

Utilization of honey-apple blends for the development of corn based breakfast snacks using extrusion technology

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(2012-419-D)



Division of Food Science and Technology
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Technology of Kashmir
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corn based breakfast snacks using extrusion technology**

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Thesis

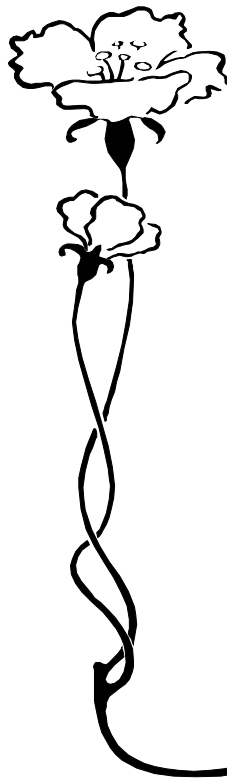
Submitted to

The Faculty of Horticulture

**Sher-e-Kashmir University of Agricultural Sciences & Technology
of Kashmir in partial fulfilment of requirement for the award of
the degree of**

Doctor of Philosophy in Food Technology

2017



Dedicated

To my

Parents

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Faculty of Horticulture, Division of Food Science and Technology

Certificate – I

This is to certify that the thesis entitled, “**Utilization of honey-apple blends for the development of corn based breakfast snacks using extrusion technology**” submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Food Technology**, to the **Faculty of Horticulture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** is a record of bonafide research work carried out by **Ms. Jasia Nissar (Regd. No. 2012-419-D)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that information received during the course of investigation has duly been acknowledged.

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Title of the Thesis : **“Utilization of honey-apple blends for the development of corn based breakfast snacks using extrusion technology”**

ABSTRACT

A study was conducted to utilize apple-honey blends for the development of functional corn based breakfast snacks, at the Division of Food process Technology, SKUAST-Kashmir, Shalimar, during 2014-15 and 2016-17. Corn var.C6, Culled apples (CV: Red delicious) and locally procured honey powder were taken for investigation. The extrusion of product was carried out on a co-rotating twin screw extruder (Basic Technology Pvt. Ltd., Kolkatta, India). Response surface methodology (RSM) was used to study the effect of processing conditions on product characteristics. Central composite rotatable design (CCRD) with composition (0-40%), moisture content (12.5-22.5%), barrel temperature (110-190°C) and screw speed (150-550 rpm) as independent variables produced 30 different combinations that were used to investigate effect of these variables on specific mechanical energy (SME) (wh/kg), bulk density (kg/m³), water absorption index (g/g), water solubility index (%), expansion ratio, breaking strength (N) and instrumental colour (L*, a*, b*, c*, ΔE and hue angle) of blended extrudates. Second order polynomial regression models were established and the adequacy of regression model was checked by correlation coefficient. Lack of fit test was used to judge the adequacy of model fit. All the functional properties of the extrudates affected product responses significantly (P≤0.01). On corn-apple blends composition and barrel temperature had a significant effect on all product

responses except on SME, while moisture content had significant effect on SME, WSI, ER,BS. Screw speed was least significant. Barrel temperature and screw speed had significant effect on all colour coordinates. Moisture had significant effect on L* and a* values while composition had interactive significant effect. The optimum conditions obtained after response surface analysis for the preparation of corn based apple incorporated snacks were corn flour to apple powder ratio (90:10), feed moisture (15%), screw speed (450rpm) and barrel temperature (170°C). Nutritional profile of optimized product was checked. The optimized corn-apple extrudates had crude protein, crude fat, crude fiber, dietary fiber, β -glucan as 6.46%, 1.53%, 2.28%, 13.82%, 1.78% respectively, whereas calcium, magnesium, potassium, phosphorus, sodium and zinc contents (mg/100g) were as 7.8, 116.0, 303.8, 193.2, 38.0 and 2.26 respectively. The optimized product was stored in high density polyethylene (HDPE) bags for three months under ambient conditions and analysed for moisture, hardness, free fatty acids, water activity and overall acceptability after every one month.

The experiment II was carried out by Incorporating honey powder to the optimized corn- apple blend. The 30 combinations of corn-apple based honey incorporated snacks generated by RSM were used to investigate the effect of independent variables on SME and product characteristics (BD, WAI, WSI, ER, BS and instrumental colour consequently temperature effected all the variables significantly, WAI and breaking strength were significantly affected by all the processing variables, whereas screw speed had no effect on SME, WSI, BD, ER. The content of crude protein, crude fat, crude fiber, dietary fiber, β -glucan was 3.32%, 1.10%, 2.053%, 12.43% and 1.738% respectively, whereas calcium, magnesium, potassium, phosphorus, sodium and zinc content (mg/100g) were as 7.8, 107.20, 306.04, 195.20, 37.62 and 2.26 respectively. The final product was stored in HDPE bags for three months under ambient conditions and. The optimum conditions obtained after response surface analysis for the preparation of corn-apple based honey incorporated snacks were corn-apple to honey powder ratio (90:10), feed moisture (15%), screw speed (450rpm) and barrel temperature (170°C). Predicted values were very close to the experimental values making the model ideal for prediction of the dependence of the extrudate functional properties on the extrusion variables. The storage studies revealed that product packed in high density polyethylene (HDPE) bags was acceptable up to 3 months, under ambient conditions.

Key words: Corn, extrusion, apple, honey, response surface methodology, storage

Signature of Student

Signature of Major Advisor

Dated : _____

Dated: _____

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Place : Shalimar, Srinagar

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Chapter - 1

INTRODUCTION

Recent awareness and interest in health and wellness has shifted focus on healthy eating and lifestyle. Breakfast snacks, have become an integral part of the daily food intake of the majority of the population. People are gradually realizing the importance and benefits of functional breakfast snacks. Health conscious people are replacing traditional breakfasts with the bowl of functional breakfast snack in order to maintain good health. The need for convenience foods, busy life schedules and increased per capita income in developing countries is giving the breakfast snack industry a new dimension to look for. Globally breakfast snack market, is worth Rs. 1957.06 billion and is forecasted to reach Rs. 2401.85 billion Rs. in 2019. Indian market for snack food is worth around 166.79 billion rupees and has an annual growth rate of 15-20% (Anonymous, 2016).

Current consumer demands have influenced the companies to reformulate their cereals to have lower sodium and low sugar content. From 2005 to 2011, sodium content in the cereals has been reduced by 14% and the added sugar has been reduced by 12% (Thomas *et al.*, 2013). The third most influential selection attribute of breakfast cereals was the presence of whole grains. In 2010, 2/3rd of ready to eat breakfast cereal had “whole grain” in them. Whole grain not only contributes to the fiber content but provides additional nutrition such as proteins, vitamins, minerals and antioxidants. Recent efforts (2012) by the American Bakers Association, National Pasta Association, Grain Foods Foundation, USA Rice and Wheat Foods Council along with corporate members like General Mills and Kellogg Company campaigned with the message “make at least half your grains whole” to strengthen the Dietary Guidelines Advisory (2010) message for young adult women and children to consume more grain (USDA, 2012).

During the recent years, quite a number of technologies in food processing have emerged and made an impact on the availability and variety of food

products. Food extrusion is one of these latest multidimensional food processing technique. Great possibilities are offered in food processing field by the use of extrusion technology to modify physicochemical properties of food components. The extruded foods, besides being preserved, have enhanced biological value, which can be characterized by physicochemical properties superior to the original raw material (Riaz, 2000). Extrusion cooking technology has almost limitless applications in the processing of cereal-based foods and other materials, and is associated with partial or complete gelatinization of the starch, complex formation, transformations and interactions involving biopolymers. The technique may be used to precook, instantize and agglomerate food components (Cheftal, 1990). Extrusion has for years provided the means of producing new and creative foods.

Corn originated in central Mexico about 7000 years ago, starting from teosinte (*Zea mays parviglumis*) which was domesticated. Corn in its different processed forms is an important food for large numbers of people in the developing world, providing significant amounts of calories and protein. On the average corn contains moisture (10%), protein (6%), fat (1.50%), ash (2%) and carbohydrate (80.50%). Corn flour has become an attractive ingredient in the extrusion industry due to its best expansion and puffing (Gujral *et al.*, 2001). In India corn is third most important crop after rice and wheat, occupying area 8.71 million hectares with annual production of 15.55 million tons (Anonymous, 2016). In J&K area under corn cultivation is 323.60 thousand hectares with annual production of 4869 thousand quintals (Anonymous, 2016).

Starch is the dominant polymer in corn and plays important role in extruded products by giving good expansion, binding and mouth feel to the extrudates. The quality of the final product depends on the processing conditions used during extrusion and this includes the composition of the raw materials, feed moisture, barrel temperature, screw speed and screw configuration. Moreover ingredients and formulation play an important role in developing the texture of the

extruded product and ultimately the acceptability of the extruded product to the consumer. The effects of these factors on quality of extruded snack foods that contain a high proportion of corn, wheat, rice and oat have been extensively studied.

Phenolics and antioxidants present in fruits have long been associated with health benefits. Factors such as season changes, high price and perishability affect the consumption of fresh fruits (Rekhy and McConchie, 2014). Therefore, it becomes necessary to incorporate beneficial fruit compounds into the diet using other forms of food such as breakfast cereal. One such fruit, apple has the potential of improving the nutritional status of the extrudates.

Apple (*Malus domestica*), is one of the most widely cultivated tree fruits. Among pome fruits, apple is on the top with respect to area and production in Jammu and Kashmir. J&K has remained the leading apple producer contributing 60% of the total production of country. In Jammu and Kashmir area under apple cultivation is 160865 hectares, with the production of 1647687 MT. In Kashmir division alone area under apple cultivation is 1,43,534 hectares, with the production of 16,33,349 MT (Anonymous, 2013). Apple is rich in carbohydrate content, vitamin A, C and minerals, despite being an excellent source of fibre and potent antioxidant. Post harvest losses in Jammu and Kashmir, have been recorded in the range of 21-48%, therefore a possible application could be its utilization for the production of extruded breakfast having high nutritional value.

Sweeteners are mainly used to replace sucrose and to provide sweetness to different kind of food products. The market of confectionary, which is using sweeteners instead of sucrose, is growing as the nutritional awareness among the people increases. This trend can be explained due to the adverse health effects of sugar (Nabors *et al.*, 1986). The number of people who are suffering from obesity is increasing. Obesity is a serious health problem, which can be traced back to an overconsumption of sugars. This disease goes hand in hand with hypertension, coronary arteriosclerotic heart disease and in-creased cholesterol in the blood.

There are even suggestions that obesity increases the chances for cancer (Nabors *et al.*, 1986). However, the choice, which sweetener to take is not only a matter of which one is the healthiest also other properties like technological and economical properties have to be considered to find out if there is a suitability for a particular food (Mitchel, 2006). Important representatives of such sweeteners is honey.

