* 2007). Extrusion cooking technology permits preparation of ready to eat nutritious foods of desirable taste, flavour, and texture. During extrusion the product undergoes glass-transition state, the starch gets gelatinized, the protein gets denatured and the antinutritional factors such as trypsin-inhibitors and haemaglutinins get degraded and microorganisms are destroyed, so overall digestibility and acceptability of product is enhanced (Malleshi, 1997). Extruded snacks available in the Indian market are generally made from cereal flours and having high carbohydrate and fat contents while lower protein content. Nowadays, consumer demand for natural and functional foods has been growing, so puffed snacks created with rice and mung bean flours may appeal to the consumer interested in healthy foods. Response surface methodology (RSM) is a statistical method used to describe the relationship between process variables and product quality characteristics (Giovanni, 1983). RSM has been effectively used in several extrusion studies to relate the product characteristics to extrusion variables (Chen *et al* 1991; Park *et al* 1993; Altan *et al* 2008; Pansawat *et al* 2008; Aylin *et al* 2008; Altan *et al* 2009).

Thus, this study has been undertaken to develop nutritious snacks from broken rice and mung bean combination with the following objectives;

Objectives

- To optimize the processing conditions for making extruded snacks utilizing broken rice and mung bean.
- To assess the physico-chemical and sensory quality of the extruded snacks during storage.

CHAPTER – II

REVIEW OF LITERATURE

An attempt has been made to review the research available to perceive the work done on processing and nutritional aspect of snacks made from cereal and legume combinations.

2.1 Broken-rice concept

2.2 Cereal-Pulses concept

2.3 Effect of processing conditions on the properties of the extruded snacks

2.4 Nutritional and Health aspects of cereal and cereal products

2.1 Broken-rice concept

Boonyasirikool and Charunuch (2000) studied the development of corn grit-broken rice based snack food by extrusion cooking. The corn grit-broken rice snacks were examined for physical properties and then coated with chicken flavour prior to subject to sensory evaluation. Extruded samples produced from 50 per cent of broken rice substitution (CR′5) was detected to decrease expansion ratio value (3.70) and increase bulk density (76.60 g/L) and compression force (96.5 N) compared to those samples composed of 93 per cent corn grit, 1 per cent $CaCO_3$, 2 per cent soybean oil, 3 per cent sugar and 1 per cent vitamins and minerals mixtures.

Ding *et al* (2005) studied the effect of extrusion conditions, including feed rate (20–32 per cent), feed moisture content (14–22 per cent), screw speed (180–320 rpm), and barrel temperature (100–140 °C) on the physico-chemical properties (density, expansion, water absorption index—WAI), and water solubility index (WSI) and sensory characteristics (hardness and crispness) of an expanded rice snacks.

Garg and Singh (2007) conducted work on the development of protein enriched snacks using starch based raw materials. Rice brokens are the by product of rice milling industry and rice flour prepared out of rice brokens can be used as important ingredient for many ready-to-eat breakfast cereals and snacks. In this study the effect of processing parameters of feed i.e. moisture content of feed (12,15,18,21 and 24 per cent), blend ratio i.e. soy flour-rice blend (10:90, 14:86, 18:82, 22:78 and 26:74), operational parameters of extruder i.e. barrel temperature (100,110,120,130 and140°C), die head temperature (160, 170, 180, 190 and 200°C) and screw speed (100, 110, 120, 130 and 140 rpm) were optimized for physical properties.

Hou *et al* (2010) studied the characterization and preparation of broken rice proteins modified by proteases. Broken rice is an underutilized by-product of milling. Proteins prepared from broken rice by treatments with alkaline protease and papain has been characterized with regard to nutritional and functional properties. The protein content and the protein recovery were 56.45 and 75.45 per cent for alkaline protease treatment, and 65.45

and 46.32 per cent for papain treatment, respectively. Protease treatment increased the lysine and valine content, leading to a more balanced amino acid profile. Broken rice proteins had high emulsifying capacity, 58.3–71.6 per cent at neutral pH, and adequate water holding capacity, ranging from 1.96 to 2.93 g/g of proteins. At pH=7.0, the broken rice protein had the highest water holding capacity and the best interfacial activities (emulsifying capacity, emulsifying stability, foaming capacity and foaming stability), which may be the result of the higher solubility at pH=7.0. The proteins prepared by the papain treatment had higher water holding capacity ($p>0.05$), emulsifying capacity ($p<0.05$) and foaming capacity ($p>0.05$) than alkaline protease treatment at the same pH or mass fraction. To test the fortification of food products with broken rice proteins, pork sausages containing the proteins were prepared. Higher yield of the sausages was obtained with the increased content of broken rice proteins, in the range of 2.0–9.0 per cent. The results indicate that broken rice proteins have potential to be used as the protein fortification ingredient for food products.

Balasubramanian *et al* (2011) examined the rheological and nutritional quality of ready-to-eat rice (*Oryza sativa*) -legume viz. black gram (*Vigna mungo*), green gram (*Vigna radiata*), lentil (*Lens culinaris*) and peas (*Pisum sativum*) based extrudates using low cost collet extruder. Extrudates were prepared keeping constant feed rate (25 kg/h) and moisture content (14 per cent wb) at 0, 5, 10 and 15 per cent legume incorporation levels. Rheological properties of porridge made of extrudate flour were evaluated using Rapid Visco Analyser (RVA).

Junior *et al* (2011) conducted a study in which physical, sensorial and nutritional characteristics of extruded snacks, obtained from different formulations with flour of broken rice (BRF) and broken bean (BBF) were analysed aiming at extending the use of these by products in human feeding. For snacks formulation, completely randomized design (CRD), with five treatments (0 per cent BRF/ 100 per cent BBF; 25 per cent BRF/ 75 per cent BBF; 50 per cent BRF/ 50 per cent BBF; 75 per cent BRF/ 25 per cent BBF and 100 per cent BRF/ 0 per cent BBF) and three repetitions, was used.

Limburger *et al* (2011) employed broken rice starch as fat substitute in sausages. About 14 per cent of broken rice is generated during processing. Nevertheless, this by-product contains high levels of starch; being therefore, great raw material for fat substitution. This study evaluated the applicability of chemically and physically modified broken rice starch as fat substitute in sausages. Extruded and phosphorylated broken rice was used in low-fat sausage formulation. All low-fat sausages presented about 55 per cent reduction in the fat content and around 28 per cent reduction in the total caloric value. Fat replacement with phosphorylated and extruded broken rice starch increased the texture acceptability of low-fat sausages, when compared to low-fat sausages with no modified broken rice. Results suggest that modified broken rice can be used as fat substitute in sausage formulations, yielding lower caloric value products with acceptable sensory characteristics.

Liu *et al* (2011) examined the preparation, physicochemical and texture properties of texturized rice produce by improved extrusion cooking technology. Using broken rice and rice bran as raw material, texturized rice (TR) was prepared by Improved Extrusion Cooking Technology (IECT) in which gelatinization is formed by means of low temperature and high pressure. The effect of rice bran addition (0 per cent and 4 per cent) and IECT conditions, including feed moisture content (26.6-33.4 per cent), screw speed (20.1-32.6 rpm) and shearing compression metering zone temperature (SCMT, 69.8-120.2 °C) on the physicochemical, texture and nutritional characteristics of TR, were investigated by response surface methodology using Central Composite Design. When the bran addition was 4 per cent, feed moisture content was 30 per cent, screw speed was 26.6 rpm, SCMT was 95 °C, prepared TR contained 16.61 ± 0.02 per cent of total dietary fibre, 9.40 ± 0.04 per cent of protein, 3.68 ± 0.03 per cent of fat, 2.42 ± 0.02 mg/g of thiamin, 0.52 ± 0.01 mg/g of riboflavin and 16.07 ± 0.12 mg/100 g of g-oryzanol (dry matter content).

2.2 Cereal - Pulses concept

Bhattacharya (1997) used rice and green gram (*Vigna radiata L.*) blend (l: l, dry basis) to extrude using a co-rotating twin-screw extruder with a barrel diameter of 31 mm. The effects of barrel temperature (100 – 175 °C) and screw speed (100-400 rpm) on the extrusion system parameters (torque and specific mechanical energy) and extrudate characteristics (expansion ratio, density and maximum shear stress) were studied.

Thakur and Saxena (2000) analyse the effect of corn flour, green gram flour, xanthan, guar gum, arabic gum and carboxymethyl cellulose (CMC) on the sensory and objective (expansion ratio) attributes of an extruded snack food using Response surface Methodology (RSM). A rotatable central-composite design was used to develop models for the sensory and objective responses. Responses were most affected by changes in corn flour, green gram flour and guar gum levels and to a lesser extent by xanthan, gum arabic and CMC levels.

Jha and Prasad (2003) developed a ready-to-eat extruded food using a single screw laboratory extruder. Blends of rice and mung flours (70:30) were used as the ingredients for extrusion. The effects of die temperature, initial feed moisture content and screw speed on properties like expansion ratio, density and hardness of extruded products were studied. Increase in die temperature, feed moisture content and screw speed resulted in an increase in expansion ratio. Density and hardness of extruded products decreased with increase in die temperature. Sensory evaluation of the extruded products was conducted. Product extruded at

170 °C die temperature, 12.6 per cent (w.b.) feed moisture content and 170 rpm screw speed was found to be the most acceptable quality. The effects of salt (0-3 per cent) and sugar (0-8 per cent) contents on the extrusion of rice-mung blend were also studied. Increasing salt and sugar contents decreased the expansion ratio and increased density and hardness of extruded products. Extrusion with sugar resulted in change of colour of extruded products. Colour of the extruded products became brown with 6 per cent sugar. Based on organoleptic evaluation, extrusion with 6 per cent sugar and 2 per cent salt produced the most acceptable quality products.

Chakraborty and Banerjee (2009) used response surface methodology to study the effect of feed moisture and metering zone temperature on the physical properties of green gram extrudate. Temperature and moisture had significant effect on expansion ratio, which decreased with the increasing moisture content. Feed moisture and die head temperature had negative effect on water holding capacity. SME for extrusion and pressure developed at die head increased with the increasing proportion of green gram in rice-green gram blend. With increase in barrel screw speed, viscosity of rice-green gram dough decreased resulting in lesser power consumption and developed pressure at die head.

Pawar *et al* (2009) prepared ready-to-eat extruded snacks from a blend of rice, corn grits and legume malt in the proportions of 8:1:1 and 7:2:1 by using single screw dry extruder. The extruded snacks were evaluated for quality attributes such as chemical composition, physical properties and sensory qualities. Snacks contained 11-12 per cent protein, 0.8-1 per cent fat, 3.0-3.2 per cent ash, 1.25-1.40 g/cm^3 density and 1.72-1.77 expansion ratio. The product was fully expanded and well cooked and uniform in size and shape. The data on sensory quality evaluation showed better quality attributes of the extruded snacks with legume malt than without legume malt. The extruded snacks with green gram malt at a ratio of 7:2:1 was better than that with moth beans malt at the same ratio.

Lazou *et al* (2010) investigated the functional properties of corn and corn–lentil extrudates as a result of extrusion conditions, including feed rate (2.5–6.8 kg/h), feed moisture (13–19 per cent wet basis) and extrusion temperature (170–230 °C). Lentil was used in mixtures with corn flour at a ratio of 10–50 per cent (legume/corn). The water absorption index of extrudates increased with extrusion temperature and feed moisture content and decreased with feed rate and lentil/corn ratio. The water solubility index of extrudates increased with temperature, but decreased with feed moisture content and feed rate. The oil absorption index of extrudates increased with extrusion temperature and decreased with feed rate, feed moisture content and lentil / corn ratio.

Cavada *et al* (2011) studied the effects of the addition of wild legumes (Lathyrus) on the physical and nutritional properties of extruded products based on whole corn and brown rice. Addition of legumes produces a decrease of expansion and an increase in solubility in both rice-containing and corn-containing samples. With only 15 per cent of legume replacement, a significant increase in protein content and quality, fibre, and mineral content was obtained. Protein digestibility was in the range of 82–84 per cent and mineral availability in the 6.4–12.1 per cent range for iron and 10–18.6 per cent for zinc.

Dandamrongrak *et al* (2011) conducted experiments to study the effect of initial conditions on the expansion ratio of two grains in a laboratory scale, single speed, and single screw extruder at Naresuan University, Thailand. Jasmine rice and Mung bean were used as the material. Three different initial moisture contents were adjusted for the grains and classified them into three groups according to particle sizes. Mesh sizes used are 12 and 14. 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.

2.3 Effect of processing conditions on the properties of extruded snacks

El-hady and Habiba (2003) investigated the effects of soaking (in water for 16 h) and extrusion conditions including barrel temperature (1401 °C and 1801 °C) and feed moisture (18 per cent and 22 per cent) on anti-nutrients, total and phytate phosphorus and protein digestibility of whole meal of four kinds of legumes (peas, chickpeas, faba and kidney beans).

Baik *et al* (2004) studied the effect of extruder screw speed on characteristics of extrudates. Increased screw speed resulted in large expansion index and higher WAI of extrudates. With increased feed rate from 89 to 96 g/min, expansion index of extrudates decreased from 3.20 to 2.78 in regular and 3.23 to 2.72 in waxy barley, the harder extrudates were produced.

Guha *et al* (2006) analyzed the effect of amylose content (5.0–28.6 per cent) of rice and barrel temperature (80 - 120 °C) on extrusion system parameters torque and net specific mechanical energy and extrudate characteristics extrudate density (ED), water solubility index, expansion ratio (ER) and Warner–Bratzler shear stress using a twin-screw extruder.

Qing *et al* (2006) reported that increased screw speed (189 - 320 rpm) caused a slight reduction of density and hardness of wheat extrudates.

Chaiyakul *et al* (2009) studied the effect of extrusion conditions on physical and chemical properties of high protein glutinous rice-based snack. Effects of protein concentration, feed moisture content and barrel temperature on the chemical and physical properties of the extruded product were investigated.

Singh *et al* (2007) conducted a study to investigate the effect of feed moisture (18 - 24 per cent), extrusion temperature (130 - 170 °C) and level of pea grits (0 - 30 per cent) on the extrusion behaviour and extrudate properties of rice grits. The extruders die pressure, specific energy consumption, expansion- ratio, density, water absorption index, and water solubility index were studied. Second-order polynomials were compared for extruder parameters and product characteristics as a function of feed moisture, extrusion temperature and pea grit level.