Honey is the natural sweet substance produced by honey bees, from the nectar of plants (blossoms). Natural honey is one of the most widely sought products due to its unique nutritional and medicinal properties. It is packed with B-vitamins, rich in minerals, having antioxidant activity. It also contains 80-85% carbohydrate (mainly glucose and fructose), 15-17% water, 0.1-0.4% protein, 0.2% ash and minor quantities of amino acids, enzymes and vitamins as well as phenolic antioxidants (James *et al.*, 2009). Each of these minor constituents is known to have distinctive nutritional or medicinal properties and the unique blend accounts for the varied and different applications of natural honeys. Honey has many nutritional and health benefits, which include boosting immunity, soothing GI effect, potent antioxidant, throat soother, antimicrobial. India produces 1800MT of honey annually. The honey production in valley has been reported 350 tons for the year 2010-12 and 350 tons for 2015-16 (Anonymous, 2016). Honey has a long history in human consumption and people prefer having it in their breakfast, incorporation of honey in breakfast snacks could be a convenient way for its proper consumption.

Potato chips followed by corn chips dominated the snack food market worldwide (Singh *et al.*, 2011). Most snacks made from cereal grains (oats, rice, corn) are usually low in nutritional components such as vitamins and minerals. Over the past ten years consumers have become more health conscious and are choosing snacks that claim to be healthier and more nutritious. Therefore the snacks that are rich in fibre, vitamins and minerals and low in fat, are more popular and high in demand. Perusal Of literature shows that little work has been conducted regarding the use of fruit and vegetable products in snack food

production, particularly incorporation of apple and honey in the extruded snack shall give a new perspective and alternative for healthy snack food production and can be found suitable in the commercial production of highly nutritious and cheap extruded products.

Keeping in view all the above mentioned factors, the present study was planned with the following objectives:

- To standardize the level of honey and apple in corn based extruded snacks.
- To study the effect of process variables on characterization of extruded snack and optimization of the processing conditions.
- To study the shelf life of final extrudates.

Chapter - 2

REVIEW OF LITERATURE

2.1 Extrusion

Extrusion has been a common practice in the food industry and continues to grow in applicability especially in preparing starch-based snack foods. It is a high temperature, short time process that runs on a continuous basis and is capable of manufacturing a vast array of foodstuffs. One of the greatest attractions of extrusion is its ability to encompass several conventional methods into one instrument with the addition of high shear forces (Balasubramanian and Singh, 2007). In an extruder there are several sections vital to product quality: feeding, conveying, kneading, forming, and pressuring. The extent of product modification depends on the extruder itself. There are several types of available extruders with twin-screw extruders being the most often utilized and is what was operated in this study. This form of extrusion allows for more versatility, high efficiency, ability to incorporate a variety of ingredients, pressure balance and a large throughput (Vessa 1990).

Extrusion cooking offers several advantages over processes it replaces. The most significant advantage is that the process is continuous. Dry powders can be preblended and fed continuously, in a uniform manner, in to an extrusion cooker. The overall utility consumption for extrusion is less than that of alternate processing. This is primarily the result of using lower moisture levels for cooking and shaping a final product. Second, less heat is lost to the surroundings (Guy and Chorley, 2001).

Extrusion cooking is somewhat unique because gelatinization occurs at much lower moisture levels (12-22%) than is necessary in other food operations. Processing conditions that increase temperature, shear and pressure tend to increase the rate of gelatinization. The presence of other food compounds,

particularly lipids, sucrose, dietary fiber and salts also affects gelatinization (Jin *et al.*, 1994).

Extrusion greatly increased wheat bran and whole flour starch susceptibility to enzymes (improves digestability), but no samples were fully gelatinized under the extrusion conditions with barrel temperatures of 30, 32, 34, 36, 38, and 40 °C and screw speed of 200 rpm. Complete gelatinization may not occur but digestibility is improved nonetheless. The branched structure of amylopectin is easily sheared off in the barrel. Reduction in molecular weight for both amylose and amylopectin has been reported (Wang *et al.*, 1993).

Chinnaswamy (1993) has summarized many factors that affect expansion of starchy materials. Extrusion pressure is a better predictor of expansion than is die nozzle length or diameter ratio. Starches with 50% amylose showed optimal expansion, barrel temperatures close to 150°C and low feed moistures favor expansion. Certain additives may also improve the expansion. Over a range of amylose content, 1% NaCl consistently produced more expansion than did the starch alone.

Extrusion cooking denatures proteins thus large proteins dissociated in to smaller subunits. Denaturation also exposes enzymes susceptible sites, thus improves digestibility. Most proteins such as enzymes and enzyme inhibitors lose activity due to denaturation caused by heat and shear within the extruder barrel. These changes are more pronounced under high shear extrusion conditions, although mass temperature and moisture are also important influences (Della velle *et al.*, 1994).

Extrusion cooking has been used increasingly in the production of food ingredients and foods such as breakfast cereals, baby foods, flat breads, snacks, meat and cheese analogues and modified starches etc. (Anderson *et al.*, 1969; Meuser and van Lengerich, 1992). The extrusion technology has been employed in developing a wide range of raw materials from cereal flour, starch granules,

tubers, legumes etc. into semi-cooked or completely cooked acceptable food products such as breakfast cereals, snacks, flakes, quick cooking pasta products, texturised vegetable protein and breakfast gruel (Iwe and Ngoddy, 1998; Iwe, 2001; Nwabueze *et al.*, 2008; Leszek, 2011).

The effects of process variables on the physical and functional properties of extrudates have been studied (Delgado *et al.*, 2015; Nor *et al.*, 2013; Krrkle, 2011; Yagci and Gogus, 2008; Altan *et al.*, 2008; Ding *et al.*, 2006; Ali *et al.*, 1996; Aylin *et al.*, 2008; Carvalho and Mitchell, 2001). Anderson *et al.* (1969a, b; 1970) and Conway (1971a, b) were among the first to describe process conditions in relation to product behaviour. The effects of mechanical energy and heat inputs employed in extrusion cooking have been studied in highly compressed systems (Guy and Horne, 1988; Colonna *et al.*, 1989).

2.2 Breakfast cereals

Directly expanded snack products such as RTE snacks and breakfast cereals are products that experience high shear stress in the extruder. At low moisture contents [15-22% (w.b.)] and at high temperature (120-200°C), food biopolymers like starch and protein convert into melt inside the extruder. Starch gelatinizes and dextrinizes while protein denatures. Gelatinization and uptake of water by the starch component contributes substantially to the viscosity and the protein constituents play a role in impacting the elasticity and gas holding properties of the melt. As temperature and pressure build up inside the extruder, the superheated steam causes vapor pressure build up in the melt. When exiting the die the drop in pressure to external atmospheric pressure causes the moisture to rapidly flash into steam thereby inflating the melt. A proper elastic melt will turn into a porous friable texture, characteristic of breakfast cereal, as it sets. Mechanisms such as velocity distribution within die, viscous dissipation and elasticity affect the product characteristics (Frame, 1994). These mechanisms are in turn dictated by the factors such as feed composition, moisture content,

mechanical shear and the barrel temperature. Every feed material is unique in its own way, as it alters and contributes to the characteristics of the final product by forming distinct macro and microstructures. Hence, in order to obtain an optimum process condition, it is important to understand and study these various factors that affect the physico-chemical properties of the extrudates.

2.3 Effects of extrusion on physico-chemical properties

2.3.1 Starch

Starch is a polysaccharide and forms a melt as it undergoes gelatinization and fragmentation. The amylose: amylopectin ratio is an important determinant in how the starch transforms inside the extruder. Amylopectin is the branched structure and is more prone to fragmentation than amylose. An increase in specific mechanical energy input results in more breakdown of starch. As starch undergoes transformation, the Tg of the material is affected. Also the screw configuration influences the amount of starch breakdown. Under high shear conditions, starch can breakdown into glucose and dextrans, the process often known as dextrinization. In common terms, the overall disruption of granular structure, swelling and solubilization causes gelatinization and is influenced by the presence of lipids, salt, sugar and protein content. Non-ionic species like sugars increase the temperature needed for gelatinization by depressing the enthalpy of gelatinization. Starch digestion is made easier after extrusion as it makes it more readily available for amylolytic enzymes (Brennan *et al.*, 2013).

2.3.2 Protein

The other major biopolymer that determines the final product properties is the type and amount of proteins. Protein denatures during extrusion which subsequently improves its digestibility. In general protein transformation mechanisms involve denaturation, association such as crosslinking, formation or disruption of covalent bonds. It is proven that vegetable protein nutrition is improved upon extrusion because of new sites opening up for enzyme attack.

Solubility of proteins in water or salt solutions is observed to decrease after extrusion (Della Valle *et al.*, 1994). Moisture content, screw speed and barrel temperatures affect the available lysine content. Lysine degradation is an indicator of protein degradation. A general suggestion to minimize lysine degradation is not to go higher than 180 °C barrel temperature and not below 15% feed moisture (Singh *et al.*, 2007). The reducing sugars react with the terminal amines of free amino acids and produce complex products, including Maillard reaction products. Fibrous texture to mimic meat products, formation of gels and emulsions, novel textures such as and cheese analogs are some examples of how protein modifications can be made using extruders.

2.3.3 Lipids

Lipids are the class of non-polar heterogeneous chemical compounds including triglycerides, phospholipids, sterols, and waxes. Lipid content over 6% generally reduces extruder performance by reducing the torque. Product expansion is compromised because of insufficient pressure development due to reduced slip between screw and barrel walls. Lipids in extrudates are reported to reduce after extrusion possibly due to loss of free oil at the die or because of the formation of lipids complexes between proteins or amylose. Extrusion denatures hydrolytic enzymes, which minimizes free-fatty acid release and subsequent oxidation of products. Some other factors like formation of Maillard reaction intermediates and complex compound formation also reduces oxidation. However presence of lipids causes rancidity in extruded products (Singh *et al.*, 2007; Brennan *et al.*, 2012).

2.3.4 Vitamins

Owing to the variety in their structure and composition, degradation of vitamins during extrusion cannot be generalized. In general higher extrusion temperatures cause loss in vitamin content. Vitamin D, K (lipid soluble) and Niacin, riboflavin (water soluble) are fairly stable during extrusion. However,

thiamine stability is highly variable (5-100%). About 63% of vitamin E degraded during buckwheat extrusion. High screw speed and moisture content lead to riboflavin decrease (Singh *et al.*, 2007; Riaz, 2000).

2.3.5 Minerals

Solid crystalline chemical elements that cannot be synthesized or decomposed by ordinary chemical reactions are called minerals. They are present in small amounts but are increasingly important for nutrition and essential for certain enzyme related reactions. Changes in these small molecules are not affected by extrusion directly as extrusion generally affects the macromolecular structures. But the changes in macromolecules indirectly affect these mineral compounds. For example, it is reported that presence of dietary fiber interferes with mineral bioavailability by reorienting during extrusion. Also some polyphenols such as tannins acts as an inhibitor by hindering mineral absorption. On the contrary iron bioaccessibility is increased in almost all extrusion process. Copper, phosphorous and calcium bioavailability also increases in extrudates because of the added water and leaching from extruder barrel walls. In peas, phytates hydrolysis occurred during extrusion causing mineral release. However, fortification with mineral compounds like calcium reduces expansion and added iron cause dark discoloration in extrudates (Singh *et al.*, 2007).

2.3.6 Phenolic compounds

Fruits and grains are naturally rich in phenolic compounds which exhibit antioxidant capacity and protect against diseases. Extrusion of pulses-cereal blend is reported to increase the phenol content, especially when using whole grain or coloured grain. For instance, raw red-dark bean extrudate showed 14% increase in phenolics as opposed to a 21% decrease in cream coloured beans, because of an 84% increase in quercetin and 40% increase of ferulic acid in the red-bean extrudate. Tannin-protein complex forms when protein is denatured and tannin can act as free radical scavenger when ingested. Significant increase in free/bound

phenolic acids like coumaric acid syringic acids from buckwheat maybe caused due to the release of these compounds from the matrix during extrusion. Yet, free phenolic compounds such as chlorogenic acid, found in potatoes, is shown to significantly decrease after extrusion. In general high barrel temperatures seems to retain more phenolics possibly due to formation of insoluble compounds while low feed moisture caused loss of phenolics (Brennan *et al.*, 2011).

2.4 Raw ingredients used in extrusion

From the time the extrusion cooking process was introduced for food application, preparation of cereal based and starch based products has been the major use. Production of cereal-based snack foods has been on the rise for the last 20 years and continues to grow in popularity. An estimated total of \$20.69 billion was spent on snack foods in 2000 averaging a 6% increase per year (Maga, 2000). As the demand for cereal snacks grows, the food industry continues to find ways to increase production and efficiency while decreasing waste. In the past, processing of these snacks was performed by traditional batch methods that included mixing, forming, baking and drying. The amount of waste produced was not only exorbitant but the required energy to fuel the equipment and time necessary can greatly hindered a company's profitability. Cereal snack processing has been revolutionized by the utilization of extrusion cooking. Twin-screw extrusion is able to decrease space, costs, overall waste, and encumbers several steps from conventional processing into one device (Maga, 1991). While extrusion is a vast improvement from the previous processing methods, perfecting the operation of its several parameters (screw speed, temperature, feed rate, feed moisture) to obtain a consistently desired product quality is still lagging. Initially, the extrusion cooking was used for the production of breakfast cereals as cereal flakes to replace the traditional process of making cereal flakes from maize grits. However, later the extrusion cooking process was used for preparation of various cereal based products, such as expanded, fortified and enriched, shaped cereal, precooked instant cereal, infant, weaning and baby foods (Linko *et al.*, 1981).

Extrusion cooked corn-soya-milk blends as protein fortified cereal grain products have also been prepared for nutrition intervention programmes (Peplinski and Pfeiffer, 1970). Simultaneous extrusion cooking of cereals and fish meal, and corn/soyabean based infant cereal has also been reported (Harper, 1980). Production of instant and quick cooking noodles and pasta (Tsao *et al.*, 1976), instant dried soup or gravy bases from modified starches with co-extrusion of cereals with meat protein, herbs, spices and vegetables (Hauck, 1980) has also been reported. Various types of snack products, have been prepared (Navam, 2014; Hernandez, 2011; Brncic, 2009 and Badifu, 2000).

The addition of fruits and vegetables to extruded snacks has been studied since the 1980's, with the first published work in 1989, by Maga and Kim. Researchers have since then studied the addition of fruit juice, paste, powders, pomace, peels and seeds into extruded products (Upadhyay *et al.*, 2010; Altan *et al.*, 2008; Yagci and Gogus, 2008; Camire *et al.*, 2007; Maga and Kim, 1989). The use of fruit and vegetable by-products is a growing trend in recent literature. One motivation is the addition of value to food processing residues and reduction of waste (Yagci and Gogus, 2010). Other drivers are the concentrated nutrient content of the byproducts (especially in terms of bioactive compounds) and growing interest in increasing the dietary fiber content of foods (Stojceska *et al.*, 2009; Nawirska and Kwasniewska, 2005; McKee and Latner, 2000).

The use of sugar as an ingredient in extrusion cooking of cereals plays the primary roles of sweetening and flavor enhancement, however little has been discussed about the use of sugars in extrusion cooking, involving their implications on extruder performance and product characteristics. Most of literature deals with relatively simple raw materials. Very few researchers viz. Moorie *et al.* (1990) studied the effect bran, sucrose and magnesium on extrudates. Carvalho and Mitchell (2001) studied the effect of sucrose and fructose incorporation into extrudates. Carlos *et al.* (2000) reported the influence of added sucrose on degree of expansion and extent of starch conversion on

extrusion processing of maize grits and wheat flour. Praneeth *et al.* (2012) investigated effects of honey incorporation on functionality of extrudates. Sopade and Le-Grys (1991) studied effect of added sucrose on extrusion cooking of maize.

2.5 Corn based extrudates

Eun Yong (1998) studied effects of processing parameters on physical properties of corn starch extrudates expanded using supercritical CO₂ injection. Corn starch was extruded with a corotating twin-screw extruder (24:1 L/D ratio, 31-mm screw diameter) and supercritical CO₂ was injected as a blowing agent. The effects of barrel temperature (80-90°C), screw speed (150-250 rpm), and water injection (30-54 g/min) on specific mechanical energy (SME) input for the process and the physical properties of extrudates, such as expansion ratio, water absorption (WA), water solubility (WS), breaking stress, and elastic modulus, were examined using a response surface methodology. Barrel temperature had the greatest effect on physical properties of extrudates but not on SME input, whereas screw speed and water injection had significant effects on SME input. Extrudates had a smooth surface, and air cells were uniform and closed, providing low WA and WS. Using superimposed contour plots, optimum barrel temperature, screw speed, and water injection rate, based on maximum expansion ratio and minimum SME input, were 94-96°C, 155-175 rpm, and 36-39 g/min, respectively.98)

Lee *et al.* (1999) studied the effect of Corn starch extruded with a corotating twin-screw extruder (24:1 L/D ratio, 31-mm screw diameter) and supercritical CO₂ was injected as a blowing agent. The effects of barrel temperature (80-90°C), screw speed (150-250 rpm), and water injection (30-54 g/min) on specific mechanical energy (SME) input for the process and the physical properties of extrudates, such as expansion ratio, water absorption (WA), water solubility (WS), breaking stress, and elastic modulus, were examined using a response surface methodology. Barrel temperature had the greatest effect on physical properties of extrudates but not on SME input, whereas screw speed and water injection had significant effects on SME input. Extrudates had a smooth

surface, and air cells were uniform and closed, providing low WA and WS. Using superimposed contour plots, optimum barrel temperature, screw speed, and water injection rate, based on maximum expansion ratio and minimum SME input, were 94-96°C, 155-175 rpm, and 36-39 g/min, respectively.

Boonyasirikool and Churunuch (2000) formulated six corn-based snack with various ratios of corngrit: calcium carbonate (CaCO_3): soybean oil. Extrusion processes were conducted by feeding each formula into an extruder at 444 g/min feed rate, employing 300 rpm. Moisture content of the raw materials were adjusted to 16.0-0.5%, with melt temperature of 156-158°C. The product samples exhibiting best physical properties composed of 93% corn grit, 1% CaCO_3 2% soybean oil, 3% sugar and 1% vitamins and minerals mixtures, which was coded as C6 and exhibited an expansion ratio (E.R.) of 3.90, bulk density (B.D) 70 g/L and compression force (C.F) 69.2 N. However, C6 corngrit based snack samples possessed the characteristics of over expanded, crisp friable mouth feel, orange-yellowish in colour and lack of corn odor. Therefore, further developing of C6, subsequently renamed as CR'0 was undertaken by substituting 10 - 80% of corn grit with broken rice, resulted in 17 formulas. The corngrit-broken rice snacks were examined for physical properties and then coated with chicken flavor prior to subject to sensory evaluation. Extruded samples produced from 50% of broken rice substitution (CR'5) was detected to decrease E.R value (3.70) and increase B.D (76.60 g/L) and C.F (96.5 N.) compared to those samples of CR'0. Among 17 formulas, CR'5 gained the highest scores in flavor and texture preference with the overall acceptability of 7.05, 7.05 and 7.15 (9-point hedonic scale) respectively, which were significantly different at $P \leq 0.05$. However, colour was not significantly different at $P \leq 0.05$ as compared to CR'0.

Pracha and Chulaluk (2000) developed corngrit-broken rice based snack food by extrusion cooking. Six formulas of corn-based snack with various ratios of corn grit: calcium carbonate (CaCO_3) : soybean oil. Extrusion processes were conducted by feeding each formula into an extruder at 444 g/min feed rate,

employing 300 rpm. Moisture content of the raw materials were adjusted to 16.5%, with melt temperature of 156-158°C. The product samples exhibiting best physical properties composed of 93% corn grit, 1% CaCO₃ 2% soybean oil, 3% sugar and 1% vitamins and minerals mixtures, which was coded as C6 and exhibited an expansion ratio (E.R.) of 3.90, bulk density(B.D) 70 g/L and compression force (C.F) 69.2 N. However, C6 corngrit based snack samples possessed the characteristics of over expanded, crisp friable mouthfeel, orange - yellowish in colour and lack of corn odor. Therefore, further developing of C6, subsequently renamed as CR'0 was undertaken by substituting 10 - 80% of corn grit with broken rice, resulted in 17 formulas. The corngrit-broken rice snacks were examined for physical properties and then coated with chicken flavor prior to subject to sensory evaluation. Extruded samples produced from 50% of broken rice substitution (CR'5) was detected to decrease E.R value (3.70) and increase B.D (76.60 g/L) and C.F (96.5 N.) compared to those samples of CR'0. Among 17 formulas, CR'5 gained the highest scores in flavor and texture preference with the overall acceptability of 7.05, 7.05 and 7.15 (9-point hedonic scale) respectively, which were significantly different at $P \leq 0.05$. However, colour was not significantly different at $P \leq 0.05$ as compared to CR'0.

Plahar *et al.* (2003) developed standardized extrusion cooking process for production of a high protein weaning food based on maize, peanuts and soybeans. Major factors evaluated included the effects of blend formulation, extrusion temperature and feed moisture content on ease of extrusion and product quality characteristics. Results showed bulk density and hardness increased while expansion index decreased with increase in feed moisture content. At a fixed range of feed moisture content, product bulk density and firmness decreased while expansion index increased with increasing extrusion temperature. For ease of extrusion and best product quality in terms of sensory attributes and cooking properties, the following extrusion parameters were established for a blend formulation of 75% maize, 10% peanut and 15% soybean: feed particle size of

300-400 µm extruded using a screw speed of 500 rpm, with a feed rate of 4.6 kg/min, feed moisture content of 16-18%, and extrusion temperature of 100-105°C. Pair-wise comparison of the sensory attributes of porridges prepared from milled samples of the weaning foods showed significant differences between extruded products and existing traditional counterparts, with very high scores for all sensory attributes of the extruded products, especially extruded raw (non-roasted) blend samples. In the Home-Use-Test, at least 92% of respondents in two out of the three major ecological zones of Ghana placed overall sensory and functional characteristics of extruded raw blend samples as 'highly acceptable.' About 7% of respondents scored sensory and functional quality attributes as 'acceptable'.