Yagci and Gogus (2009) used response surface methodoly to investigate the effects of extrusion conditions including the moisture content of blend (12-18 per cent), barrel temperature (150-175 °C), screw speed (200-280 rpm) and change in feed composition on the product characteristics of the snack food developed from rice grit in combination with durum clear flour, partially defatted hazelnut flour and fruit wastes. The blend was made up of rice grits (67 per cent), durum clear flour (8-20 per cent), PDHF (5-15 per cent), and fruit waste (3-7 per cent).

Hoan *et al* (2008) used Response Surface Methodology with a 3×3 factorial plan to investigate the effects of starch content (60-70 g/100 g dry matter), lipid content (6.2-10.2 g/100 g dry matter) and moisture content (10-16g/100 g wet matter) on extrusion behaviour of rice based blends, on the physicochemical properties of extrudates, and the apparent viscosity of resulting gruels.

Duarte *et al* (2009) studied the effects of soybean hull, moisture content and temperature on the production of expanded maize extrudates. Mixtures of maize grits and soybean hull were extruded in a single screw extruder to produce directly expanded extrudates, and the effects of three independent variables, screw speed (100-200 rpm), temperature (100-200 °C) and soybean hull content (0- 40 per cent) were investigated using a central composite rotatable design and response surface methodology. The response variables used in this study were: specific mechanical energy (SME), sectional expansion index (SEI) and the paste viscosity readings (cold viscosity, peak value, breakdown and setback). They reported that interaction between soybean hull and temperature increased breakdown and reduced setback, while specific mechanical energy and sectional expansion index decreased as the addition of soybean hull and the temperature were increased.

Cheng Yu *et al* (2011) evaluated the effects of extrusion processing conditions on the physico-chemical properties of Mung bean extrudates. The domestic Tainan No.5 mung bean was used as material in this research, to produce mung bean extrudates by single screw extruder at different screw speed (20, 30, 40 rpm) and barrel temperature (90 °C, 100 °C), then the physico-chemical properties (moisture content, color, water activity, thermal property and resistant starch content) were also analyzed. The results showed that no significant difference was found in moisture content and water activity after extrusion processing and storage. As to the color, the L value decreased with the increasing of storage time. In addition, the degree of gelatinization was not affected by screw speed and barrel temperature. The resistant starch content increased with the increasing of storage time at barrel temperature 90 °C, but at barrel temperature 100 °C was not.

Yu et al (2012) evaluated the effects of feed moisture, screw speed, and barrel temperature on physical properties of extruded corn flour and soy protein isolate (SPI) blends in a co-rotating twin-screw extruder using a response surface methodology. Corn flour and SPI were mixed with a ratio of 4:1. The screw speed was set at five levels between 60 and 140 rpm, barrel temperature between 140 °C and 180 °C, and feed moisture between 18 per cent and 38 per cent. All physical properties of the extruded material evaluated—included expansion ratio, density, breaking strength, water solubility index, rehydration ratio, and color—were significantly ($p<0.05$) affected by the three process variables. Feed moisture was the most significant variable with quadratic effects on most of the physical properties. Response surface regression models were established to correlate the physical properties of the extruded product to the process variables. Understanding the effect of these variables on the product physical properties was deemed useful for the development of protein-rich extruded products.

2.4 Nutritional and health aspects of Cereal, Pulses and their and their products

Agugo and Onimawo (2009) conducted the study to evaluate the nutritional value of mung beans (*Vigna radiata*) by heat application. Treatments consist of diets formulated with raw mung beans (RMD), toasted mung beans (TMD), and boiled mung beans (BMD). Nutritional value of mung beans was by chemical analysis as well as by rat assay. Mung beans contain 22.90 per cent protein which was reduced on boiling and toasting. It had 130 mg calcium, 2.7 mg zinc and 4.22 mg iron which were reduced by heat. The protein Efficiency Ratio (PER) of mung beans was reduced by heat from 1.72 in raw to 1.42 and 1.38 in boiled and toasted respectively. On the contrary boiling and toasting resulted in some improvement in the Net Protein Utilization (NPU), True Digestibility (TD) and Biological Value (BV). Generally the nutritional value of mung beans was improved on boiling than in toasting.

Limsangouan *et al* (2009) demonstrated the effect of extrusion processing on the functional properties of extruded snack foods developed from cereal and legumes, and the by-products from herbs and vegetables. The functional properties considered were antioxidant capacity, total phenolic compounds and resistant starch content. The results showed that Japanese green tea had the highest antioxidant capacity and phenolic content (68.31mmol Trolox/g and 337.58 mg GAE/g, respectively) and egoma leaves had the second highest (8.35 mmol Trolox/g and 60.60 mg GAE/g, respectively). Red kidney beans had the highest resistant starch content (33.78 per cent w/w) and corn grits had the second highest content (13.67 per cent w/w). The extrusion process slightly decreased the antioxidant capacity (3.61-13.07 per cent) and phenolic content (4.54-29.75 per cent), but substantially decreased the resistant starch content (89.17-96.33 per cent) for all extruded products. The extrusion process was suitable to produce functional snack foods, while retaining their antioxidant capacity.

Boye *et al* (2010) stated that pulses (pea, chickpea, lentil and bean) are an important source of food proteins. They contain high amounts of lysine, leucine, aspartic acid, glutamic acid and arginine and provide well balanced essential amino acid profiles when consumed with cereals and other foods rich in sulphur-containing amino acids and tryptophan. The protein content of most pulse legumes fall within the range of 17–30 per cent (d.w.b.). Apart from their nutritional properties, pulse proteins also possess functional properties that play an important role in food formulation and processing. Examples of such functional properties include solubility, water and fat binding capacity and foaming. Various research studies indicate that some functional properties of pulse proteins may be comparable to those of other frequently used proteins such as soy and whey. The functional properties of pulse proteins have been exploited in the preparation and development of products such as bakery products, soups, extruded products and ready to eat snacks. The growing body of research on the health benefits associated with the consumption of pulses has increased interest in developing innovative technologies to expand the use of pulses in food products. At the same time, there are growing global food security challenges and protein malnutrition continues to be a problem in many countries around the world. Pulses, especially when blended with cereal proteins, may offer a promising alternative source for nutritional and functional proteins.

Pal *et al* (2010) stated that mung bean is a widely consumed legume of India as well as of Asia. In India, two varieties of this bean, scented and non-scented, are available. The scented variety produces a beautiful aroma when fried, boiled or cooked. This study was carried out for comparison of the physicochemical and biochemical characteristics of these two varieties. The inter-varietals variation in moisture, sugar, lipid, phospholipids, protein and lipid composition as well as fatty acid composition of the triglyceride oil was investigated in this study. Characterization of sterols was also made by GC. Detailed study of amino acid composition of the two variant was also reported. The study of ultra-structure of the scented and non-scented mung bean was done by Scanning Electron Microscopy.

CHAPTER – III

MATERIALS AND METHODS

3.1 Materials

3.1.1 Raw materials used in investigation

Rice-brokens (PR-116) were procured from local rice mills and Mung bean (SML-668) was procured from Directorate of Seeds, PAU, Ludhiana.

3.1.2 Milling

Rice-brokens and mung bean were subsequently ground in Lab scale super mill 3303 (Perten instrument AB, Sweden) to pass through 200 µm sieves.

3.1.3. Spice mix

Spice mix used in final product preparation was mixture of sugar (4 per cent), salt (2 per cent), ginger powder (0.75 per cent), onion powder (1 per cent), cheese powder (1 per cent), garlic powder (0.75 per cent), chilli powder (0.25 per cent) and citric acid (0.25 per cent).

3.2 Methods

3.2.1 Physico-chemical composition of rice and mung bean flours

Physico-chemical characteristics of rice and mung bean flours were determined using standard methods (AACC, 2000).

3.2.1.1 Moisture content

Weighed samples (2 g) were dried in a hot air oven at 130 +/-1°C for 1 hr. and moisture content in percent was calculated from loss of weight.

3.2.1.2 Crude protein

Macro-kjeldhal method was used to determine nitrogen. Conversion factor of 5.95 and 6.25 was used for rice and mung bean crude protein estimation. 1g sample was digested in Kjeldhal flask with digestion mixture (copper sulphate and potassium sulphate in 1:9 ratio) and concentrated H_2SO_4 (20 ml) till light green colour appeared and finally cooled. Ammonia released by distillation of digested samples with saturated NaOH (80 ml) was captured in 0.1 N HCl and percent N was estimated. The protein content was calculated as per cent nitrogen × factor.

3.2.1.3 Crude fat

Fat analysis of samples was carried out using Soxtec 2045 (Foss instrument, Sweden). Extraction cups were dried in oven at 130 °C for 15 min and the weight of empty cups was noted. Weighed sample (3 g) was taken in thimble. Dried empty cups were cooled and 70 ml of petroleum ether was added. Switched on and preheated the instrument, When temperature was attained, the extraction cups were attached to the instrument and left them boiling for 30 minutes, followed by rinsing for 20 minutes and all recovery of the solvent was done for 10 minutes. The recovered ether was collected and the fat contained in extraction cups was estimated.

3.2.1.4 Ash

Weighed (5 g) sample was first incinerated on hot plate until there were no more fumes. It was kept in a muffle furnace at 550 °C for 5 hours, weighed and results were expressed in per cent (AACC 2000).

3.2.1.5 Crude fibre

Crude fibre of broken-rice and mung bean were estimated using Fibertec (Foss instrument, Sweden). Capsules (for holding the sample) were kept in hot air oven at 100 °C for 20 minutes for drying, cooled and weighed. One gram of the sample was weighed in the capsule (Defatting of samples was done if necessary). Capsules were fixed in the rotating stand and put it into the extraction cup, 250 - 275 ml of 1.25 per cent H_2SO_4 was added to the extraction cup and immersed the stand into the beaker. Acid extraction was done by boiling it for 30-40 minutes followed by its washing with hot water. Then alkali washing was done with 1.25 per cent NaOH for the same time duration followed by hot water washing. Finally, capsules were dried in oven for 2 hours at 130 °C and then placed at 550 °C for 5 hours, cooled and weighed for crude fibre estimation (AOAC 2000).

3.2.1.6 Carbohydrates

Per cent carbohydrate content was determined by subtracting other constituents. Carbohydrates = 100 - (Moisture + Protein + Fat + Ash + Fibre).

3.2.1.7 Pasting characteristics

A Rapid Visco Analyzer (RVA) model Starch Master (Newport Scientific, Warrie Wood, Australia) was used to determine the pasting properties of rice-brokens and mung bean flours using the following procedure:

RVA was switched on and allowed it to warm up for 30 minutes prior to the experiment. Weighed 3.0 g (14 per cent moisture basis) of flour in a canister followed by placing the paddle into the canister and vigorously jogged the blade through the sample up and down 10 times or until it mixes uniformly. Insert the canister into the pre-adjusted instrument in profile 1. Initiation of the measurement cycle by depressing the motor tower of the instrument was done. Canister was then removed on completion of test and discarded.

Profile 1.

Time	Type	Value
00:00:00	Temp.	50°C
00:00:00	Speed	960 rpm
00:00:10	Speed	160 rpm
00:01:00	Temp.	50°C
00:04:42	Temp.	95°C
00:07:12	Temp.	95°C
00:11:00	Temp.	50°C

Idle Temp. : 50+/-1°C

End of test: 13 min.

Time between readings: 4 seconds.

Noted the pasting temperature (°C), peak viscosity (cP), hold viscosity (cP), final viscosity (cP), breakdown (cP) and setback (cP) from the instrument.

3.2.1.8 Preliminary trials

Rice flour and mung bean were blended in the ratio of 100:0, 95:5, 90:10, 85:15, 80:20, 75:25, 70:30, 65:35, 60:40 and subjected to extrusion cooking at 15 per cent moisture, 500 rpm screw speed and 160 °C temperature. The samples were subjected to sensory evaluation. The extruded snacks were evaluated organoleptically and best combination was (70:30) that was further used for optimization. Extruded snacks were evaluated for sensory attributes (appearance, texture, flavour and overall acceptability) through a panel of six semi-trained judges using 9-point hedonic scale (Larmond 1970). The following Performa was used for sensory evaluation.

SENSORY EVALUATION PERFORMA

NAME OF THE PANELIST: DATE:

Sr. No.	Appearance	Texture	Flavour (Taste and Odour)	Overall Acceptability	Comment (If Any)

SCORING:

Liked extremely – 9	Liked slightly – 6	Disliked moderately – 3
Liked very much – 8	Neither liked nor disliked – 5	Disliked very much – 2
Liked moderately – 7	Disliked slightly – 4	Disliked extremely – 1

SIGNATURE OF PANELIST

3.3.1 Extrusion process

3.3.1.1 Experimental design and data analysis

Statistical package Design-Expert Version 8.01 (Statease Inc., Minneapolis, MN, USA) was used to design the experiment. The central composite design for the three independent variables was performed. The independent variables considered were Moisture (A), Screw speed (B) and Die temperature (C). The independent variables and variation levels are shown in Table 3.1.

Table 3.1: Process variables used in the central composite design for three independent variables

Process variables	Code	Variables level codes				
		-1.682	**-1**	**0**	**1**	**1.682**
Moisture (%)	A	12.64	14	16	18	19.36
Screw speed (rpm)	B	348.87	400	475	550	601.13
Temperature (°C)	C	116.36	130	150	170	183.64

The levels of each variable were established based on the results of earlier experiments and preliminary trials. The outline of experimental design with the actual level is presented in Table 3.2. Dependent variables were specific mechanical energy (SME), density (BD), water absorption index (WAI), water solubility index (WSI) and hardness. Response surface methodology was applied for experimental data, for generation of contour plots and for statistical analysis of experimental data. The results were analyzed by a multiple linear regression method which describes the effects of variables in the models derived. Experimental data were fitted to the selected models and regression coefficients were obtained. The analysis of variance (ANOVA) tables were generated for each of the response functions. The individual effect of each variable and also the effects of interaction term in coded levels of variables were determined.