Bhandari *et al.* (2006) determined the effect of extrusion processing condition on the flavour retention and extrudate properties. Corn starch containing five levels of β -cyclodextrin-d-limonene capsules (0-5%) were extruded at five different maximum barrel temperatures (133-167 °C) and screw speeds (158-242 rpm) using a twin screw extruder. The effect of these parameters on the flavour retention, expansion, texture, colour difference (ΔE), Water Absorption Index, Water Solubility Index, and residence time distribution (RTD) were investigated. Barrel temperature and capsule level predominantly influenced flavour retention and extrudate properties, while screw speed primarily affected extruder performances such as torque, die pressure, specific mechanical energy and RTD.

Brncic *et al.* (2009) Evaluated textural properties for whey enriched direct extruded and puffed corn based products. The issue of this work was to incorporate different amount of whey protein concentrate (WPC) in corn flour as raw material during extrusion cooking for achievement extrudates with higher protein content in order to enrich and improve nutritional quality of product and determination of textural-mechanical properties of such a manufactured product. Research was conducted in co-rotating twin screw extruder with setup designed to manufacture direct expanded extrudates based on pure corn flour and enriched

with whey protein concentrate. Experimental data were analyzed with multi parameter correlation analysis using software package statistica 6. Achieved textural properties of direct expanded extrudates with addition and without addition of whey protein concentrate as: extrudate diameter (de), expansion ratio (Er), bulk density (BD), extrudate weight equivalent (EWE), hardness and breaking strenght index (BSI) in bending mode, and penetration mode as well were compared with versatile process parameters (feed moisture content and whey protein concentrate intake). Also water absorption index (WAI), and water solubility index (WSI) were also correlated with empirical models.

Li-Jia (2010) studied mechanical and microstructural properties of expanded extrudates prepared from blends of high amylase corn (*Zea mays* L. ssp. Mays) starch (HACS) and soy protein concentrate (SPC) in relation to the physicochemical changes in starch. Effects of screw speed (230 and 330 rpm) and SPC level (10, 20, 30 and 50%) on expansion and mechanical properties were determined. Compared with 230 rpm, screw speed at 330 rpm resulted in increased specific mechanical energy, expansion ratio, water absorption and water solubility indices and decreased bulk density and piece density. Varying screw speeds did not significantly affect the mechanical strength of extrudates or starch molecular weight distribution. Bulk and piece densities, and water absorption index (WAI) only slightly increased or exhibited no significant trends as SPC level increased to 20%. A substantial increase in bulk and piece densities and decrease in expansion ratio and WAI were observed as SPC level increased from 20 to 30%. The trends were either reversed or moderated as SPC increased to 50%. These results in combination with average crushing force and water solubility index data provided a significant insight into the interactions between HACS and SPC during extrusion processing. As compared to an earlier baseline study by our research group on normal corn starch - SPC extrudates, results from the current study indicated that the expansion of extrudate containing HACS alone was lower than that of extrudates containing normal corn starch. However,

expansion of the HACS-SPC blends was not significantly impacted at 10-20% SPC levels, whereas the expansion of normal corn starch was significantly reduced.

Zeng *et al.* (2011) examined functionalities and relationships between raw and extruded maize flour blends were. The extruded flour had higher water absorption and water solubility indices, and had no differential scanning calorimetry endotherm. The parameters of RVA peak, breakdown, setback, and final viscosity were lowered and the parameters of cold viscosity were improved as the fraction of the extruded flour in the mixture increased. In starches from raw flour, a bimodal distribution of the chain length was found by gel permeation chromatography while in the extruded starches only one fraction was observed. The dough quality of 60% raw and 40% extruded flour mixture was found to be better than with other mixture proportions.

Jose and Kirsi (2012) evaluated lipid stability of corn based snacks containing amaranth and quinoa exposed to different storage temperatures. A co-rotating twin-screw extruder was used to obtain corn-based extrudates containing various concentrations of amaranth and quinoa flour (tested flours). Samples for analyses (content of tested flours, TF: 20, 35 and 50%) were collected under specific extrusion conditions (water content of mass: 14%; screw speed: 350 and 500 rpm; temperature of die: 140 and 150 °C). Analyses included determination of sectional expansion index (SEI), hardness and water content of extrudates (WCE). Formation of hexanal was evaluated from extrudates stored in sealed headspace vials at 20 and 40 °C in darkness using headspace gas chromatography at intervals during storage (0, 1, 3 and 5 weeks). Extrudates containing 20% TF presented significantly higher SEI ($p < 0.05$) than those containing 35 and 50% TF. Hardness and WCE was generally higher in extrudates containing 35% TF than in those containing 20 and 50% TF. SEI was above 8 and hardness below 70 N/mm regardless of the TF. In general, extrudates containing quinoa presented lower hexanal production than extrudates containing amaranth in storage. Extrudates

containing quinoa and exposed to 20°C presented a stable hexanal production along time in contrast to those containing amaranth. At 40°C, extrudates containing quinoa and amaranth showed a rapid increase in hexanal production after 1 week of storage. This study proved that it is possible to obtain expanded extrudates with relatively low hardness and containing up to 50% amaranth or quinoa. Extrudates containing amaranth appeared more sensitive to oxidation than those containing quinoa.

Samaila and Titus (2013) evaluated extrudates made from full fat blend of African breadfruit-soybean-corn was studied. The raw flour blend was extruded in a single screw extruder at 21% moisture content, 140°C barrel temperature, 140 rpm screw speed fitted with 2mm die nozzle diameter. Food extrusion significantly ($p < 0.05$) reduced the moisture and crude protein from 21.00 to 9.70% and from 30.80 to 24.50% respectively. Extrusion cooking did not significantly ($p > 0.05$) affect the fat, crude fibre and energy values of the extrudates. While ash and carbohydrate contents were significantly ($p < 0.05$) increased from 2.85 to 5.15% and from 48.00 to 54.10% respectively upon extrusion. Extrusion cooking did not significantly ($p > 0.05$) affect vitamins B1, C and E of the extrudates; however, vitamin A was significantly ($p < 0.05$) reduced. Extrusion cooking had no significant ($p > 0.05$) effect on histidine, lysine, threonine and phenylalanine contents of the extrudates; while valine, methionine, leucine, tryptophan, arginine and isoleucine contents of the extrudate was negatively affected. Food extrusion significantly ($p > 0.05$) reduced the anti-nutrient contents of the extrudates with trypsin inhibitor having the highest reduction (69.77%) and tannin having the lowest reduction (34.78%).

2.6 Fruits and vegetables in extruded products

Badifu *et al.* (2000) reported the use of locally available raw materials to enrich the contents of provitamin A (beta-carotene) and other nutrients in a corn-based traditional complementary food for infants and pre-school children in Benue State, Nigeria. Fermented corn, dehulled soybean, and sliced mango

mesocarp were dried in a mobile wooden solar cabinet dryer (65-70°C) to a moisture level of 8-10 per cent. The dried products were milled separately. Blends containing different proportions of the flours were prepared to determine the most appropriate blend for preparing an infant food, which was tested by sensory analysis. The most appropriate blend consisted of 55 per cent corn, 25 per cent soy meal, and 20 per cent mango flour (blend B); its beta-carotene content was 233µg/100g. The beta-carotene contents of other blends were 199 µg/100g for 60 per cent corn, 25 per cent soy protein, and 15 per cent mango (blend C), and 158µg/100g for 70 per cent corn, 30 per cent soy protein (blend A), whereas that of traditional maize akamu was 67µg/100g. The provitamin A retention percentages were 89 per cent for blend A, 92 per cent for blend B, 91 per cent for blend C, and 88 per cent for akamu. A healthy, well-fed infant 6 to 11 months of age is expected to consume 200-300 ml of the food, which provides 13-20 µg of retinol activity, compared with 1-2 µg of retinol activity expected from akamu. The porridge prepared with blend B had accepted sensory properties. Detailed nutritional composition, including essential amino acids, was determined.

Osundahunsi (2005) determined the proximate composition and functional properties of extruded/fermented soybeans with plantain flour blends were determined. Plantain flours were prepared from mature unripe and ripe plantain (*Musa aab*) after oven drying at 80°C for 12 hours. Cleaned soybean seeds were manually dehulled after soaking in water at room temperature for 3 hours. The sample was then oven-dried and another batch was fermented. Dehulled soybean and fermented soybean were extruded and blended with each of the unripe and ripe plantain flours at ratios 0, 25, 50, 75 and 100. Proximate composition showed that fermented extruded soybean had the highest protein content (41.1%). The value recorded for non-fermented extruded soybean was 31.5% while the values for the formulated blends ranged from 7.0 to 29.8%. The lowest content (4.4%) was recorded for plantain flour. When compared with both fermented and non-fermented soybean samples, the protein content of the formulated blends

increased as the percentage of protein inclusion increased. Extrusion cooking reduced the moisture content of the products hence prolonging the shelf-life. Water absorption capacity ranged from 120 to 270%. The highest value was recorded for fermented extruded soybean; the values for raw soybean and non-fermented extruded soybean were 220 and 250% respectively. Fermentation decreased oil absorption capacity and emulsion capacity of the formulated blends. Least gelation concentrations of fermented extruded, non-fermented extruded and raw soybean were 24, 22 and 18% respectively. Loose and packed bulk densities showed advantage of economy with packaging. These results indicate potential food uses of fermented and non-fermented extruded soybeans with plantain flour blend as breakfast food, soup bases and ingredient in formulated foods.

Enwere and Ntuen (2005) investigated the effects of various concentrations of ripe fruit pulps on the sensory properties and nutritive quality of a breakfast cereal. The breakfast cereal was formulated using 1kg composite flour (600 mg corn flour and 400 g soy meal) in addition to 100 g cassava starch, 225 g sugar and 12 g salt. Pineapple, pawpaw and banana ripe fruit pulps were added separately to the breakfast formulations at concentrations of 0-400 g/kg composite flour. Sensory evaluation was performed to determine the best product; a comparison with a commercial breakfast cereal, Golden Morn, was also made. Chemical analysis of breakfast cereals was performed to determine moisture, ash, crude protein, crude fibre, dietary fibre and carbohydrate contents. Values for pH, vitamin A, vitamin C, Ca, Na, K, and P were also analysed. Samples containing 100g pineapple, 100g banana, 100g pawpaw fruit pulp per kg of composite flour (equivalent to 7 per cent of the total weight of the breakfast cereal formulation) were the most acceptable. These samples were comparable in sensory evaluation scores with the commercial breakfast cereal sample, Golden Morn, and also in most quality attributes except for Ca, Na, K, and P contents. Chemical analysis indicated that there was an increase in beta-carotene (vitamin A precursor) and

vitamin C and a slight increase in the mineral content of the breakfast cereal as a result of the addition of fruit pulp.