Table 3.2: Response surface experimental design interms of coded levels and actual levels

Run no.	Coded levels			Actual levels		
	A	**B**	**C**	**Moisture (%)**	**Screw speed (rpm)**	**Temperature (°C)**
1.	-1	-1	-1	14	400	130
2.	-1	-1	1	14	400	170
3.	-1	1	-1	14	550	130

4.	-1	1	1	14	550	170
5.	1	-1	-1	18	400	170
6.	1	-1	1	18	400	170
7.	1	1	-1	18	550	130
8.	1	1	1	18	550	170
9.	-1.682	0	0	12.6	475	150
10.	+1.682	0	0	19.4	470	150
11.	0	-1.682	0	16	349	150
12.	0	+1.682	0	16	601	150
13.	0	0	-1.682	16	475	116.4
14.	0	0	+1.682	16	475	183.4
15.	0	0	0	16	475	150
16.	0	0	0	16	475	150
17.	0	0	0	16	475	150
18.	0	0	0	16	475	150
19.	0	0	0	16	475	150
20.	0	0	0	16	475	150

3.3.1.2 Extrusion cooking

Extrusion experiments were performed on a co-rotating intermeshing twin screw extruder (Clextral, Firminy, France) shown in Fig. 3.1. The barrel diameter and its length to diameter ratio (L/D) were 2.5 mm and 16:1, respectively. The extruder barrel is divided into four zones. Temperatures of the first, second and third zone was maintained at 40°, 70° and 100°C, respectively, throughout the experiments, while the temperature at the fourth zone was varied according to the experimental design. The die plate had one circular hole with 6 mm diameter. The extruder was powered by an 8.5 kW motor with speeds variable from 0 to 682 rpm. The screw configuration is shown in Fig. 3.2 and Table 3.3. The extruder was equipped with a torque indicator, which showed percent of torque in proportion to the current drawn by the drive motor. Raw materials were metered into the extruder with a single screw volumetric feeder (D S and M, Modena, Italy). The feed rate was varied for optimum fill according to screw speed. The moisture content of the feed was adjusted by injecting water (approximately 30 °C) into the extruder with a pump. A variable speed die face cutter with four bladed knives was used to cut the extrudates.

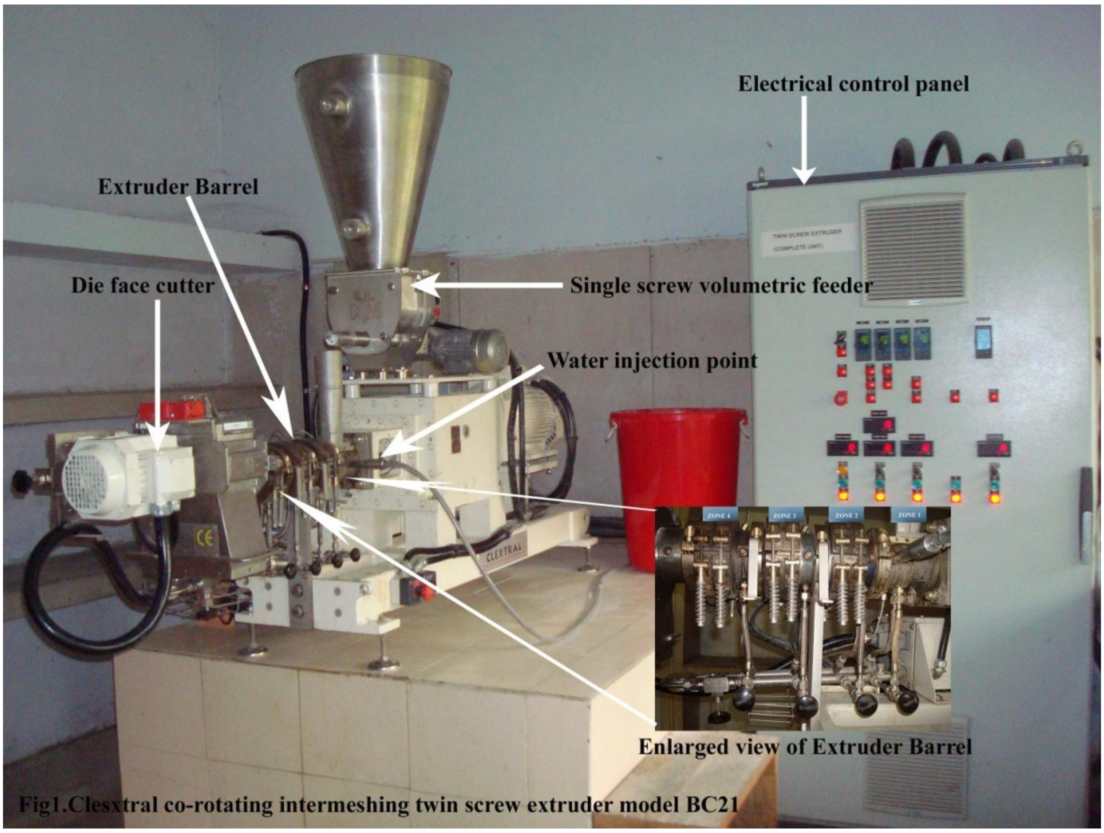


Fig. 3.1: Clextral co-rotating intermeshing twin screw extruder model BC21

Table 3.3: Screw configuration in different sections of the extruder (From hopper to die)

Screw section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Screw element	BAGUE	C2F	C2F	C2F	C2F	C2F	INO0	C1F	CF1C	C1F
Length (mm)	20	50	50	50	50	50	5	50	25	50
Pitch (mm)	-	50	33.33	25	25	16.66	-	16.66	12.5	12.5

Fig. 3.2: Screw profile

3.4.1 SME (Specific mechanical energy)

Specific mechanical energy (Wh/kg) was calculated from rated screw speed (682 rpm), motor power rating (8.5kW), actual screw speed, % motor torque, and mass flow rate (kg/h) using the following formula (Pansawat *et al* 2008).

$$\text{SME (Wh/kg)} = \frac{\text{Actual screw speed (rpm)}}{\text{Rated screw speed (rpm)}} \times \frac{\text{Per cent motor torque}}{100} \times \frac{\text{Motor power rating}}{\text{Mass flow rate (kg/h)}} \times 1000$$

3.4.2 Physical Properties of Extruded Snacks

3.4.2.1 Density

The density (g/cc) of extruded snacks was measured by using a 100 ml graduated cylinder by rapeseed displacement. The volume of 20 g randomized samples was measured for each test. The ratio of sample weight and the replaced volume in the cylinder was calculated as density (Pan *et al* 1998; Patil *et al* 2007).

$$\text{Density (g/ml)} = \frac{\text{Weight of extrudates}}{\text{Volume displaced by extrudates}}$$

3.4.2.2 Water absorption index (WAI)

Water absorption index of the snacks was determined by method outlined by Anderson *et al* (1969). The WAI measures the volume occupied by the granule or starch polymer after swelling in excess of water. The ground extrudates were suspended in distilled water at room temperature (34 °C) for 30 minutes, gently stirred during this period, and then centrifuged at 3000 × g for 15 minutes. The supernatant liquid was poured carefully into tared evaporating dish. The remaining gel was weighed and WAI was calculated as the grams of gel obtained per gram of solid.

$$\text{WAI (g/g)} = \frac{\text{Weight of sediment}}{\text{Weight of dry solids}}$$

3.4.2.3 Water solubility index (WSI)

WSI determines the amount of free polysaccharides or polysaccharides released from the granule on addition of excess water. The WSI was the weight of dry solids in the supernatant from the water absorption index test described above (Anderson et al 1969) expressed as a percentage of the original weight of the sample.

$$\text{WSI (per cent)} = \frac{\text{Weight of dissolved solid in supernatant}}{\text{Weight of dry solids}} \times 100$$

3.4.2.4 Texture analysis

Hardness

Textural quality of the snack samples was examined by using a TA-XT2i Texture Analyzer (Stable Microsystems, Surrey, UK). The compression probe (50 mm dia., aluminium cylinder) was applied to measure the compression force required for samples breakage which indicates hardness. Testing conditions were 1.0 mm/s pre-test speed, 2.0 mm/s test speed, 10.0 mm/s post test speed and 5 mm distance (Pardhi, 2011).

3.5 Optimization

Optimization can be defined as the processing conditions that give the optimum (maximum or minimum) value of a function of certain decided variables subject to constraints that are imposed. For optimization Design-Expert Version 8.01 (Statease Inc., Minneapolis, MN USA) was used. The software allows to set criteria for all dependent variables. By using the optimization parameter, the numerical values can be set for dependent variables as goal. Optimization may be the process maximizing a desired quality or minimizing an undesired one. The values of the processing variables that produce the desired optimum value are called optimum conditions. Product responses such as density, texture and hardness were the important major parameters determining the quality of extrudates. Therefore, optimum conditions for extrusion of rice and mung bean flours were determined to obtain the minimum density and hardness, maximum WAI and WSI, whereas SME was not considered for optimization being a process parameter.

3.5.1 Validation

Samples were extruded using optimized conditions. Predicted and actual values of product response were compared.

3.6 Storage Studies

Extruded snacks were packed (50 g) in HDPE (200 gauge) bags in triplicate. Samples were stored at room temperature (30 to 35 C) conditions for shelf life estimation over a period of 3 months and the product was evaluated for moisture content, free fatty acids, hardness, and overall acceptability, at an interval of one month, during the storage period.

3.6.1 Free Fatty Acids

Standard AOAC procedure was followed with slight modification. Weighed (5 g) sample was taken in flask. 50 ml benzene was added and it was kept for 30 min. for extraction of free fatty acids. Five ml extract was taken in flask, five ml benzene, ten ml alcohol and two drops of phenolphthalein solution were added and it was titrated against 0.02N KOH till light pink colour disappeared.

$$\text{FFA (per cent)} = \frac{282 \times 0.02\text{N KOH} \times \text{ml. of alkali used} \times \text{dilution factor}}{1000 \times \text{Weight of sample taken}}$$

3.6.2 Chemical properties of extruded snack

3.6.2.1 Moisture content (AACC 2000). (3.2.1.1)

3.6.2.2 Crude protein (AACC 2000). (3.2.1.2)

3.6.2.3 Crude fat (AACC 2000). (3.2.1.3)

3.6.2.4 Crude fibre (3.2.1.4)

3.6.2.5 Carbohydrates (3.2.1.5)

3.6.2.6 Ash (AACC 2000). (3.2.1.6)

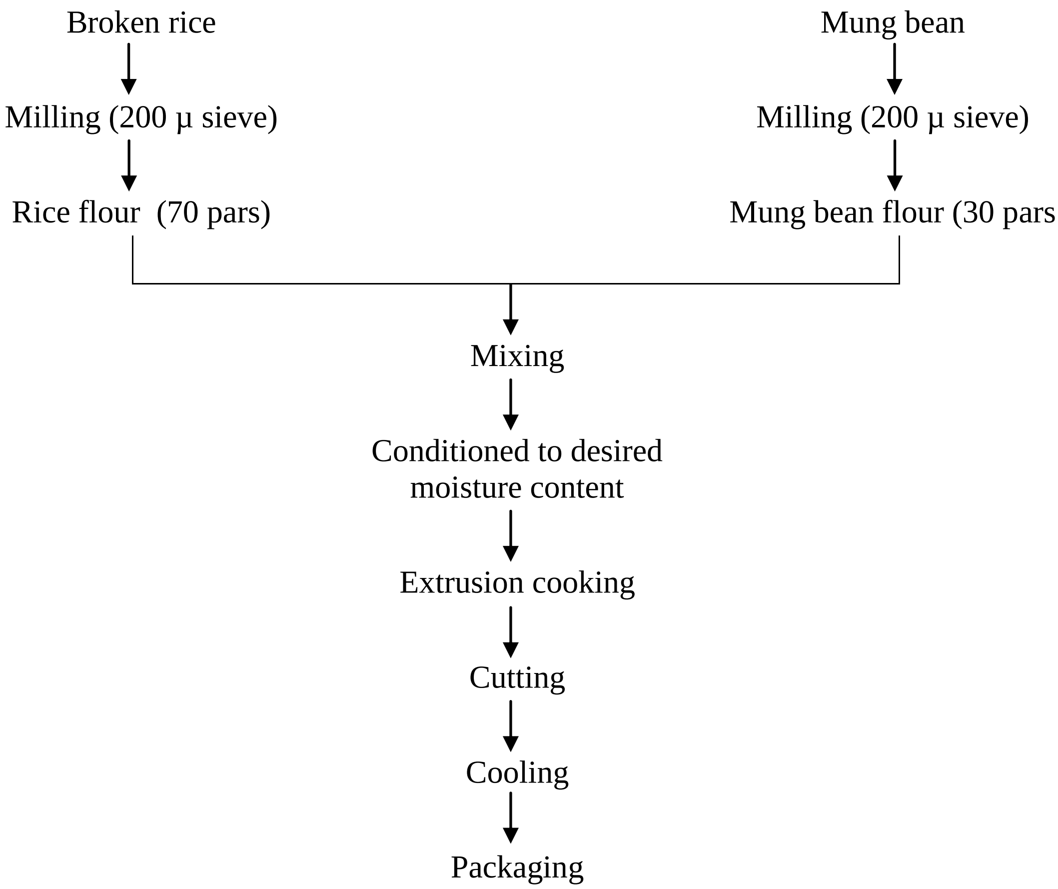
3.6.2.7 Minerals

0.5 gm of ground sample was taken for digestion. Di-acid mixture of nitric acid and perchloric acid in 4:1 proportion was added. It was kept for digestion in digester and then 0.5-1.0 ml aliquot of sample was taken from digester and dilutes to 100 ml with double distilled water. Subsequently it was subjected to analysis in the Atomic absorption spectrophotometer (AOAC 1990).

3.7 Cost of production

Cost of the final product was evaluated arithmetically on the basis of the cost of raw material, processing and packaging cost.