Altan *et al.* (2008b) extruded barley flour-grape pomace blends in 930mm APV co-rotating twin-screw extruder. Response surface methodology using a central composite design was used to evaluate the effects of independent variables, namely die temperature (140-160), screw speed (150-200 rpm) and pomace level (2-10 per cent, db) on product responses (expansion, bulk density, texture and colour). Sensory analysis was carried out for selected extrudates for appearance (colour, porosity), taste (bran flavour, bitterness and sweetness), off-odour, texture (hardness, crispness and brittleness) and overall acceptability. Multiple regression equations were obtained to describe the effects of each variable on product responses. The product responses were most affected by changes in temperature, pomace level and to a lesser extent by a screw speed. Blends of 2 per cent grape pomace extruded at 160°C, 200 rpm and 10 per cent grape pomace extruded at 160°C, 150 rpm had higher preference levels for parameters of appearance, taste, texture and overall acceptability. However, graphical optimization studies resulted in 155-160°C, 4.47-6.57 per cent pomace level and 150-187rpm screw speed as optimum variables to produce acceptable extrudates. The results suggest that grape pomace can be extruded with barley flour into an acceptable snack food.

Karkle (2011) investigated the effect of apple pomace addition in corn based extrudates. In the first part of this study a lab-scale twin screw extruder was used for processing directly expanded products based on corn flour and apple pomace (0-28%), resulting in a total dietary fiber content of 1.1-22.5%. Apple pomace increased nucleation and favored axial expansion. The change in cell size and alignment explained the higher mechanical resistance caused by apple pomace. The objective of the second part was to study the effect of preconditioning regimen on the extent of matrix transformation and impact on texture, microstructure and digestibility. The material was processed on a pilot

scale extruder. The results showed that increasing the opportunity for hydration increased starch gelatinization at all pomace levels. Apple pomace promoted milder extrusion conditions, resulting in less starch gelatinization and solubilization and reduced starch digestibility. Digestibility was also affected by structure, with a strong correlation between the available starch fraction and cell wall thickness/cell size ratio ($r=0.90$). The third part of this study was designed to gain a better understanding of the impact of the individual cell wall components (cellulose, lignin, xyloglucan and pectin) on expansion and structure formation. The results suggest that compatibility with starch is critical for good dispersion in the matrix, therefore good expansion and structure forming properties.

Hernandez *et al.* (2011) processed blends of banana and lentil flour in a single screw extruder modifying the flour properties of the blend (20.5-79.5%), at selected range of die temperature (145-175 °C) and the feeding moisture content (20-24%). Functional characteristics evaluated in the extrudates were water absorption index (WAI), water solubility index (WSI), bulk density (BD), paste viscosity properties, microstructure and resistant starch content. The concentration of lentil/banana blends and temperature were the most important variables acting dependent variables WAI, WSI, BD and viscosity properties. The results of this study indicated that extrusion cooking induced desirable functional characteristics to lentil/banana blends by increasing their resistant starch content.

Anjineyulu (2013) Carried evaluation and characterization of extruded product by using various by-products. Broken rice flour was added in proportions (75%) to equal amount of dehydrated pineapple waste pulp powder and red gram powder (12.5%) were extruded in a twin-screw extruder. The formulation was extruded at different moisture content (17-21%), screw speed (260-340 rpm) and die temperature (120-140°C). The lateral expansion, bulk density, water absorption index, water solubility index, hardness and sensory characteristics were measured as responses. In the experiments, increase in barrel temperature resulted in extrudate with higher expansion, higher hardness, lower bulk density, lower

WSI and higher WAI. Increasing in screw speed resulted in higher expansion, lower bulk density, higher overall acceptability and lower hardness; whereas, increasing level of moisture resulted in lower hardness, lower expansion and minimum bulk density and higher overall acceptability. In the experiment, optimization studies resulted in 132.27°C of barrel temperature, 315 rpm of screw speed and 18.48% of feed moisture.

Nor *et al.* (2013) discussed potential use of dried pumpkin flour as an ingredient in ready-to-eat (RTE) snack foods the addition of ready-to-eat snacks were made by extruding corn grits with 5, 10, 15 and 20% of pumpkin flour. Snacks made from 100% corn grits were used as control products for this work. The effect of formulation and screw speeds of 250 rpm and 350 rpm on torque and specific mechanical energy (SME, kWh/kg), physical characteristics (expansion ratio, bulk density, true density and hardness) and the microstructure of the snacks were studied. Increasing the screw speed resulted in a decrease of torque for all formulations. When pumpkin flour was added the specific mechanical energy (SME) decreased by approximately 45%. Increasing the percentage of pumpkin flour at the higher screw speed resulted in a harder texture for the extruded products. X-ray tomography of pumpkin flour-corn grit snacks showed that increased levels of pumpkin flour decreased both the bubble area and bubble size. However, no significant differences ($p>0.05$) in bubble wall thickness were measured. By understanding the conditions during extrusion, desirable nutritional characteristics can be incorporated while maximizing expansion to make a product with low bulk density, a fine bubble structure and acceptable organoleptic properties.

Ruth (2013) investigated the interactions between fruit powders, extrusion process and physical properties and nutritional qualities of the resulting product. Five different samples were extruded using the same process conditions including a solid feed rate of 20 kg/h, moisture of 13% and barrel temperatures of 80 and 120 °C. Nutritional properties (soluble and insoluble fibre and total antioxidant

content) and physical properties (including bulk density, lateral expansion, and hardness) were evaluated. The addition of fruit powder has significant ($P < 0.05$) effect on expansion and density of the extrudates. Both soluble and insoluble fibre increased substantially after extrusion process while antioxidant levels significantly ($P < 0.05$) decreased. The resulting products had an improved nutritional profile compared with other extruded snack products being low in fat and sugar and a good source of fibre. The snacks received a good level of acceptance on sensory analysis with the preferred sample scoring 4 and 4 out of 5 for appearance and taste respectively. Further work would investigate the effect of varying the levels of fruit powder and the process conditions and considering how nutritional qualities could be further improved (in particular protecting antioxidants during the extrusion process and fortification with vitamins and minerals).

Ying and Gi-Hyung (2014) conducted a systematic comparison of the physicochemical properties of white ginseng (WG), extruded white ginseng (EWG), red ginseng (RG), and extruded red ginseng (ERG) was performed. The aim of the present study was to identify the effects of the physicochemical properties of ginseng by extrusion cooking. The highest value of the water absorption index (WAI) was 3.64 g/g obtained from EWG, and the highest value of the water solubility index (WSI) was 45.27% obtained from ERG. The ERG had a better dispersibility compared with other samples. Extrusion cooking led to a significant increase in acidic polysaccharide and total sugar content but resulted in a decrease in crude fat and reducing sugar contents. Enzyme treatment led to a sharp increase in acidic polysaccharide content, especially the cellulose enzyme. Extrusion cooking led to a significant increase in 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity and reducing power, and the increases in WG and RG were 13.56% (0.038) and 3.56% (0.026), respectively. The data of this study provide valuable information about the effects of extrusion on quality changes of EWG and ERG.

Delgado *et al.* (2015) studied effects of extrusion processing on functionality of snack foods using raw materials rich in carotenoids and dietary fibre. This research studied the effect of extrusion temperature (ET, 93.45-140.55°C), moisture content (MC, 21.27-34.73%), and the winter squash flour content (WSF, 0.43-15.57%) on physicochemical characteristics and content of bioactive compounds of third-generation (3G) snack foods expanded by microwave heating. The ingredients used for their elaboration were corn starch, whole-grain yellow corn and winter squash flours. A single-screw extruder was employed, and the response surface methodology was applied. The lowest bulk density and the highest water solubility index (WSI) and water absorption index, occurred at high ET with low MC. The highest values of total carotenoids and dietary fiber (total and soluble) were obtained at high WSF and ET. Furthermore, when the WSF was increased, the colour L* value diminished, whereas b* value and WSI increased. These results suggest that it is possible to elaborate 3G snack foods with acceptable physicochemical characteristics and excellent bioactive compounds content, improving their potential health benefits.

Ya-Ling Huang and Ya-Sheng Ma (2015) studied the effect of extrusion processing on the physicochemical properties of extruded orange pomace. Extrusion technology was applied to enhance the SDF obtained from orange pomace, a byproduct of juice extraction containing a high level of DF. The pomace was processed in a single-screw extruder at various barrel temperatures (X1; 115-135 °C), feed moistures (X2; 10-18 g/100 g), and screw speeds (X3; 230-350 rpm). Based on response surface methodology, the optimum extrusion conditions, which produced a maximum SDF value of 30.36%, were as follows: barrel temperature, 129 °C; feed moisture, 15%; and screw speed, 299 rpm. Compared with unextruded pomace, SDF fraction in extrudate had a higher level of uronic acid. Furthermore, the extrusion process improved the physicochemical properties of extrudate, increasing the water-holding capacity, swelling, water

solubility index, and cation-exchange capacity and decreasing the oil-holding capacity.

2.7 Use of sugars in extrusion

Sopade *et al.* (1991) studied the effect of sucrose (20-50%, solid basis) on the extrusion cooking of maize starch was investigated. An increase in sucrose content decreased the specific power consumption, die pressure and melt temperature, and increased the tendency of the extrudate to collapse on cooling. The collapse phenomenon was associated with reductions in the starch concentration. Sucrose content increased melt elasticity and longitudinal expansion. Both starch gelatinization and sucrose dissolution were complete up to the 35% sucrose level. The presence of sucrose inhibited degradation of the starch granule. At the 50% sucrose level, the degree of starch gelatinization reduced as moisture content was increased or as barrel temperature was decreased. Sucrose dissolution at the 50% sucrose level was enhanced by an increase in temperature and was decreased on increasing the moisture content.

Fan *et al.* (1996) studied the effects of sugars (sucrose, glucose, fructose, xylose, lactose and maltose) on both sectional (radial) and longitudinal expansion and subsequent shrinkage of maize extrudates have been investigated. Sugars reduced the sectional expansion, monosaccharides more than disaccharides. Reduced sectional expansion and increased density with sugar content was interpreted as a combination of a reduction in bubble growth and an increase in the degree of shrinkage on leaving the die. The decrease in bubble growth was considered to be the result of a temperature reduced driving force for bubble growth and reduced bubble wall extension before rupture caused by less starch conversion with increasing sugar content. Shrinkage stops when the temperature decreases to approximately $T_g + 30^\circ\text{C}$, where T_g is the glass transition temperature. The addition of sugars and water will reduce the glass transition temperature (T_g) of the melt and hence increase the temperature range over which the extrudate will shrink. The driving force for shrinkage is the release of stored elastic energy

following bubble rupture and the pressure difference between the interior of closed cells in the product and atmospheric pressure.