3.8 Flow diagram for preparation of extruded snacks



Flow diagram for preparation of extruded snacks

CHAPTER – IV

RESULTS AND DISCUSSION

The present study on "Development of Extruded Snacks Utilizing Broken Rice and Mung bean" was carried out in the Department of Food Science and Technology, PAU, Ludhiana. The results obtained during investigation are discussed here:

4.1 Properties of raw materials

4.1.1 Proximate analysis of raw materials

4.1.2 Pasting characteristics of raw grains flour

4.2 Extrusion processing: Extruded snacks

4.2.1 Preliminary trials

4.2.2 Experimental design

4.2.3 Specific mechanical energy

4.2.4 Density

4.2.5 Water Absorption Index

4.2.6 Water Solubility Index

4.2.7 Hardness

4.3 Optimization

4.4 Validation

4.5 Storage study of extruded snacks

4.6 Proximate composition of final extruded snacks`

4.7 Economics – cost of the extruded product

4.1 Properties of raw materials

4.1.1 Proximate analysis of raw materials

The data given in Table 4.1 depicts the chemical composition of broken rice and mung bean flours. Broken rice flour contains 11.10 per cent moisture, 7.12 per cent crude protein, 0.47 per cent fat, 1.57 per cent ash, 1.35 per cent crude fibre, 78.39 per cent carbohydrates as compared to mung bean flour that contains 9.74 per cent moisture, 22.62 per cent crude protein, 1.08 per cent fat, 3.80 per cent ash, 6.40 per cent crude fibre, 56.36 per cent carbohydrates. Habibullah *et al* (2007) analyzed different varieties of mung bean for their proximate composition using standard methods. The moisture, protein, fat, ash, fibre and carbohydrate contents of variety M1 were found to be 9.74 per cent, 23.7 per cent, 1.9 per cent, 3.9 per cent, 6.8 per cent and 54.9 per cent, respectively while in variety NM-92 different constituents were found to be 8.3 per cent, 20.8 per cent, 2.2 per cent, 3.0 per cent, 7.1 per cent and 58.9 per cent, respectively. The data revealed that M1 had relatively higher values of moisture, ash and protein while NM-92 was found to be a bit higher in fat, fibre and carbohydrate content. The food energy value of M1 (340 kcal/100g) and NM-92 (347 kcal/100g) was almost equal. Hussain *et al* (2011) reported moisture in the range of 9.0-9.40 percent in mung beans. Mung beans protein has been reported from 20.3 to 25 per cent by other workers (Calloway *et al* 1994 and Bhatty *et al* 2000) and 3.02 – 3.42 per cent ash was found by Hussain *et al* (2011).

Table 4.1: Proximate chemical composition of broken rice and mung bean flours (n=3)

Types of grains	Moisture (%)	Crude protein (%)	Fat (%)	Ash (%)	Crude Fibre (%)	Carbohydrates (%)
Broken Rice flour	11.10±0.58	7.12±0.04	0.47±0.20	1.57±0.09	1.35±0.04	78.39±0.95
Mung Bean flour	9.74±0.32	22.6±0.05	1.08±0.04	3.80±0.03	6.40±0.03	56.36±0.45

Mean ± SD

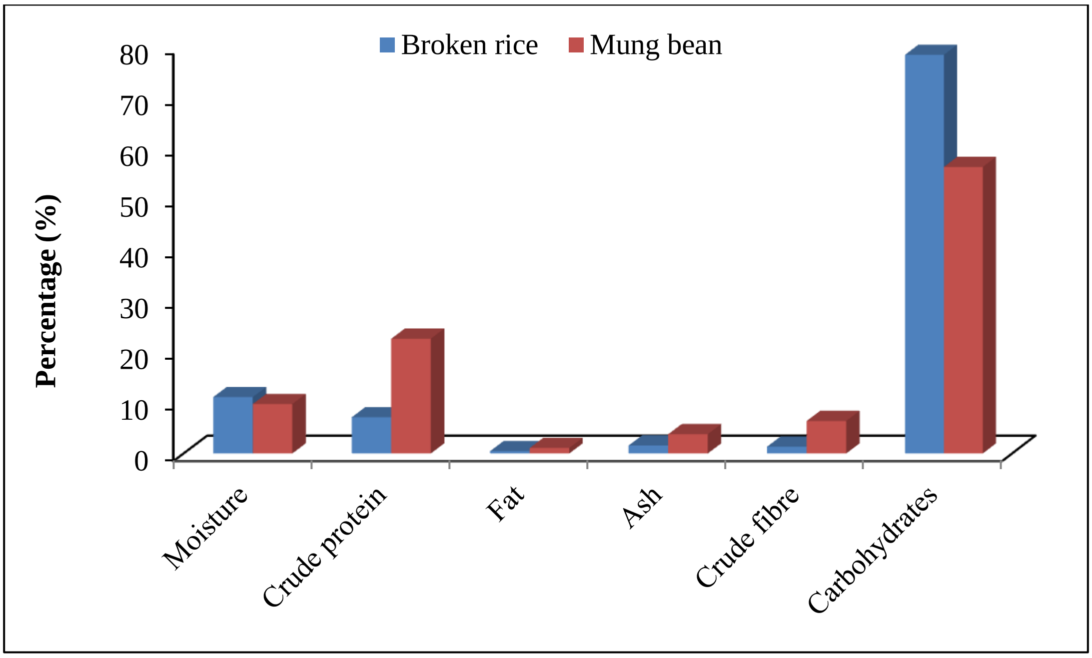


Fig. 4.1: Proximate composition of broken rice and mung bean flours

4.1 Pasting characteristics of broken rice flour and mung bean flour

Table 4.2: Pasting characteristics of broken rice and mung bean flours (n=3)

Types of grains	Pasting temperature (°C)	Peak viscosity (cp)	Hold viscosity (cp)	Final viscosity (cp)	Break down (cp)	Set back (cp)
Broken rice flour	94.5±0.25	1225±8.5	1209±9	3341±108.5	16.5±0.5	2132±99.5
Mung bean flour	80.31±0.03	1475±20.5	1410±17	3735±29.5	65.0±13.5	2325±12.5

Mean ± SD

The pasting properties of rice flour and mung bean flour evaluated by rapid visco analyzer are presented in Table 4.2. Pasting properties are dependent on the rigidity of starch granules, which in turn affect the granule swelling potential (Rani and Bhattacharya 1989) and the amount of amylose leaching out in the solution (Morris 1990). Significant differences were observed among different grains in their behaviour during heating and cooling in excess water during experiment. More starch granules with higher swelling capacity resulted in a higher peak viscosity. The pasting temperature, peak viscosity, hold viscosity, final viscosity, break down and setback for rice flour were 94.5, 1225.5, 1209, 3341.5, 16.5, and 2132.5 cP, respectively whereas for mung bean flour peak viscosity, hold viscosity, final viscosity, break down and set back were 1475, 1410, 3735, 65.0, and 2325 cP, respectively. Batey and Curtin (2000) reported that pasting properties depend upon flour composition and enzymatic activity. Additionally, differences in the protein content in these cereals could also affect pasting viscosities and properties. Chedid and Kokini (1992) reported that the presence of the proteins decreased the peak viscosity of starch and that the amylose-amylopectin ratio, the type of protein and temperature, coupled in with residence time and moisture content, appeared to affect the extent of viscosity change. The pasting temperature of mung bean starch was 78.13±0.04 °C. Consequently, because the mung bean starch paste increased the viscosity of the paste and decreased durability during heat treatment, it was assumed that the retrogradation of mung bean starch was faster than the other starches, as suggested by the pasting properties.

During the experiment, it was found that values of peak viscosity, hold viscosity and final viscosity were higher for rice than that of mung bean flour. Yadav *et al* (2006) reported that the gelling on the account of reassociation (retrogradation) of starch molecules occurs upon cooling and leads to increase solution viscosity again. Marti *et al* (2010) found that final viscosity of milled rice was found to be 3780 cP. Breakdown is a measure of the ease with which the swollen starch granules can be disintegrated. High values of breakdown were associated with high peak viscosity, which in turn could be related to degree of swelling of starch during heating. The lower peak viscosity indicates the decrease of swelling capacity of starch granules, leading to the higher shear stability (the decrease of breakdown value).

4.2 Extrusion processing: Extruded snacks

4.2.1 Preliminary trials

The Table 4.3 depicts the sensory evaluation data of extruded snacks having different combinations of rice and mung bean level.

Table 4.3: Sensory evaluation of snacks

Rice: Mung bean	Appearance	Texture	Flavor (Taste and Odour)	Overall Acceptability
100:0	8.4	7.8	8.0	8.06
95:5	8.2	7.7	7.5	7.80
90:10	7.9	7.5	7.8	7.73
85:15	8.0	7.7	7.5	7.73
80:20	8.0	7.5	7.6	7.70
75:25	8.0	7.9	7.7	7.86
70:30	**7.8**	**8.0**	**8.0**	**7.96**
65:35	7.7	7.5	7.0	7.4
60:40	7.0	6.0	7.5	6.83

With the blending of mung bean in rice flour, there were not many changes in the sensory score for different parameters up to 30 per cent level of mung bean. Beyond 30 per cent level the sensory scores decreases considerably. Keeping in view the sensory quality and nutritional importance of mung bean, the blend of rice flour and mung bean flour with 70:30 ratios was selected for further study.

4.2.2 Effect of extrusion conditions on product responses

Data with respect to effect of extrusion conditions on product responses is presented in Table 4.4. During the extrusion process, the dough viscosity, elastic swell effect and bubble growth effect contributed to the structure change of extrusion mix and thus affected product expansion and density. Gelatinization is one of the important effects that extrusion has on the starch of foods. It may be expected that as the starch granule structure is disrupted, more water is bound to starch molecules, resulting in changes to the extrudate properties like WAI and WSI. Specific mechanical energy (SME) gives the amount of energy delivers by the extruder to extrude material at particular set of condition like moisture content, die temperature and screw speed. Similarly texture (Hardness) determines the amount of force required to break the material it relates with the human sense of chewing.

4.2.3 Specific Mechanical Energy (SME)

The amount of mechanical energy delivered to the extruded material plays an important role in starch conversion. Higher SME usually results in greater degree of starch gelatinization and extrudate expansion. Hence, increased SME is desired for expanding products (Meng *et al* 2010).

Table 4.4: Effect of Extrusion condition on process and product responses (n=3)

Extrusion Conditions			Responses				
A: Moisture (%)	**B:Screw speed (rpm)**	**C: Temperature (°C)**	**SME (Wh/Kg)**	**Density (g/cm^3)**	**WAI (g/g)**	**WSI (%)**	**Hardness (N)**
14 (-1)	400(-1)	130(-1)	166.17	0.198	5.66	15.52	112.2
14 (-1)	400(-1)	170(+1)	162.02	0.121	5.95	20.00	91.97
14 (-1)	550(+1)	130(-1)	176.56	0.156	6.21	18.5	111.2
14 (-1)	550(+1)	170(+1)	166.17	0.128	5.65	19.2	80.27
18(+1)	400(-1)	130(-1)	151.56	0.296	5.38	13.6	262.6
18(+1)	400(-1)	170(+1)	125.63	0.234	6.54	12.8	165.82
18(+1)	550(+1)	130(-1)	155.71	0.304	4.71	16.0	213.62
18(+1)	550(+1)	170(+1)	124.63	0.237	4.49	13.6	159.23
12.6(-1.682)	475(0)	150(0)	179.71	0.131	5.62	18.6	81.92
19.4(+1.682)	475(0)	150(0)	135.65	0.319	5.09	12.4	266.04
16 (0)	349(-1.682)	150(0)	154.28	0.199	5.92	16.0	114.02
16 (0)	601(+1.682)	150(0)	160.24	0.196	5.23	18.0	110.03
16 (0)	475(0)	116(-1.682)	167.14	0.267	5.94	14.4	180.94
16 (0)	475(0)	184(+1.682)	135.31	0.199	5.78	15.2	106.69
16 (0)	475(0)	150(0)	169.15	0.158	6.31	13.6	149.02
16 (0)	475(0)	150(0)	169.28	0.152	6.03	14.01	137.77
16 (0)	475(0)	150(0)	169.35	0.164	6.25	13.6	114.33
16 (0)	475(0)	150(0)	169.22	0.167	6.03	14.0	120.05
16 (0)	475(0)	150(0)	169.14	0.159	6.25	13.6	122.07
16 (0)	475(0)	150(0)	170.00	0.161	6.06	13.9	149.4

Regression analyses were carried out to fit the mathematical models to the experimental data (Table 4.5). The predicted model for SME can be described by the following equation in terms of coded levels.

$$SME = 169.39 - 13.73\,A + 2.03\,B - 9.16\,C - 1.42\,AB - 5.31\,AC - 1.42\,BC - 4.34\,A^2 - 4.48\,B^2 - 6.62\,C^2 \quad (1)$$

Table 4.5: ANOVA for SME (Specific Mechanical Energy)

Factors	Coefficient estimate	Sum of squares	SE	DF	F-Value	Prob>F
Intercept of Model	169.39	5041.24	0.39	9	613.13	<0.0001
A: Moisture content	-13.73**	2573.98	0.26	1	2817.48	<0.0001
B: Screw speed	2.03**	56.29	0.26	1	61.61	0.0031
C: Temperature	- 9.16**	1145.61	0.26	1	1253.98	<0.0001
(Moisture x screw speed) AB	-1.42**	16.22	0.34	1	17.75	0.0177
(Moisture x temperature) AC	-5.31**	225.46	0.34	1	246.79	0.6940
(Screw speed x temperature) BC	- 1.42**	16.22	0.34	1	17.75	0.0045
(Moisture x moisture) A^2	-4.34**	270.99	0.25	1	296.63	0.3833
(Screw speed x screw speed) B^2	-4.48**	289.71	0.25	1	317.12	0.2240
(Temperature x temperature) C^2	-6.62**	631.30	0.25	1	691.02	0.1238
R^2 = 0.98						

* Significant at P < 0.05 R^2 = Coefficient of Correlation

** Significant at P < 0.01

The significance of coefficient of fitted quadratic model was evaluated by using F-test and P- value. The value of R^2 was found to be 0.98. The calculated SME ranged from 124.63 to 179.71 Wh/Kg (Table 4.4). Moisture, screw speed and temperature had significant effects on SME (P<0.01). The negative coefficients of the linear terms of moisture and temperature level indicated that SME decreases with increase of these variables, while positive coefficients for screw speed indicated that SME increases with increase in screw speed (Fig. 4.2). High moisture produced a lubricating effect resulting in less energy use and subsequently reduced SME. High temperature facilitated the transformation from solid flow to viscoelastic flow and reduced the melt viscosity, which resulted in decrease in SME. Increase in screw speed resulted in higher shear which resulted into higher SME. The SME is

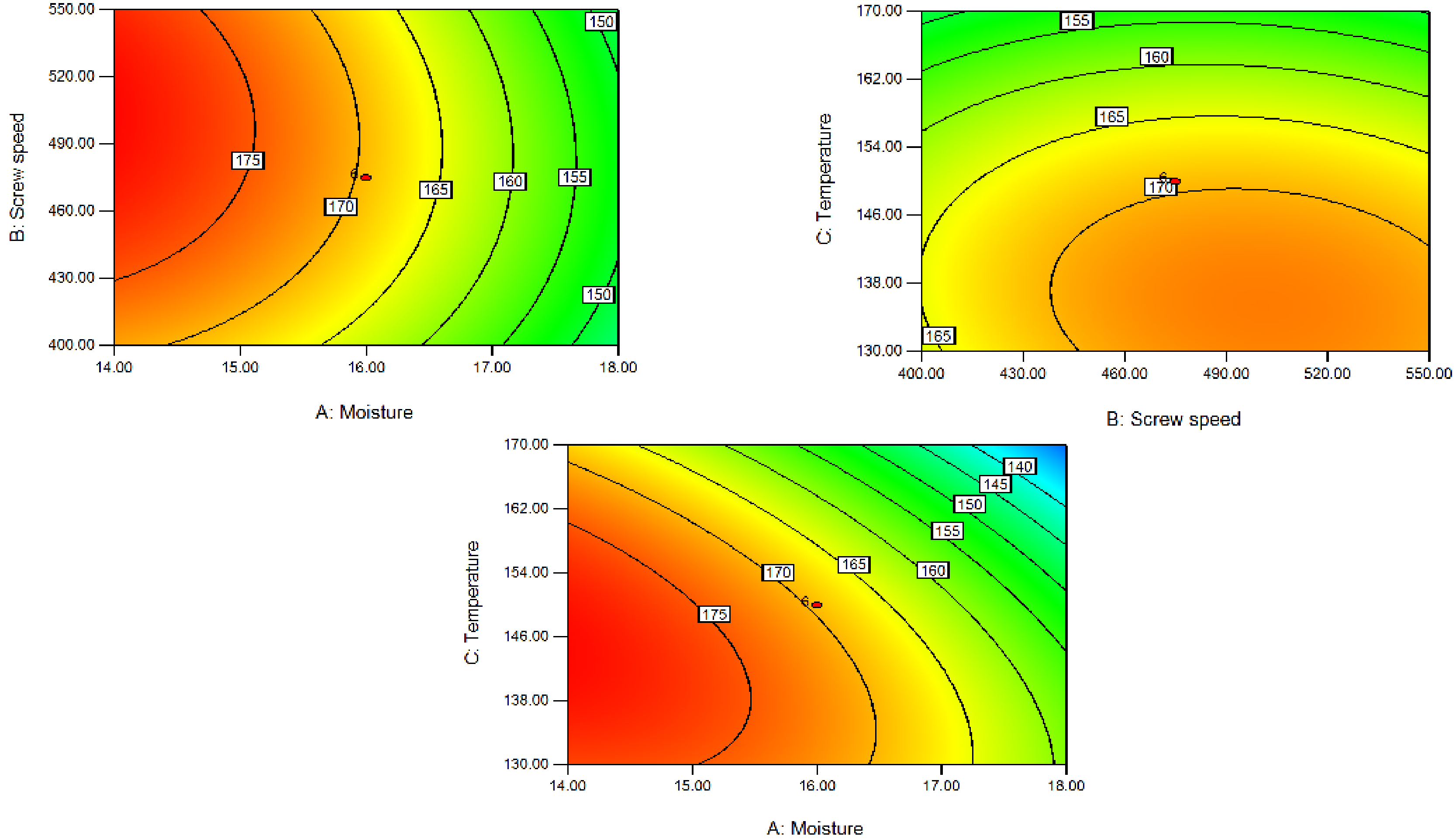


Fig 4.2: Effect of moisture, screw speed and temperature on the Specific Mechanical Energy

related to the degree of product transformation, and influences extrudate properties such as expansion, density and other geometric and textural characteristics (Iwe *et al* 2001). The amount of mechanical energy delivered to the extruded material plays an important role in starch conversion. Higher SME usually results in greater degree of starch gelatinization and extrudate expansion. Hence, increased SME is desired for expanding products (Meng *et al* 2010).

The results are in agreement with the work of Dogan and Karwe (2003), they processed whole quinoa in an extruder and found that an increase in temperature reduced the SME values. Similar correlations of moisture, screw speed and temperature with SME were reported by Ryu and Ng (2001) and Altan *et al* (2008) for wheat-corn and barley extrudates respectively.

4.2.3 Density

Density is a measure of how much expansion has occurred as a result of extrusion. The heat developed during extrusion can increase the temperature of the moisture above the boiling point so that when the extrudate exits from the die, a part of the moisture would quickly flash-off as steam and result in an expanded structure with large alveoli and low density. On the other hand, if not enough heat is generated to flash-off enough of the moisture (either through low process temperature or high feed moisture), less expansion occurs resulting in a high density product with collapsed cells which usually disintegrates on cooling.

The quadratic model obtained from regression analysis for density (BD) in terms of coded levels of the variables was developed as follows:

$$\text{Density} = +0.16 + 0.057\,A - 0.0021\,B - 0.026\,C + 0.0057\,AB - 0.0030\,AC + 0.0055\,BC + 0.020\,A^2 + 0.011\,B^2 + 0.023\,C^2 \quad (2)$$

The density of the extrudates varied between 0.121 and 0.319 g/cm^3 (Table 4.4). The significance of coefficient of fitted quadratic model was evaluated by using F- test and P-value. The value of R^2 was found to be 0.98. Density was significantly affected by fed moisture and barrel temperature in linear ($P < 0.001$) and squared ($P < 0.001$) terms (Table 4.6, Fig. 4.3).

Density increased with increase in feed moisture and it decreased with increase in temperature. Screw speed showed a non significant negative correlation with density. The high dependence of density and expansion on feed moisture would reflect its influence on elasticity characteristics of the starch- based material. Increased feed moisture content during extrusion may reduce the elasticity of the dough through plasticization of the melt, resulting in reduced SME and therefore reduced gelatinization, decreasing the expansion and increasing the density of extrudate (Mercier and Feillet, 1975). It was observed that an increase in barrel temperature resulted in an extrudate with low density. Density values decreased when the extrusion temperature and the screw speed increased, probably due to starch gelatinization. Increase in the barrel temperature decreased the melt viscosity, and reduced viscosity would favour the bubble growth during extrusion and thereby decreasing the density. High temperature provides more thermal input, leading to complete gelatinization even at high screw speed that decreased residence time. Structural breakdown of protein and starch in the high shear environment also leads to low density of products (Lin *et al* 2003). Identical results were shown by other researchers for extrusion of chick pea flour (Meng *et al* 2010), for corn starch (Chinnaswamy and Hanna 1988), amaranth (Chavez *et al* 2000) and rice (Hagenimana *et al* 2006).

Table 4.6: ANOVA for Density

Factors	Coefficient estimate	Sum of squares	SE	DF	F-Value	Prob> F
Intercept of Model	0.16	0.068	0.0047	9	56.45	<0.0001
A: Moisture content	0.057**	0.045	0.0031	1	338.73	<0.0001
B: Screw speed	–0.0021	6.177E-005	0.0031	1	0.46	<0.0001
C: Temperature	–0.026**	0.0088	0.0031	1	66.85	0.0007
(Moisture x screw speed) AB	0.0057	0.0002	0.0040	1	1.99	0.0008
(Moisture x temperature) AC	–0.0030	7.200E-005	0.0040	1	0.54	0.0196
(Screw speed x temperature) BC	0.0055	0.0002	0.0040	1	1.82	0.0111
(Moisture x moisture)A^2	0.020**	0.0058	0.0030	1	44.34	0.0003
(Screw speed x screw speed) B^2	0.011**	0.0015	0.0030	1	11.95	0.0180
(Temperature x temperature) C^2	0.023**	0.0076	0.0030	1	57.61	0.6977
R^2 = 0.9807						

* Significant at P < 0.05 R^2 = Coefficient of Correlation
** Significant at P < 0.01

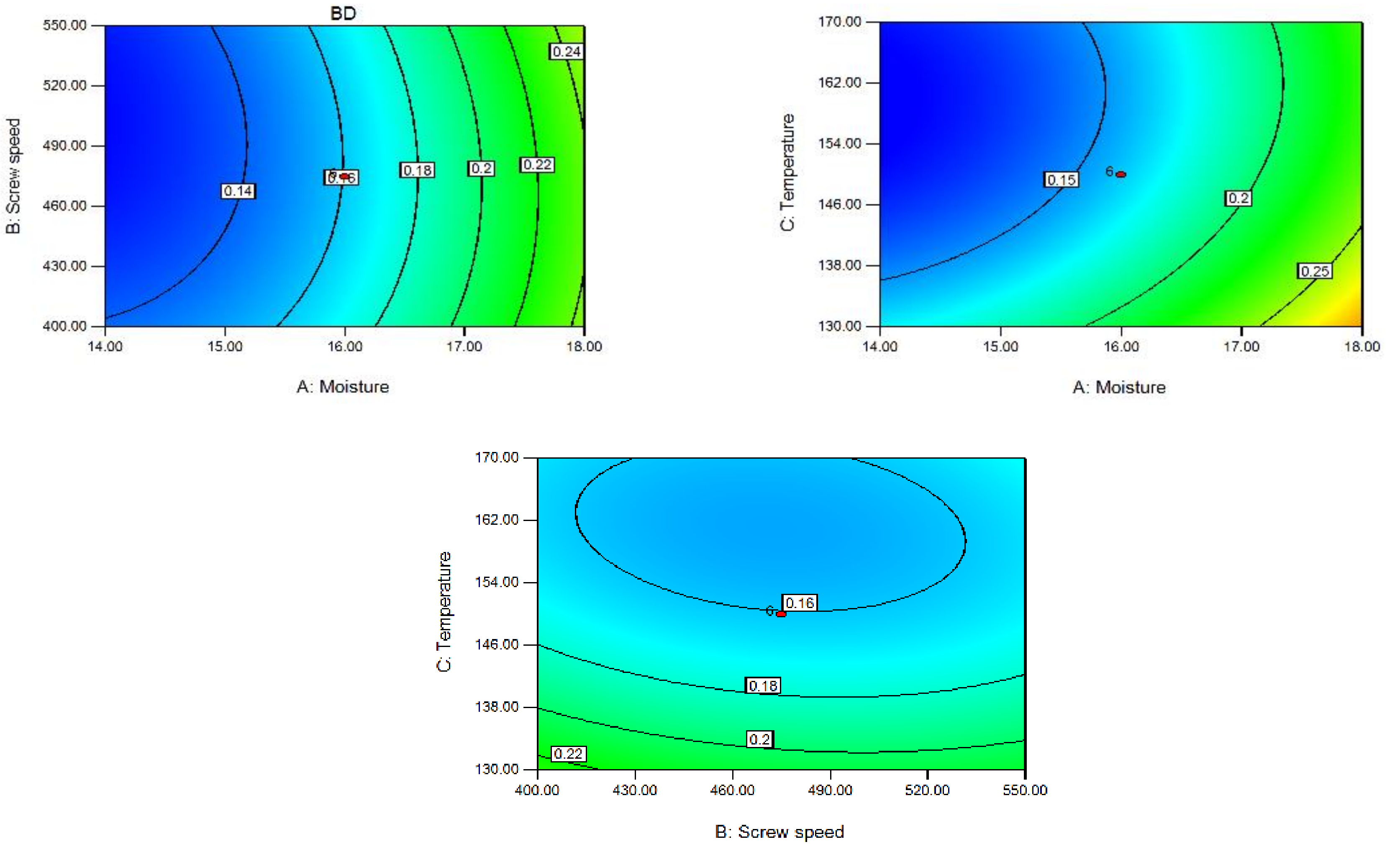


Fig 4.3: Effect of moisture, screw speed and temperature on the Density

4.2.4 Water Absorption Index (WAI)

WAI has been generally attributed to the dispersion of starch in excess water, and the dispersion is increased by the degree of starch damage due to gelatinization and extrusion–induced fragmentation, that is, molecular weight reduction of amylose and amylopectin molecules (Yagci and Gogus, 2009). WAI measures the water holding by the starch after swelling in excess water (Mason and Hoseney, 1986), which corresponds to the weight of the gel formed. WAI depends on the availability of hydrophilic groups and on the capacity of gel formation of the macromolecule (Gomez and Aguilera, 1984). The quadratic model obtained from regression analysis for water absorption index in terms of coded levels of the variables was developed as follows.

$$WAI = + 6.15 - 0.24A - 0.27B + 0.029C – 0.037AB + 0.15AC – 0.28 BC - 0.28A^2 – 0.20B^2 - 0.10C^2 \quad (3)$$

The significance of coefficient of fitted quadratic model was evaluated by using F-test and P- value. The value of R^2 was found to be 0.95. WAI values for the extrudates ranged between 4.49 to 6.54 g/g (Table 4.4). Regression analysis results showed that increase in feed moisture content and screw speed resulted in significant decrease in WAI in linear and squared terms (Table 4.7, fig. 4.4). Gelatinisation, the conversion of raw starch to a cooked and digestible material by the application of water and heat, is one of the important effects

Table 4.7: ANOVA for Water Absorption Index

Factors	Coefficient estimate	Sum of squares	Standard error	DF	F-Value	Prob>F
Intercept of Model	6.15	5.28	0.067	9	21.58	<0.0001
A: Moisture content	- 0.24**	0.77	0.045	1	28.28	<0.0001
B: Screw speed	- 0.27**	0.97	0.045	1	35.48	<0.0001
C: Temperature	0.029	0.012	0.045	1	0.43	<0.0001
(Moisture x screw speed) AB	- 0.37**	1.10	0.058	1	40.53	0.1159
(Moisture x temperature) AC	0.15*	0.18	0.058	1	6.73	<0.0001
(Screw speed x temperature) BC	- 0.28**	0.62	0.058	1	22.85	0.0221
(Moisture x moisture)A^2	- 0.28**	1.13	0.043	1	41.69	0.0076
(Screw speed x screw speed) B^2	- 0.20**	0.59	0.043	1	21.78	0.0087
(Temperature x temperature) C^2	- 0.10*	0.15	0.043	1	5.51	<0.0001
R^2 = 0.9510						

* Significant at P < 0.05 R^2 = Coefficient of Correlation
** Significant at P < 0.01