Carlos *et al.* (2000) reported the influence of added sucrose on degree of expansion and extent of starch conversion on extrusion processing of maize grits and wheat flour. Very different behavior was found by two cereal systems. In agreement with previous work, replacement of maize by sucrose at constant water content reduced the specific mechanical energy and as a consequence, reduced the degree of starch conversion and sectional expansion. In contrast, replacement of wheat flour by sucrose even at the levels as high as 20% of flour weight had little effect. Possible causes discussed were less efficient plasticization of wheat flour by sucrose compared with maize grits at low water contents, a specific role for gluten and the larger particle size of maize grits compared with wheat flour.

Praneeth *et al.* (2012) optimized process variables to study their effect on functional properties of honey based ready-to-eat expanded snack food. The blends of rice flour, wheat flour and honey were extruded in a twin-screw extruder. Experimental design with temperature (115 to 135°C), screw speed (270 to 350 rpm) and feed proportion (5 to 15%) as independent variables which produced 20 different combinations, were studied using response surface methodology to investigate the effect of these variables on product responses (lateral expansion, bulk density, colour, Water absorption and solubility index characteristics). Multiple regression equations were obtained to describe the effects of each variable on product responses. Results showed that increasing the barrel temperature resulted in extrudate with higher expansion, water absorption index, and lower bulk density. Increasing screw speed resulted in higher expansion, water solubility index and lower bulk density whereas, increasing honey proportion of feed composition resulted in higher bulk density, water solubility index and lower expansion, water absorption index. The graphical optimization studies resulted in temperature (119 to 122°C), screw speed (301 to

321 rpm) and feed composition (9.68 to 10.35%) as optimum variables to produce acceptable honey based extrudates.

2.8 Storage studies of extruded snacks

Shaviklo *et al.* (2011) studied quality and storage stability of extruded puffed corn fish snacks during 6-month storage at ambient temperature. Three types of extruded corn-fish snacks, containing 150 g kg⁻¹ carp mince and 150 g kg⁻¹ trout mince, 30 g kg⁻¹ freeze-dried saithe protein and a regular corn snack (control) were produced to study quality changes and storage stability of the products during 6-month storage at 27±2 °C. All products had the same level of water activity and proximate composition except for protein. Fortified snacks had a protein content of 93-98 g kg⁻¹, compared with 65 g kg⁻¹ in the control. A significant increase was observed for peroxide value during storage (0.0 to 2.8 meq kg⁻¹). Scores for attributes describing oxidation and off odors and flavors increased after 5-6months' storage but attributes describing puffed corn snack odor and flavor did not change during storage of any of the products.

Balfour *et al.* (2014) developed fortified corn snack by single type screw extruder using corn Meal, oat meal and whey protein concentrate. The studies were conducted on incorporation of different ratios of CM, OM and WPC. Shelf life study was conducted for two months. Three different ratios of CM, OM and WPC were taken in the proportion of (90:7:3) for the first, (80:16:4) second and (70:25:5) third treatment. Spinach and mint leaves were used for flavouring and seasoning. Physic-chemical and sensory attributes of the samples were evaluated. During storage it was observed that moisture content of sample showed slight increase whereas there was slight decrease in all other parameters. It was observed that all the proximate parameters increased from the control sample to different treatments.

Alam *et al.* (2015) studied the keeping quality and shelf life of carrot pomace chickpea incorporated rice based snacks. The extruded snacks using

ingredients: rice flour, chickpea flour, carrot pomace powder and cheese powder in the proportion of 75:11.25:11.25:2.5 respectively was developed under optimized conditions of 440 rpm screw speed, 150°C die temperature and 24 kg/h feed rate. The developed snacks were exposed to different packaging treatments and stored under room conditions. The stored samples were evaluated for its moisture content, protein content, hardness, overall acceptability and colour attributes at a regular interval for six months. Effect of storage period was more prominent than the packaging treatments. Moisture content, protein content and colour attributes were significantly affected by the storage period and treatments ($p < 0.05$). The quality of snacks was acceptable up to six months in all the packaging treatments. Vacuum packed aluminum laminate samples were found to be best throughout the storage period witnessing highest (84.90%) overall acceptability.

Syed *et al.* (2015) studied the storage behaviour of rice based snacks extruded at pre-optimised conditions (10% walnut kernel incorporation, 14% moisture content, 550 rpm screw speed and 170 °C barrel temperature) was studied in the present investigation. The optimised extruded snacks were packed in low density polyethylene bags and kept under ambient conditions for a period of three months and were analysed at an interval of one month for moisture content, water activity, free fatty acids, hardness, total plate count and sensory evaluation. Gradual increase in moisture content, free fatty acid and a gradual decrease in hardness and overall acceptability was observed during three months of storage. However no recordable change was observed in total plate count. There was very small change in moisture content, water activity, free fatty acid content, hardness and overall acceptability of snacks. It can be therefore concluded that walnut kernel incorporated rice based extruded snacks could be stored in LDPE bags for three months under ambient conditions.

Chapter - 3

MATERIALS AND METHODS

The present investigation titled “Utilization of honey-apple blends for the development of corn based breakfast snacks using extrusion technology” was carried out in the Division of Food Science and Technology, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-Kashmir), Shalimar. The section enlists the materials used and elaborates the processing techniques, analytical procedures and the organoleptic evaluation methods followed during the research.

3.1 Experimental materials

3.1.1 Raw materials used in the investigation

The corn (C-6) variety procured from Division of Genetics and Plant Breeding, SKUAST-Kashmir, was milled in mill (Model 3303, Perten Sweden) in the Division of Food Science and Technology. Culled apples (CV: Red delicious) and honey powder were procured from Kane-Grade Flavours, New Delhi. Culled apples were dehydrated in tray dryer (NSW-154) and ground in grinder (Black and FG-550) to form powder, sieved and stored under ambient conditions ($25\pm 2^{\circ}\text{C}$, 60-62%RH) in high density polyethylene (HDPE) until used.

3.2 Extrusion process

Extrusion experiments were performed on a co-rotating twin screw extruder (Basic Technology Pvt. Ltd., Kolkatta, India). The length to diameter ratio (l/d) was 8:1. The extruder has three barrel zones. Temperature of first and second zone was maintained at 65 and 75 °C throughout the experiment, whereas in third zone (die section) it was varied according to experimental design.

The circular die of 6.0 mm was used. Samples were prepared as per the experimental design. Required moisture content of the blends was adjusted by conditioning through moisture addition.

3.3 Physicochemical composition of raw materials

The physico-chemical characteristics of corn flour, apple powder and honey powder were determined using standard procedures.

3.3.1 Moisture content (%)

Standard AACC (AACC, 2000) procedure was followed for determination of moisture content. Two grams of samples in triplicates (corn, apple and honey) were dried in a clean, dry and pre weighed moisture dish at $130\pm 1^\circ\text{C}$ for 1 hour for corn flour, $105\pm 1^\circ\text{C}$ for apple powder and honey samples were dried to constant weight at 70°C , in an oven, cooled in the desiccators (Silica gel used as adsorbent) and weighed. The moisture loss was calculated and expressed in percentage.

3.3.2 Crude protein (%)

Total nitrogen was determined by the Micro-Kjeldhal procedure (AACC, 2000). Two grams of samples were digested in Kjeldhal flask with digestion mixture (copper sulphate and potassium sulphate in 1:9 ratio) and concentrated H_2SO_2 (20 ml) till light green colour appeared and finally cooled. Ammonia released by distillation of digested samples with saturated NaOH (80ml) was captured in 0.1N HCl and per cent nitrogen was estimated. The protein content was calculated as per cent nitrogen \times factor ($\text{N} \times 6.25$).

3.3.3 Crude fibre (%)

Crude fibre was estimated by the Fibre Tech (AOAC, 1995). The sample was subjected to acid and alkali digestion, residue obtained comprised ash. The residue was ignited, organic matter was oxidised and inorganic residue or ash was left behind. The difference in weight before and after ashing was determined.

$$\text{Crude fibre (\%)} = \frac{W_1 - W_2}{W} \times 100$$

Where,

W = wt. of sample in grams

W₁ = wt. of residue (crude fiber + minerals) in grams

W₂ = wt. of ash remained

3.3.4 Dietary fibre (%)

Dietary fibre was estimated by the dietary fibre system (fibraplus DF). The method is given by JAOAC (1988).

A known quantity of sample was incorporated in four 500ml beakers in equal amount. 50ml of 0.08 M phosphate buffer (pH-6) was added to each beaker with 0.1ml α -amylase. Beakers were covered with aluminum foil and placed in water bath shaker for 15 mints at 95°C. After cooling the beakers to room temperature. 10ml of 0.275 N NaOH solutions was added to the beakers to adjust the pH to 7.5. 5mg of protease was added to each beaker and 0.1 ml of 0.08M phosphate buffer to adjust the pH to 6. Again the beakers were incubated in water bath shaker for 30 mints at 60°C. After cooling, 10ml of 0.325N hydrochloric acid solution was added to maintain pH to 4.5. 0.3ml of amylo glucosidase was added to each beaker and incubated for 30 mints at 60° C. Solution obtained was filtered through glass crucibles. Precipitate was transferred from enzymatic digest to crucibles and washed with 20ml of 78 % ethanol and 10ml of 95% ethanol and finally with 10ml of acetone. Crucibles containing residue were dried in hot air oven and cooled. Crucibles were weighed to determine the weight of IDF (insoluble dietary fiber) residue. Duplicate residue was analyzed for protein by micro- Kjeldahl Method as outlined by Thimmaiah (1999). Another residue was incinerated for Ash. The left over filtrate, four volumes of 95% ethanol were added to precipitate SDF (soluble dietary fiber). After one hour, the precipitate was transferred into crucibles, fitted in filtration module and the above procedure of estimating protein in sample residue and ash content in duplicate sample residue is repeated to get SDF value.

Calculations:

$$\text{Blank \%} = \frac{\text{Wt. of the blank residue} - (\text{protein in blank residue} + \text{ash in blank residue})}{\text{Wt. of sample (g)}} \times 100$$

$$\text{IDF (\%)} = \frac{(\text{Wt. of IDF residue}) - (\text{protein in IDF residue} + \text{ash in IDF Residue}) - \text{blank}}{\text{Wt. of sample (g)}} \times 100$$

$$\text{SDF (\%)} = \frac{(\text{Wt. of SDF residue}) - (\text{protein in SDF residue} + \text{ash in SDF Residue}) - \text{blank}}{\text{Wt. of sample (g)}} \times 100$$

$$\text{TDF (\%)} = \text{IDF} + \text{SDF}$$

For maximum removal of the starches and proteins from the fibre concentrate on the screen. The residue was then slurried sequentially in 8 parts of aqueous ethanol (50 % v/v) containing Bromelain and α -amylase. After each enzyme addition, the mixture was incubated at 35 oC for 20 h to hydrolyze proteins and starches, respectively, filtered and washed with ethanol (96.1 %) to recover β -glucan concentrate. The wet concentrate was oven-dried at 50-55oC for 24-48 h to obtain a gum. Gum was weighed and expressed as percentage recovery.