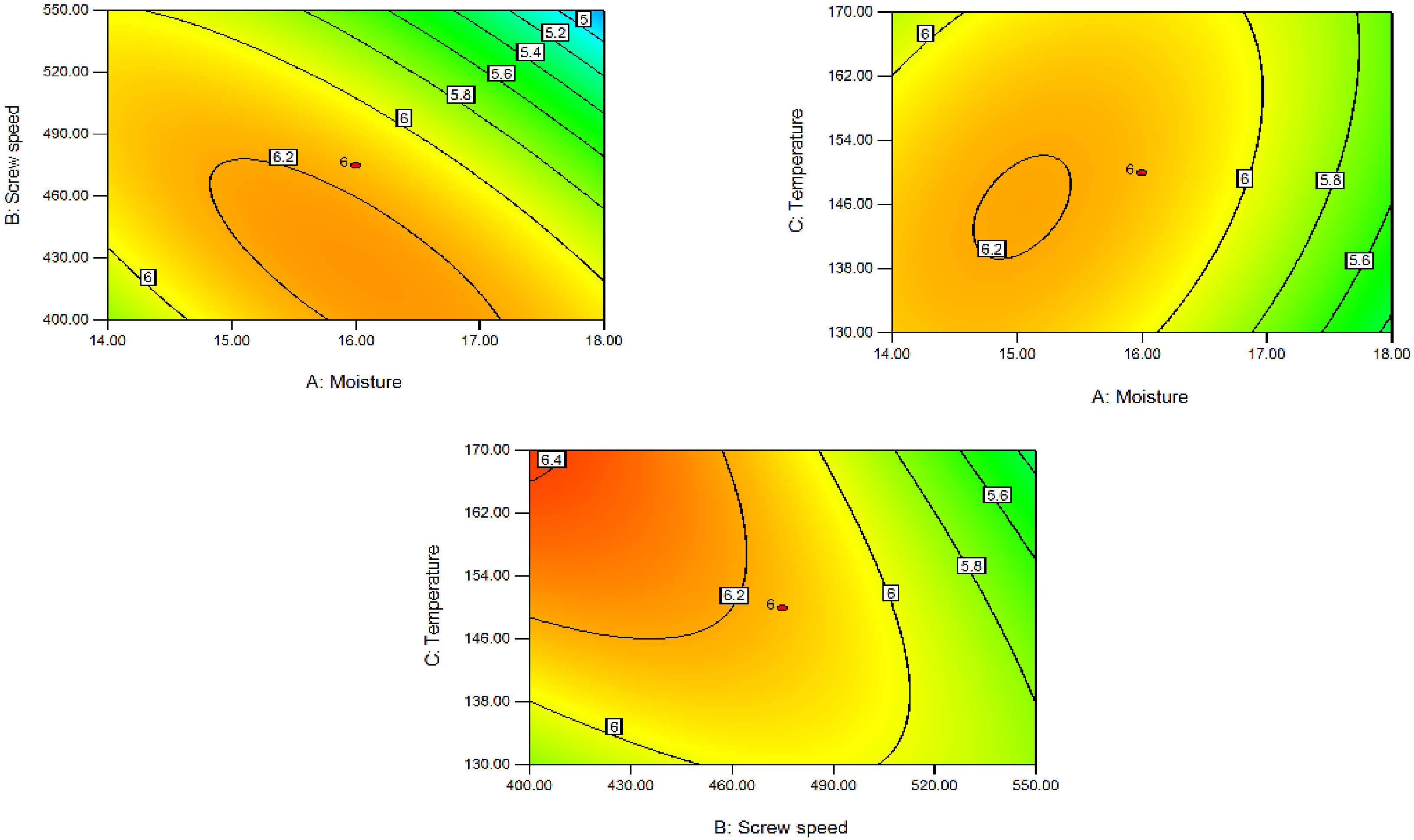


Fig 4.4: Effect of moisture, screw speed and temperature on the Water Absorption Index

that extrusion has on the starch component of foods. Water is absorbed and bound to the starch molecule with a resulting change in the starch granule structure. Barrel temperature and feed moisture are found to exert the greatest effect on gelatinisation. It has been reported earlier that maximum gelatinisation occurs at high moisture and low temperature or vice versa (Lawton *et al* 1972). A decrease in WAI with addition of pea grits may be due to the dilution of starch in rice pea blends. Jones *et al* (2000) reported a decrease in WAI with decrease in starch content.

4.2.5 Water Solubility Index (WSI)

WSI, often used as an indicator of degradation of molecular components (Kirby *et al* 1988) measures the degree of starch conversion during extrusion which is the amount of soluble polysaccharides released from the starch component after extrusion.

$$WSI = +13.78 - 2.02\,A + 0.64\,B + 0.24\,C + 0.13\,AB - 1.05\,AC - 0.67\,BC + 0.66\,A^2 + 1.19\,B^2 + 0.41\,C^2 \quad (4)$$

The significance of coefficient of fitted quadratic model was evaluated by using F-test and P- value. The value of R^2 was found to be 0.98. The WSI values for the extrudates ranged between 12.4 and 19.20 per cent (Table 4.4). The WSI was influenced significantly by moisture, screw speed ($P < 0.01$) and temperature ($P < 0.05$). There was also significant interaction between all the three independent variables (Table 4.8, Fig. 4.5).

Table 4.8: ANOVA for Water Solubility Index

Factors	Coefficient estimate	Sum of squares	Standard error	DF	F-Value	Prob>F
Intercept of Model	13.78	100.61	0.15	9	81.63	<0.0001
A: Moisture content	- 2.02**	55.97	0.10	1	408.71	<0.0001
B: Screw speed	0.64**	5.60	0.10	1	40.88	<0.0001
C: Temperature	0.24*	0.81	0.10	1	5.91	0.0324
(Moisture x screw speed) AB	0.13	0.13	0.13	1	0.95	0.2207
(Moisture x temperature) AC	-1.05**	8.78	0.13	1	64.10	0.0013
(Screw speedx temperature) BC	-0.67**	3.62	0.13	1	26.42	0.4825
(Moisture x moisture)A^2	0.66**	6.32	0.097	1	46.17	0.0973
(Screw speed x screw speed) B^2	1.19**	20.50	0.097	1	149.71	0.0025
(Temperature x temperature) C^2	0.41**	2.48	0.097	1	18.12	<0.0001
R^2 = 0.9866						

* Significant at $P < 0.05$

** Significant at $P < 0.01$

R^2 = Coefficient of Correlation

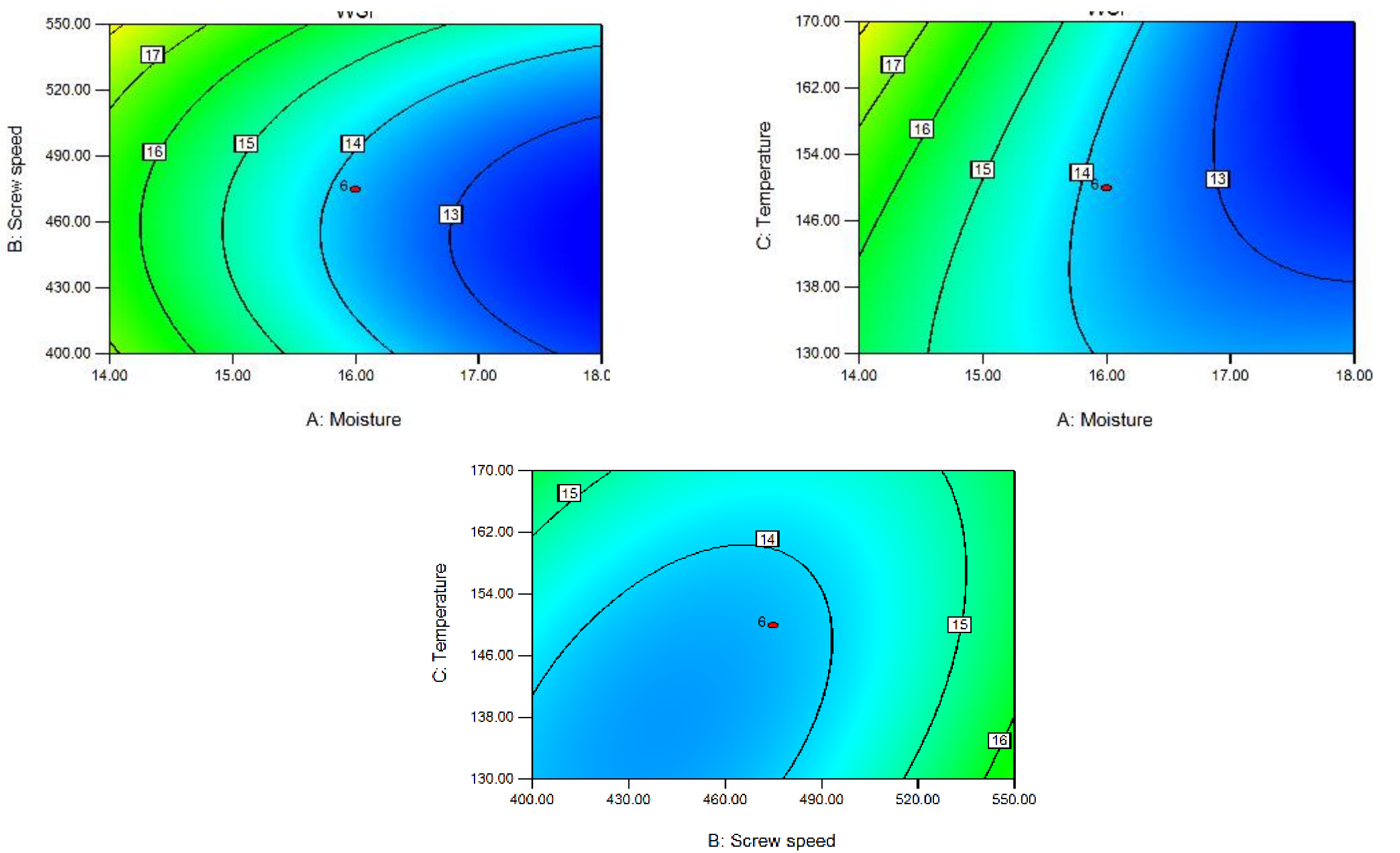


Fig 4.5: Effect of moisture, screw speed and temperature on the Water Solubility Index

The WSI is related to the quantity of soluble molecules, which is related to dextrinization. In other words, WSI can be used as an indicator for the degradation of molecular compounds and measures the degree of starch conversion during extrusion (Colonna *et al* 1989; Ding *et al* 2005).

Altan *et al* (2008) reported increase in WSI with increase in screw speed during the extrusion of barley–tomato blends. Mezreb *et al* (2003) reported that the increase of screw speed induced a sharp increase of specific mechanical energy, the high mechanical shear degraded the macromolecules, and so the molecular weight of starch granules decreased and hence increased WSI. Mercier and Feillet (1975) reported increase in soluble starch with increasing extrusion temperature and decreasing feed moisture. WSI often is used as an indicator of degradation of molecular components (Kirby *et al* 1988).

4.2.6 Hardness

The hardness of expanded extrudates is a perception of the human being and is associated with expansion and cell structure of the product. The hardness is the peak force required for a probe or parallel blades (e.g. Kramer Shear Cell) to penetrate the extrudate. The higher the value of maximum peak force required, the higher the hardness of the sample.

The regression analysis was carried out to fit the mathematical models to the experimental data. The predicted model can be described by the following equation in terms of coded levels.

$$\text{Hardness} = +131.92 + 52.38\,A - 5.49\,B - 23.96\,C - 5.36\,AB - 12.50\,AC + 3.96\,BC + 16.00A^2 - 5.90B^2 + 5.33\,C^2 \qquad (5)$$

Table 4.9: ANOVA for Hardness

Factors	Coefficient estimate	Sum of squares	Standard error	DF	F-Value	Prob>F
Intercept of Model	131.92	52113.09	5.62	9	30.46	<0.0001
A: Moisture content	52.38**	37463.09	3.73	1	197.05	<0.0001
B: Screw speed	- 5.49	411.67	3.73	1	2.17	0.1719
C: Temperature	- 23.96**	7839.42	3.73	1	41.23	<0.0001
(Moisture x screw speed) AB	- 5.36	229.73	4.87	1	1.21	0.2974
(Moisture x temperature) AC	- 12.50*	1250.25	4.87	1	6.58	0.0282
(Screw speed x temperature) BC	3.96	125.53	4.87	1	0.66	0.4354
(Moisture x moisture)A^2	16.00**	3689.06	3.63	1	19.40	0.0013
(Screw speed x screw speed) B^2	- 5.90	502.49	3.63	1	2.64	0.1351
(Temperature x temperature) C^2	5.33	410.11	3.63	1	2.16	0.1727
R^2 = 0.9648						

* Significant at P < 0.05 R^2 = Coefficient of Correlation
** Significant at P < 0.01