3.3.5 Crude fat (%)

Fat analysis was done using Soxtec 2045 (Foss Instrument, Sweden) (AACC, 2000). Weighed sample were taken in thimble. Extraction cups were dried in oven at 130°C for 15 minutes and weight of empty cups was taken. After cooling 70 ml of petroleum ether was added. When temperature was attained, the extraction cups were attached to the instrument and boiled for 30 minutes and rinsed for 20 minutes. The recovered ether was collected and the fat contained in extraction cups was estimated.

$$\text{Fat (\%)} = \frac{\text{Weight of fat (g)}}{\text{Weight of sample}} \times 100$$

3.3.6 Ash (%)

Standard AACC procedure (AACC, 2000) was followed. 5 g sample was put in a preweighed silica dish, charred on the hot plate and incinerated in muffle furnace at a temperature of 550 ± 10 °C for about 3 hours. The dish was cooled, weighed and ash content was expressed as percent ash as below:

$$\text{Ash (\%)} = \frac{\text{Weight of ash (g)}}{\text{Weight of sample (g)}} \times 100$$

3.3.7 Total solids

Total solids of the sample were determined by drying the samples in hot air oven at 70 °C as discussed by Ranganna (1986) and using following formula.

$$\text{Total solids (\%)} = 100 - \text{moisture content (\%)}$$

3.3.9 Reducing sugar (%)

Reducing sugars were estimated by phenol sulphuric acid method (Dubois *et al.*, 1956). 100 mg of ground extrudate was hydrolysed by keeping in boiling water bath for 3 hrs with 5 ml of 2.5N HCl and cooled to room temperature. The solution was neutralised with solid Na_2CO_3 until the effervescence ceases and the volume was made upto 100 ml with distilled water the contents were then centrifuged at 8000 rpm for 30 min at 27°C. 1 ml of supernatant was diluted to 100 ml with distilled water. About 1 ml diluted sample was transferred in test tube and 1ml of 5 percent phenol, 5 ml of concentrated sulphuric acid was added. The mixture was shaken well and kept in water bath maintained at 30 °C for 20 min. The absorbance of the solution was measured at 490 nm in spectrophotometer. Reducing sugar in test sample was calculated using standard graph prepared with standard solution of glucose (Appendix-I).

3.3.10 Total sugar (%)

Total sugars were determined by the methods described by Ranganna (1986) with slight modifications. To a known quantity of sample (10 ml or 10 g), 10 ml of 45% lead acetate solution was added and after 10 to 20 min, 5 g

potassium oxalate was mixed. The content was filtered through Whatman No. 41 filter paper and the volume of the filtrate was made up to 100 ml with water. 75 ml of this filtrate was titrated against Fehling's solutions A and B (5 ml each). The remaining 25 ml filtrate is mixed with 5 ml conc. HCl and kept overnight. It is then, neutralized with 10% NaOH solution using phenolphthalein as an indicator. The volume of this pink coloured solution was made up to 75 ml and then, titrated against Fehling's solutions A and B (5 ml each).

$$\text{Per cent total sugar (as invert sugars)} = \frac{0.05 \times V_1 \times V_2}{T \times W \times 25} \times 100$$

Where,

V_1 = Volume of the extract made up to 100 ml.

V_2 = volume made up after neutralization.

T = Titre value.

W = weight or volume of sample taken.

3.3.11 Non reducing sugar (%)

Non reducing sugars were determined by the difference method as follows:

Non-reducing sugars (%) = Total sugars (%) – reducing sugars (%).

3.3.12 Carbohydrates (%)

Per cent carbohydrate was determined by the difference method as follows:

$$\text{Carbohydrate (\%)} = 100 - (\text{Moisture \%} + \text{Fat \%} + \text{Protein \%} + \text{Ash \%} + \text{crude Fibre\%})$$

3.3.13 Calorific value (Kcal/100g)

Calorific value was estimated by the formula given below :

$$\text{Energy (Kcal)} = 9 \times \text{Fat} + 4 \times \text{Protein} + 4 \times \text{Carbohydrate}$$

3.3.14 Vitamins

The samples of extrudate were ground to a homogenous state using a food processor. Analysis of three B group vitamins (thiamin, riboflavin and niacin) was performed using HPLC (Younglin^R 930D) in the Division of Entomology, SKUAST-Kashmir, Kashmir.

Thiamin analysis. A portion of the sample was acid autoclaved at 121.1°C, followed by enzymatic digestion to release protein-bound vitamin and break any thiamin–phosphate bonds. The extract was then assayed by ionpair reversed phase HPLC with a buffered mobile phase (methanol–citrate, pH 2.4). The thiamin was oxidized to thiochrome by post-column reaction with hexacyanoferrate (III) and detected by fluorescence (Gehring *et al.*, 1995).

Riboflavin analysis. A portion of the sample was acid autoclaved at 121 1C, followed by enzymatic digestion to release protein-bound vitamin and break any riboflavin phosphate bonds. The extract was assayed by reversed phase, ion-pair HPLC techniques and detected by fluorescence detection (Egberg and Potter, 1975).

Niacin analysis. A portion of the sample was heated with dilute hydrochloric acid to extract the vitamin and hydrolyze the niacinamide to niacin. The extract was cooled, made to a known volume and subjected to HPLC analysis, using reversed-phase, ion-pair techniques and UV detection at 270 nm (Woollard, 1984).

3.3.15 Minerals (mg/100 g)

0.5g of ground samples were taken for digestion. Di acid mixture of Nitric acid:Perchloric acid in 4:1 proportion was added. It was kept for digestion in digestor than 0.5-1 ml aliquot of samples were taken from digestor and diluted with 100ml of double distilled water. Subsequently it was analysed using atomic absorption spectrometer.

3.3.16 Antioxidant activity

The ground samples (0.5 g) were extracted twice with 10 mL of an ethanol:water (80:20 v/v) solution. The first extraction involved stirring for 2 hours at 30°C and the extracts were pooled. Then, the solid was re-extracted under the same conditions for 12 hours. The extracts were pooled and centrifuged at 1500 g for 20 minutes. The supernatants (about 20 mL) were transferred into a sample vial for total phenolic content, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity, and reducing power analyses.

3.3.17 Beta glucan (%)

Beta glucan estimation was done by alcohol based wet extraction technique (Vasanthan and Temelli, 2009). 50 g of flour was added 300 ml of ethanol (50 %) to form a slurry and refluxed for six hours. The slurry was filtered through a cheese cloth to separate the fibre concentrate and the filtrate was discarded. This process was repeated to allow for maximum removal of starches and proteins from the concentrate on screen. The residue was slurried sequentially in 8 parts of aqueous ethanol (50 v/v) containing bromelain and α -amylase after each enzyme addition, the mixture was incubated at 35 °C for 20 hours to hydrolyze protein and starches, respectively filtered and washed with ethanol (96.1%) to recover β -glucan concentrate. The wet concentrate was oven dried at 50-55°C for 24-40 hours to obtain a gum. Gum was weighed and expressed as per cent recovery.

3.3.18 HMF (hydroxyl methyl furfurals)

HMF was determined by Spectrophotometric method (Winkler) Two grams (± 0.01 g) of samples were dissolved in 5 ml water and transferred to a 10 ml volumetric flask. 2 ml of the solution and 5.0 ml of p-toluidine solution were put in two different test tubes; to one tube was added 1 ml of distilled water (reference solution); to the second 1 ml of 0.5% barbituric acid solution (sample solution). The absorbance of the sample solution against the reference solution at 336 nm

and 550 nm was determined by using spectrophotometer. The quantitative value of HMF was determined using the proposed formula for the method (Bogdanov *et al.*, 1997).

$$\text{HMF (mg/kg)} = \frac{A_{336} - A_{550} \times 149.7 \times D}{W}$$

Where,

A_{336} = absorbance at 336 nm

A_{550} = absorbance at 550 nm

149.7 = Factor

W = Weight of sample

D = Dilution factor

3.3.19 Organic acids

The extraction of organic acids in samples was analyzed according to the method of Wang *et al.* (2008) and Zhang *et al.* (2010). With some modifications, sample was treated as follows, 5 g of fresh sample was grounded into homogenized, followed by transferring to 50 mL volumetric flask and the ultrapure water was added to the scale, organic acids were extracted. Then 8 mL extracts was transferred to the centrifuge tube, the samples were centrifuged at 10000 r/min for 15 min. The supernatant solution was filtered through a 0.45 μm nylon membrane filter. A serial dilution of organic acids (malic acid, fumaric and citric acid) was made by dissolving the required amount of authentic standard in deionised water (dH₂O). All standards were filtered through a 0.22 μm nylon filter before HPLC analysis. Each standard was analysed in duplicate for calibration and their concentrations ranged from 1 to 800 mg/L for organic acids. Qualitative analysis of extracts was carried out according to the external standard method. The injection volume was 20 μL .

3.3.20 Acidity (%)

The titratable acidity of samples was estimated by titrating 5 ml of sample against 0.1N NaOH solution using phenolphthalein as an indicator. The acidity

was calculated and expressed as percent anhydrous citric acid (AOAC, 1995).

3.3.21 Pasting properties

Pasting properties of flours were determined using Rapid Visco analyzer (RVA Starch TM, New Port, Scientific Warriewood, Australia). Flour samples (3.45 g) were taken in aluminum canister and 25 ml of distilled water was added to it. Then they were subjected to programmed heating and cooling cycles where samples were held at 50°C for 1 minute, heated to 95°C for 2 minutes, it is then cooled to 50°C in 7 minutes and then held for 50°C for 2 minutes. The centrifuge rotating speed was maintained at 160 rpm. Parameters including pasting temperature, pasting time, peak viscosity, breakdown, hold, setback and final viscosity were recorded.

Experiment No. 1 : Optimization of processing conditions for the development of apple incorporated corn based extruded snack

Experimental design : The central composite rotatable design (CCRD) for the four independent variables was performed. The independent variables considered were composition (A), moisture content (B), screw speed (C) and Barrel temperature (D). The formula used for determination of number of factors/levels in CCRD design is:

$$\text{CCRD design (No. of factors)} = 2^n + 2xn + \text{centre points}$$

Where, n = No. of independent variable

The independent variables and variation levels are given in Table 3.1.

Response surface methodology (RSM) is a statistical method used to describe the relationship between process variables and product quality characteristics. The main advantage of RSM is that it reduces the number of experimental runs needed to provide sufficient information for statistically acceptable results. RSM is typically used for mapping a response surface over a

particular region of interest, optimizing the response, for selecting operating conditions to achieve target specifications or customer requirements.

Response surface methodology was applied for experimental data. The results were analyzed by a multiple linear regression method to describe 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).