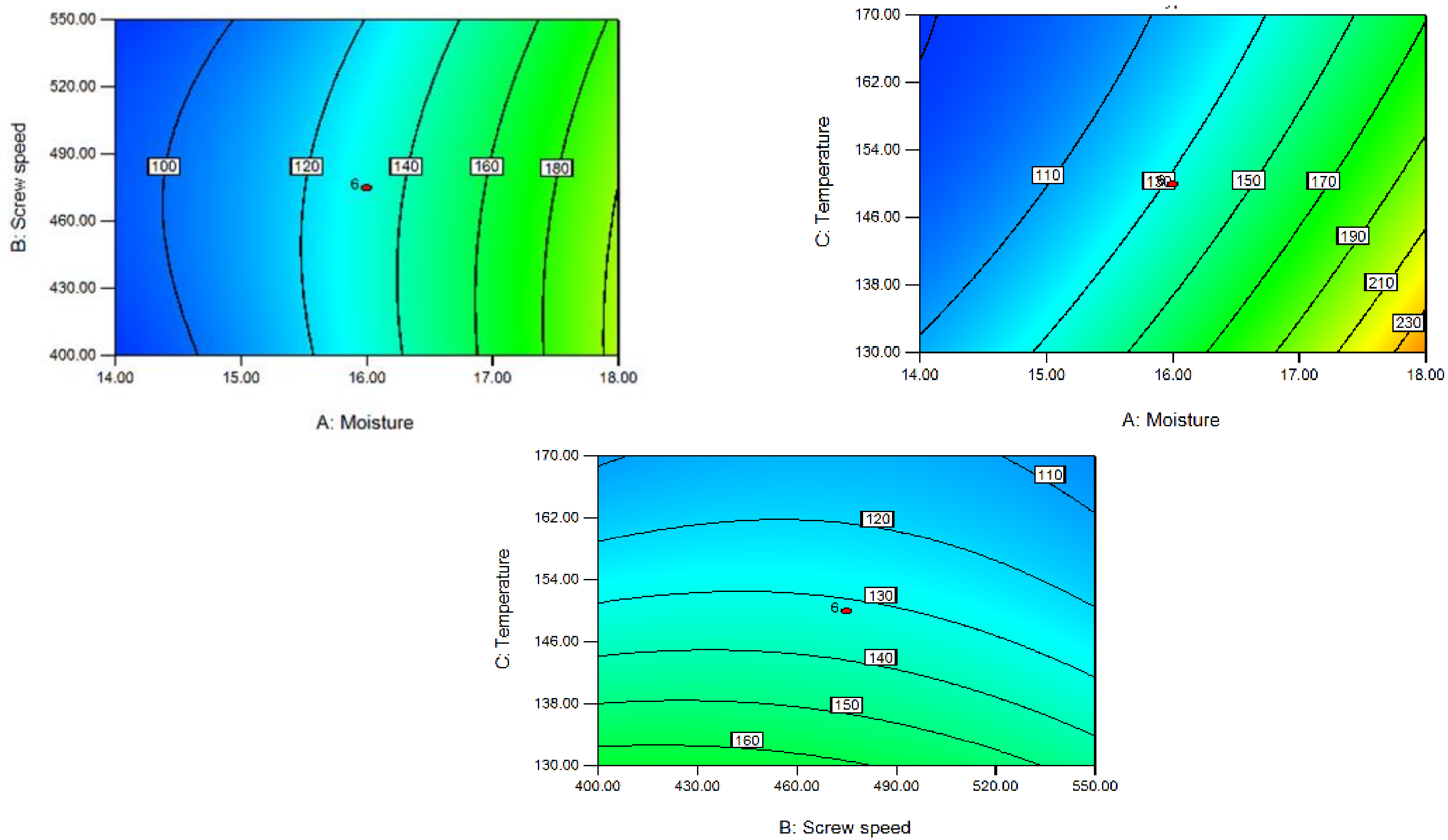


Fig 4.6: Effect of moisture, screw speed and temperature on the Hardness

The significance of coefficient of fitted quadratic model was evaluated by using F-test and P- value. The value of R^2 was found to be 0.96. The hardness of the extrudates ranged from 80.27 to 266.04 N (Table 4.4). Feed moisture content, barrel temperature showed highly significant effects on extrudate hardness in linear and quadratic terms (Table 4.9, Fig. 4.6). The positive coefficient of the linear term of moisture level indicated that hardness increases with increase in moisture, while negative coefficients of the linear terms of the barrel temperature indicated that hardness decreased with increase in variables. Increase in hardness with increase in moisture might be due to the reason that, water acts as a plasticizer to the starch-based material reducing its viscosity and the mechanical energy dissipation in the extruder and thus the product becomes dense and bubble growth gets compressed.

Hardness decreased with the increase in screw speed and temperature. It is expected that increasing temperature as well as screw speed would decreased melt viscosity, which favours the bubble growth and produce low density products with small and thin cells, thus increasing the crispness of the extrudates. A low-density product naturally offered low hardness. High correlation between density and hardness has been demonstrated earlier (Altan *et al* 2008; Bhattacharya 1997; Ding *et al* 2005). The effect of screw speed on hardness might be through its influence on extrudate expansion. The decrease in hardness with increasing screw speed was also observed in corn- and barley-based extrudates (Altan *et al* 2008; Liu *et al* 2000).

4.3 Optimization

Optimization can be defined as the processing conditions that give the optimum (maximum or minimum) value of a function of certain decided variables subject to constraints that are imposed. Optimization may be the process maximizing a desired quantity or minimizing an undesired one. The values of the processing variables that produce the desired optimum value are called optimum conditions. Product responses such as density, texture and hardness were the important major parameters determining the quality of extrudates being consumed as snack foods. Therefore, optimum conditions for extrusion of rice and mung bean flours were determined to obtain the minimum density and hardness, maximum WAI and WSI, whereas SME was not considered for optimization for being as a process parameter. The desirability graph is shown in Fig. 4.7 for obtaining optimal conditions in extrusion cooking of rice and mung bean flours. The desirability obtained was 0.929. The optimum feed moisture content, temperature and screw speed were 14 per cent, 148 °C and 549 rpm respectively. By applying these optimal conditions, extrudates with a density equal to 0.128 g/ml, WAI equal to 6.06 g/g, WSI equal to 18.07 per cent and hardness (peak force) 90.54 could be produced.

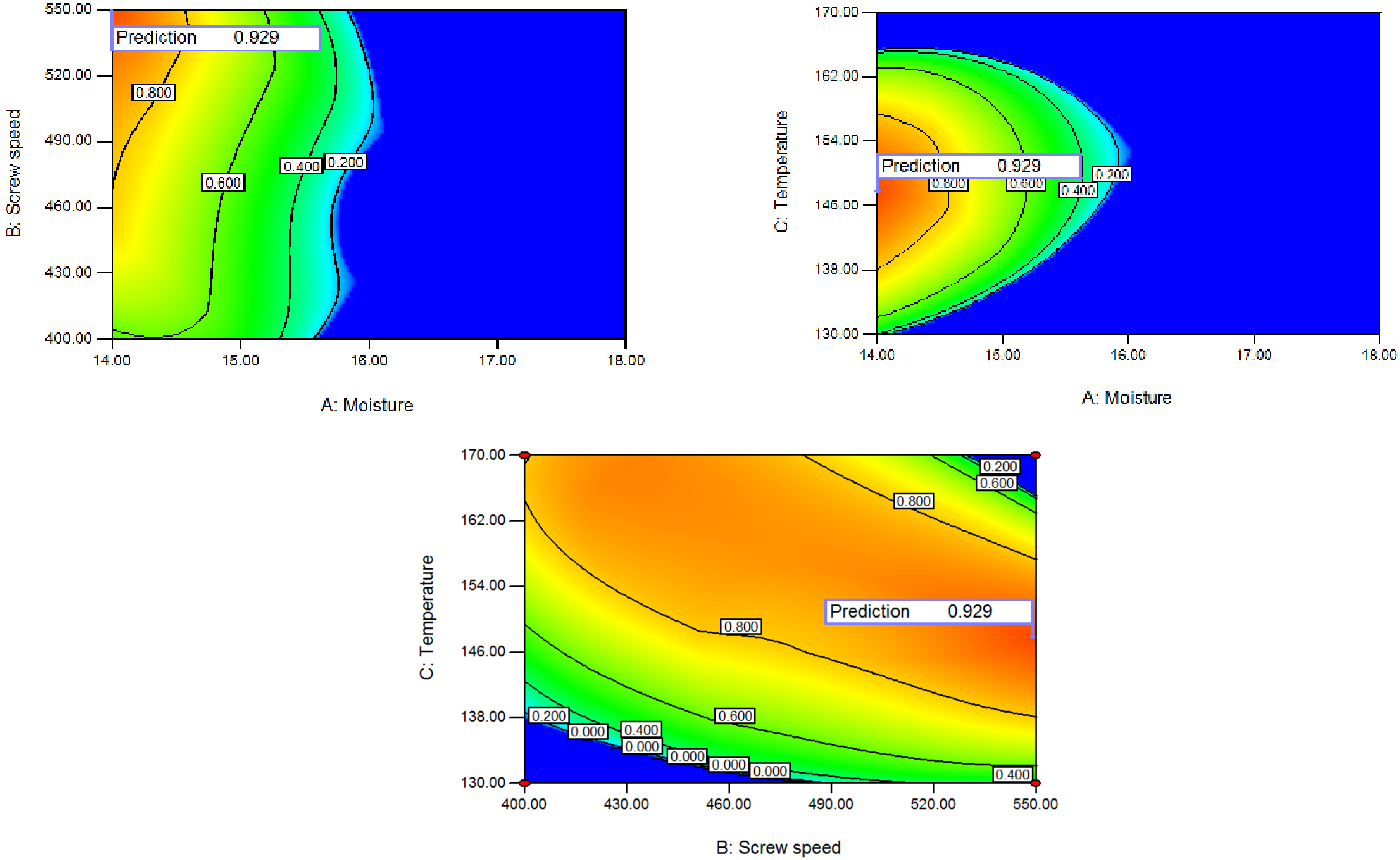


Fig: 4.7 Desirability function graphs for rice and mung bean flour extrudates

4.4 Validation

Data with respect to predicted and actual values of responses is presented in Table 4.10. The extruded snacks were prepared utilizing the optimized conditions i.e., moisture content = 14 per cent, screw speed = 549 rpm and temperature = 148 °C. Variation in the predicted and actual values was found to be less than 5 per cent.

Table 4.10 Predicted response vs. Actual response

Values	Density (g/ml)	WAI (g/g)	WSI (%)	Hardness (N)
Predicted	0.128	6.06	18.07	90.54
Actual	0.133	5.93	18.85	88.00
Variation (%)	3.90	2.14	4.31	2.80

4.5 Storage study of snacks

Table 4.11and Fig. 4.8 to 4.11 shows the effect of storage on the moisture content, free fatty acids, hardness and overall acceptability of snacks.

Table 4.11: Effect of storage period on Moisture content (%), Free Fatty Acids (%), Hardness and Overall Acceptability of snacks (n=3)

Storage period (months)	Moisture (%)	Free Fatty Acids (%)	Hardness (N)	Overall Acceptability
0	5.88	0.242	90.5	7.66
1	6.02	0.421	87.2	7.39
2	6.77	0.561	83.6	7.30
3	7.18	0.603	79.5	7.00

There was an increase in moisture content during a storage period of 3 months. Increase in moisture content was due to the hygroscopic nature of the snacks. Initially moisture content was 5.88 per cent that increased up to the 7.18 per cent at the end of 3 months storage. Charunuch *et al* (2008) reported that there was an increase in moisture content in Thai rice extruded snack supplemented with mulberry from 3.5 to 5 per cent during storage of 4 months.

RICE-MUNG BEAN SNACKS

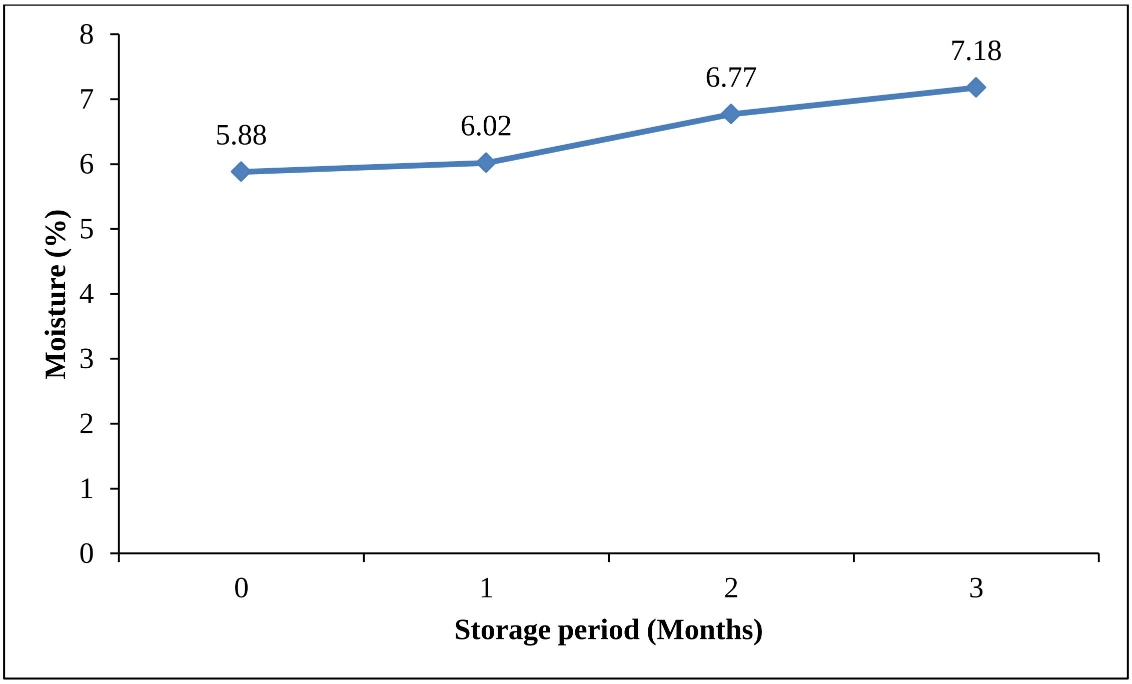


Fig. 4.8: Effect of storage on moisture content of snacks

The free fatty acids (per cent) for extruded snacks increased significantly during the storage period of 3 months, but the values remained in the acceptable range because of which the taste, flavour and acceptability of snacks were not much affected at the 3rd month of storage.

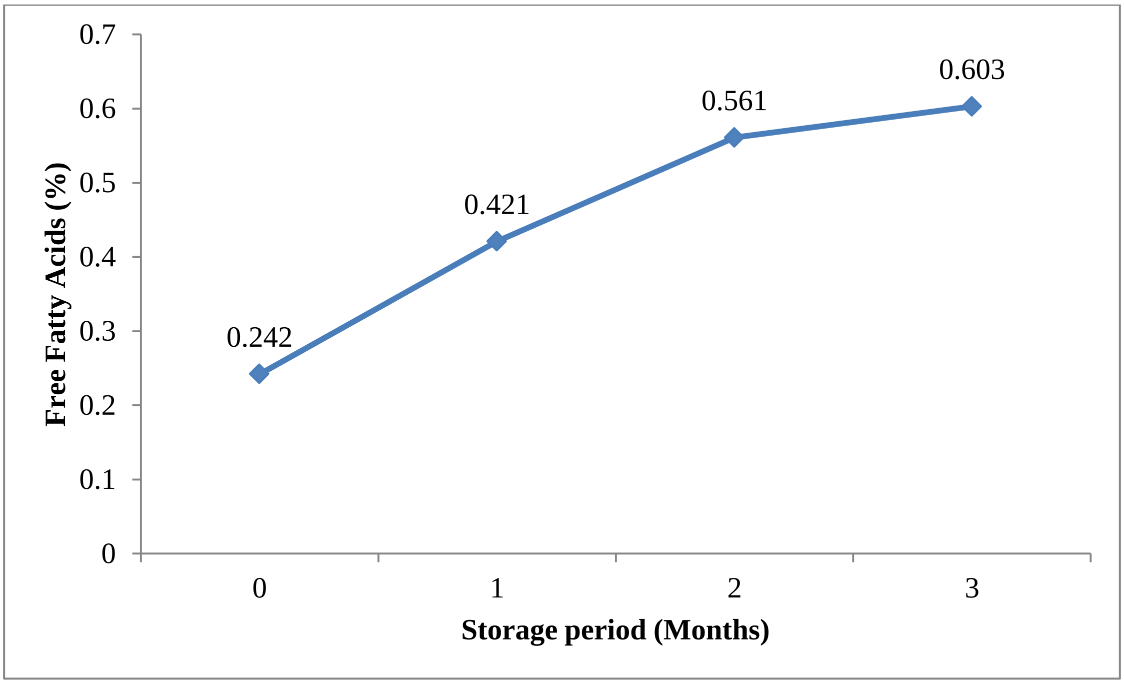


Fig. 4.9: Effect of storage on free fatty acid value of snacks

The hardness of the extrudates decreased from 90.5 to 79.5 N after a storage period of 3 months. Charunuch *et al* (2008) reported in their study for the development of iron fortified extruded thai rice snacks for 0-4 months of storage that there was a decrease in hardness of snacks from 21.38 to 19.44 N.

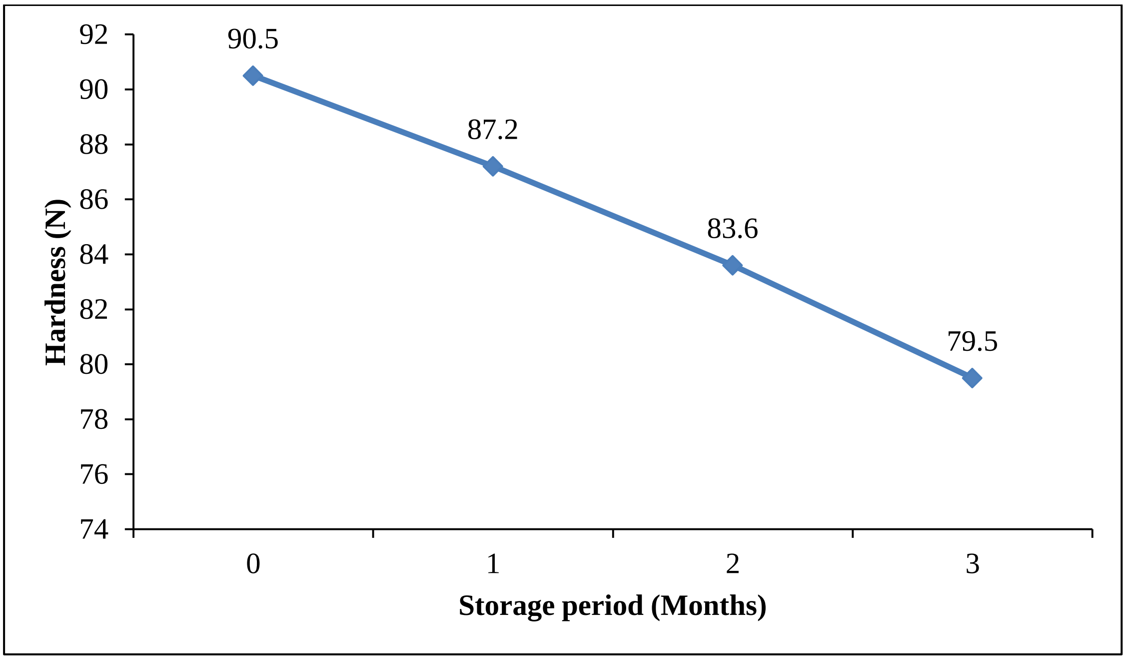


Fig. 4.10: Effect of storage on the Hardness of the snacks.

Storage slightly affected the overall acceptability of snacks (Table 4.5). During the entire period of 3 months of storage, overall acceptability of snacks was within acceptable range. During the first month of storage snacks have overall acceptability of 7.39 which decreased to 7.00 at the end of storage.

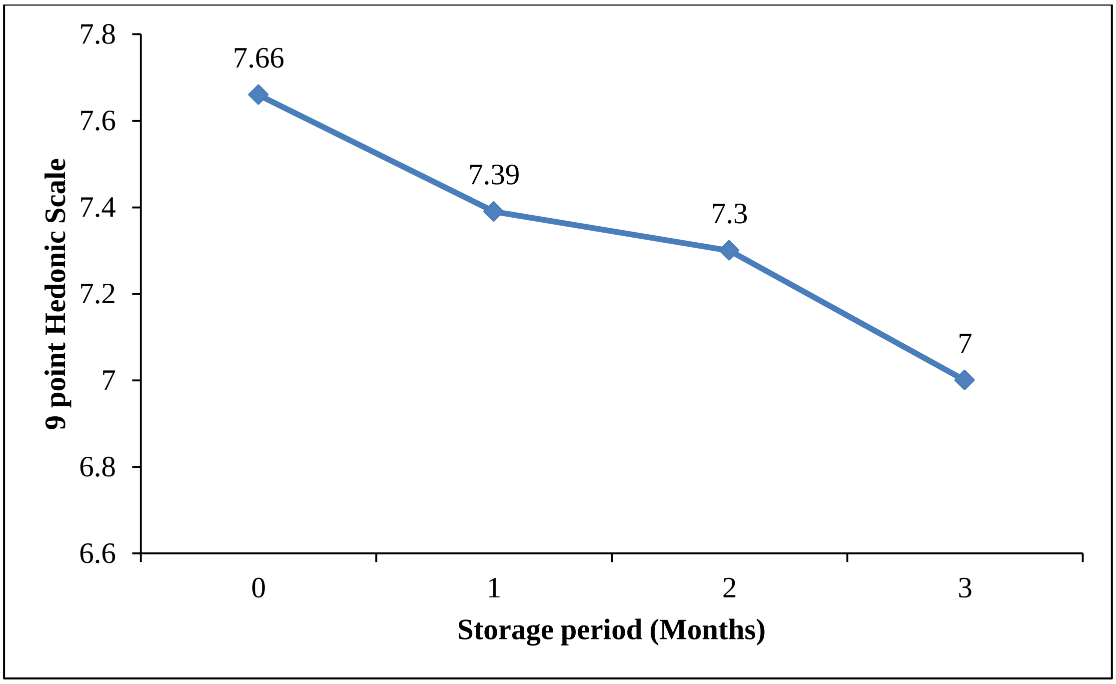


Fig. 4.11: Effect of storage period on the overall acceptability of the snacks.

4.6 Proximate composition of extruded snacks

Proximate composition of snacks is given in Table 4.12. Extruded snacks have low fat and high protein content as compared to snacks having rice flour only or even brown rice snacks. Pastor *et al* (2011) reported that 1.19 per cent ash, 0.53 per cent fat, 3.81 per cent fibre, 7.38 per cent protein and 86.86 per cent carbohydrates in brown rice snacks. Final extruded snacks for broken rice and mung bean had 12.77 per cent protein as compared to snacks from rice flour that had 7.12 per cent protein only while low carbohydrate content was 75.14 per cent as compared to 78.39 per cent in rice flour.

Table 4.12: Proximate composition of extruded snacks (n=3)

Types of Snacks	Moisture (%)	Crude protein (%)	Fat (%)	Ash (%)	Crude Fibre (%)	Carbohydrates (%)
Broken Rice & Mung bean snacks	5.91±0.18	12.7±0.31	0.68±0.02	2.56±0.10	2.94±0.08	75.14±0.81

Mean ± SD

4.6.1 Mineral composition of snacks

In Table 4.13 the results were expressed in mg/100 g of rice and mung bean snacks on wet basis and presented in a decreasing order of concentration. Potassium was the most abundant mineral in final extruded snacks followed by Mg, Ca, Na, Fe, Zn, Mn, and Cu. Habibullah *et al* (2007) studied the range of mineral content in mung bean varieties M1 and NM-92 and compared the mineral contents. M1 variety contained K 1443, Mg 204, Ca 216, Na 22, Fe 11.34, Zn 1.88, Mn 1.23 and Cu 1.27 mg/ 100 g while NM-92 variety had K 1298, Mg 174, Ca 122, Na 18, Fe 9.10, Zn 1.54, Mn 1.49 and Cu 1.92 mg/100g respectively. Incorporation of mung bean improved the mineral content of the snacks.

Table 4.13: Mineral content of broken-rice & mung bean snacks (mg/100g) (n=3)

Types of Snacks	K (mg)	Mg (mg)	Ca (mg)	Na (mg)	Fe (mg)	Zn (mg)	Mn (mg)	Cu (mg)
Broken rice & Mung bean snacks	504.74±0.11	102.38±0.20	72.86±0.24	7.14±0.14	3.85±0.09	2.03±0.22	0.845±0.31	0.514±0.41

Mean

4.7 Economic cost

Cost of rice – mung bean based snacks = Rs. 71/Kg

where, Cost of raw material = Rs. 40/ Kg

Processing cost = Rs. 26/ Kg

Packaging cost = Rs. 5/ Kg

CHAPTER – V

SUMMARY

The present investigation was carried out to study the "Development of Extruded Snacks utilizing Broken rice and Mung bean". Experimental procedures are given in Chapter III under Materials and Methods. The results of the investigation are summarized below:

Rice brokens were procured from local rice mill and mung bean procured from Directorate of Seeds, PAU, Ludhiana. Rice-brokens and mung bean were subsequently ground in lab mill to pass through 200 µm sieves. Broken rice flour and mung bean flour were analysed for proximate composition (moisture, protein, fat, ash, crude fibre, carbohydrates). Broken rice flour contains 11.10 per cent moisture, 7.12 per cent crude protein, 0.47 per cent fat, 1.57 per cent ash, 1.35 per cent crude fibre, 78.39 per cent carbohydrates. Mung bean flour contains 9.74 per cent moisture, 22.62 per cent crude protein, 1.08 per cent fat, 3.80 per cent ash, 6.40 per cent crude fibre, 56.36 per cent carbohydrates on fresh weight basis.. The pasting temperature, peak viscosity, hold viscosity, final viscosity, break down and setback for rice flour were 94.5, 1225.5, 1209, 3341.5, 16.5, and 2132.5 cP, respectively and for mung bean flour peak viscosity, hold viscosity, final viscosity, break down and set back were 1475, 1410, 3735, 65.0, and 2325 cP, respectively.

Rice and mung bean flours were blended in the ratio of 100:0, 95:5, 90:10, 85:15, 80:20, 75:25, 70:30, 65:35, 60:40 and subjected to extrusion cooking at 15 per cent moisture, 500 rpm screw speed and 160 °C temperature. The samples were subjected to sensory evaluation. The extruded snacks were evaluated organoleptically and best combination (70:30) was used for further study. Statistical package Design-Expert Version 8.01 was used to design the experiment. The central composite design for the three independent variables was performed. The independent variables considered were Moisture (A), Screw speed (B) and Die temperature (C). Dependent variables were specific mechanical energy (SME), density, water absorption index (WAI), water solubility index (WSI) and hardness. The regression models for the SME, density, WAI, WSI and hardness were highly significant with R^2 value of 0.99, 0.98, 0.95, 0.98 and 0.96 respectively.

The calculated SME ranged from 124.63 to 179.71 Wh/Kg. Moisture, screw speed and temperature had significant effects on SME ($P<0.01$). The negative coefficients of the linear terms of moisture and temperature indicated that SME decreased with increase of these variables, while positive coefficients for screw speed indicated that SME increased with increase in screw speed. The density of the extrudates varied between 0.121 and 0.319g/cm^3. Density increased with increase in feed moisture and it decreased with increase in temperature. Screw speed showed a non significant negative correlation with density. WAI values for the extrudates ranged between 4.49 to 6.54 g/g. Regression analysis results showed that increase in feed moisture content and screw speed resulted in significant decrease in WAI in linear and squared terms. The WSI values for the extrudates ranged between 12.4 and 19.20 per cent. The WSI was influenced significantly by moisture, screw speed and temperature. There is also significant interaction between all the three independent variables. The hardness of the extrudates ranged from 80.27 to 266.04 N. Feed moisture content, barrel temperature showed highly significant effects on extrudate hardness in linear and quadratic terms. The positive coefficient of the linear term of moisture level indicated that hardness increased with increase in moisture, while negative coefficients of the linear terms of the barrel temperature indicated that hardness decreased with increase in temperature.

Optimum conditions for extrusion of rice and mung bean flours were determined to obtain the minimum density and hardness, maximum WAI and WSI, whereas SME was not considered for optimization for being as a process parameter. The desirability obtained was 0.929. The optimum feed moisture content, screw speed and temperature were 14 per cent, 549 rpm and 148 °C, respectively. By applying these optimal conditions, extrudates with 0.128 g/ml density, 6.06 g/g WAI, 18.07 per cent WSI and 90.54 N hardness (peak force) could be produced. The extruded snacks were prepared utilizing the optimized conditions i.e., moisture content = 14 per cent, screw speed = 549.11 rpm and temperature = 147.81 °C. Variation in the predicted and actual values was found to be less than 5 per cent.

Storage slightly affected the overall acceptability of snacks. During the entire 3 months of storage, overall acceptability of snacks was within acceptable range. During the first month of storage, snacks have overall acceptability of 7.39 which decreased to 7.00 at the end of 3 months of storage. The final extruded snacks have moisture, protein, fat, fibre, ash and carbohydrates as 5.91, 12.77, 0.68, 2.94, 2.56 and 75.14 per cent, respectively. The broken rice and mung bean based snacks contain P 504.7, Mg 102.3, Ca 72.8, Na 7.1, Fe 3.8, Zn 2.0, Mn 0.84 and Cu 0.51 mg/100g, respectively. The cost of the rice mung bean based snacks was calculated to be Rs. 71/Kg.

The snacks were acceptable after 3 months of storage. The moisture, protein, fat, fibre, ash and carbohydrate content of snacks were 5.91, 12.77, 0.68, 2.94, 2.56 and 75.14 per cent respectively.

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VITA

Name of the student	**:**	Chetan Sharma
Father's name	**:**	Mr. Jaspal Sharma
Mother's name	**:**	Mrs. Geeta Sharma
Nationality	**:**	Indian
Date of birth	**:**	30 July, 1987
Permanent Address	**:**	V.P.O. Timmowal, Tehsil-Baba Bakala Distt. Amritsar, Pin code 143119 Punjab

EDUCATIONAL QUALIFICATIONS

Bachelor's degree	**:**	B.Sc. (Hons.) Food Science & Technology
University and year of award	**:**	Guru Nanak Dev University (2009)
% marks	**:**	75.6%
Master's degree	**:**	M.Sc. (Food Technology)
University and year of Award	**:**	Punjab Agricultural University, Ludhiana 2012
OCPA	**:**	7.64/10.00
Title of Master's Thesis	**:**	Development of Extruded Snacks Utilizing Broken Rice and Mung bean