Table-3.1: Process variables used in the central composite rotatable design (CCRD) for four independent variables

Process variables	Code	Variables Level Codes				
		-2	-1	0	+1	+2
Composition (Corn:Apple)	A	100:0	90:10	80:20	70:30	60:40
Moisture content (%)	B	12.50	15	17.50	20	22.50
Screw speed (rpm)	C	150	250	350	450	550
Barrel temperature (°C)	D	110	130	150	170	190

*(C:A)-(Corn:Apple)

Table 3.2: Response surface experiment in terms of actual levels

Standard	Composition (C:A)	Moisture (%)	Barrel temperature (°C)	Screw speed (rpm)
1.	90:10	15.00	170	250
2.	80:20	22.50	150	350
3.	70:30	15.00	170	450
4.	90:10	15.00	130	250
5.	80:20	17.50	150	350
6.	70:30	15.00	170	250
7.	70:30	20.00	130	450
8.	70:30	20.00	170	250
9.	90:10	15.00	130	450
10.	90:10	15.00	170	450
11.	80:20	12.50	150	350
12.	80:20	17.50	150	350
13.	80:20	17.50	150	550
14.	80:20	17.50	150	350
15.	80:20	17.50	150	150
16.	80:20	17.50	150	350
17.	80:20	17.50	150	350
18.	70:30	15.00	130	450
19.	80:20	17.50	110	350
20.	90:10	20.00	130	450
21.	90:10	20.00	170	450
22.	60:40	17.50	150	350
23.	100:00	17.50	150	350
24.	70:30	15.00	130	250
25.	70:30	20.00	130	250
26.	80:20	17.50	150	350
27.	90:10	20.00	130	250
28.	90:10	20.00	170	250
29.	70:30	20.00	170	450
30.	80:20	17.50	190	350

Responses obtained as a result of the proposed experimental design were subjected to regression analysis in order to assess the effects of composition, moisture content, screw speed and barrel temperature on product characteristics. Second order polynomial regression models shall be established for the dependent variables to fit experimental data for each response using statistical software Design-Expert 8 (Stat-Ease Inc, Minneapolis, MN, USA).

$$y_i = b_0 + \sum_{i=1}^4 b_i x_i + \sum_{i=1}^4 b_{ii} x_i^2 + \sum_{i=1}^4 \sum_{j=1}^4 b_{ij} x_i x_j$$

Where, x_i ($i = 1, 2, 3, 4$) are independent variables (Composition, Moisture, Screw speed and Barrel temperature respectively) and b_0 , b_i , b_{ii} , and b_{ij} are coefficient for intercept, linear, quadratic, and interactive effects respectively. Data shall be analyzed by multiple regression analysis and statistical significance of terms shall be examined by analysis of variance (ANOVA) for each response.

3.4 Extrudate characteristics and optimization of processing conditions

3.4.1 System extruder property

3.4.1.1 SME (Specific Mechanical Energy)

Specific mechanical energy (Wh/kg) was calculated from rated screw speed, motor power rating (8.5 kw), actual screw speed, per cent motor torque and flow rate (kg/hr) using following formula (Pansawatet *et al.*, 2007)

$$SME = \frac{\text{Actual screw speed (rpm)}/\text{Rated screw speed} \times \% \text{ motor torque}}{100 \times \text{motor power rating}/\text{mass flow rate (kg/h)}} \times 1000$$

3.4.2 Physical properties of extruded snacks

3.4.2.1 Bulk density (weight/unit volume)

The bulk densities of extrudates were determined by volumetric displacement procedures as described by Patil *et al.* (2007). The volume of expanded sample was measured by using a 100-ml graduated cylinder by rapeseed displacement. The volume of 20 g randomized sample was measured for each test.

The ratio of sample weight and the replaced volume in the cylinder was calculated as bulk density (w/v) (Pan *et al.*, 1998).

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 water absorption index (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 for 30 minutes, gently stirred during this period and then centrifuged at 3000 g for 15 min. The supernatant liquid was poured carefully into tarred evaporating dish. The remaining gel was weighed and WAI was calculated as the grams of gel obtained per gram of solid.

$$\text{WAI (g/g)} = \frac{\text{Weight gain by gel}}{\text{Dry weight of extrudate}}$$

3.4.2.3 Water solubility index (WSI)

Water solubility index (WSI) was determined from the amount of dried solids received by evaporating the supernatant from the water absorption index test described above. WSI was expressed as follows:

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

3.4.2.4 Expansion ratio

Expansion ratio was determined (Halek and Chang, 1992) by using a Digital Vernier Calliper (Diginatic Solar Mitutoya, Japan). The average thickness of ten randomly selected pieces of extrudates from each test was calculated. The expansion ratio was determined as the ratio between the thickness of the extrudate and the die diameter.

$$\text{ER} = D/d$$

Where, D = diameter of the extrudate, and d = diameter of the die hole

3.4.2.5 Instrumental colour

Colour was determined by using Hunter Lab colourimeter (Model SN3001476, Accuracy Micro-sensors, New York). The instrument was calibrated with the user supplied black plate calibration standards that were used for Zero setting. Minotta supplied white calibration setting were used for white calibration. The samples were uniformly packed in clean petriplates with lids. The instrument was placed on the plate and their exposure at different places was conducted. Reading were displayed as L^* , a^* and b^* colour parameter according to the CIELAB system of colour measurement. L^* (Luminosity or brilliance) varies from black (zero) to white (100), a^* from red (+) to green (-) and b^* from yellow (+) to blue (-). Total colour difference (ΔE), chroma values (c^*) and hue angle ($^\circ$) were evaluated from the colour parameters L^* , a^* and b^* using:

$$\Delta E = \sqrt{(L - L^*)^2 + (b - b^*)^2 + (c - c^*)^2}$$

$$\text{Chroma } (c^*) = \sqrt{a^2 + b^2}$$

$$\text{Hueangle } (^\circ) = \tan^{-1}\left(\frac{b}{a}\right)$$

The control (c-6) was used as reference to calculate ΔE

3.4.2.6 Breaking strength

Textural quality of the extrudates were examined by using TA-XT2i Texture analyser (Stable Microsystems, United Kingdom). The compression probe (50 mm diameter, aluminum cylinder) was applied to measure compression force required for sample breakage which indicates hardness. Testing conditions were: 1.5 mm/s pre-test speed; 1.5 mm/s test speed; 10 mm/s post-test speed and 8mm distance.

3.4.3 Sensory evaluation

Extruded snacks were evaluated for sensory attributes (appearance, colour,

texture, flavour, mouthfeel and overall acceptability) through a panel of 10 semi-trained Judges using 5-point headonic scale. The proforma given in Annexure-1 was used for sensory evaluation by ten semi-trained panellists from Division of Food Science and Technology for colour, Appearance, texture, mouthfeel, flavour and overall acceptability.

Table 3.3: Sensory Evaluation Proforma

Name of Panellist: _____ Date: _____

S. No.	Appearance	Colour	Texture	Flavour	Mouthfeel	Overall Acceptability	Comments if any

Excellent = 5
 Very Good = 4
 Good = 3
 Fair = 2
 Poor = 1

Signature of panellist

3.4.4 Optimization of extrusion process variables

Numerical optimisation of the process variables was performed with the help of statistical software Design-Expert 9 (Stat-Ease Inc. Minneapolis, MN, USA). The optimization was carried out under following constraints: Expansion ratio, Specific mechanical energy, water absorption index and water solubility index were maximised while as Bulk density and Hardness were minimised. The software was used to generate optimum processing conditions and to predict the corresponding responses as well.

3.5 Proximate analysis of optimized extruded snacks

- 3.5.1** Moisture (%) (same as in 3.3.1)
- 3.5.2** Crude protein (%) (same as in 3.3.2)
- 3.5.3** Crude fiber (same as in 3.3.3)
- 3.5.4** Dietary fiber (%) (same as in 3.3.4)
- 3.5.5** Crude fat (%) (same as in 3.3.5)
- 3.5.6** Ash (%) (same as in 3.3.6)
- 3.5.7** Total solids (%) (same as in 3.3.7)
- 3.5.8** Titrable acidity (%) (same as in 3.3.8)
- 3.5.9** Reducing sugar (%) (same as in 3.3.9)
- 3.5.10** Non-reducing sugar (%) (same as in 3.3.10)
- 3.5.11** Total sugar (%) (same as in 3.3.11)
- 3.5.12** Carbohydrate (%) (same as in 3.3.12)
- 3.5.13** Calorific value (kcal/g) (same as in 3.3.13)
- 3.5.14** Vitamin (%) (same as in 3.3.14)
- 3.5.15** Mineral profile (%) (same as in 3.3.15)
- 3.5.16** Antioxidant activity (%) (same as in 3.3.16)
- 3.5.17** Water activity

Water activity was measured using water activity meter (AQUA, LAB, SN:PRE000197)

- 3.5.18** Pasting characteristics (Same as in 3.3.21)

Pasting properties were determined by Rapid Visco-Analyser (%) (Newpirt Scientific, Warrie Wood, Australia).

3.5.19 Betaglucan (Same as in 3.3.17)

3.5.20 Colour (Same as in 3.4.2.5)

3.5.21 Break strength (N/mm²) (Same as in 3.4.2.6)

3.6 Storage studies of optimized extruded snack

Optimised product was packed in high density polyethylene bags (HDPE) of 200 gauge and stored for three months under ambient conditions (25±2°C, 60-62% RH) Evaluation tests were carried at 0, 1, 2 and 3 months for :

3.6.1 Moisture content (%) (Same as in 3.3.1.1)

3.6.2 Water Activity (Same as in 3.5.17)

3.6.3 Breaking strength (N) (same as in 3.4.2.6)

3.6.4 Free fatty acids (%)

Standard AOAC procedure (2005) was followed for free fatty acid determination of extrudates with slight modification. Product sample (5g) was taken in flask and 50 ml benzene was added and kept for 30 minutes for extraction of free fatty acids. After extraction, 5ml extract, 5 ml benzene, 10 ml alcohol and phenolphthalein as indicator was taken in flask and titrated against 0.02 N KOH till pink colour disappeared

The acid value was calculated by using the following formula:

$$\text{Acid value as oleic acid} = \frac{282 \times 0.02 \text{ N KOH} \times \text{ml of alkali} \times \text{Dilution Factor}}{1000 \times \text{wt of the samples (g)}} \times 100$$

3.6.5 Organoleptic evaluation (5 point scale) (Same as in 3.3.4.7)

3.6.6 Total plate count (cfu/g)

The samples prepared were analysed for total bacterial and fungal count by standard serial dilution plate count method using nutrient agar (Anonymous, 1957), Martin's Lose Bengal Agar (Martin, 1950).

The total micro-flora of snacks was analysed by suspending 10 g of

extrudates in 90 ml water blank. The aliquots after stirring for 5 minutes were serially diluted and used for plate count techniques. One ml of aliquots from appropriate dilutions was transferred aseptically into sterile plates and molten agar media cooled to 50 °C was poured into respective plates. The plates were gently rotated to uniformly distribute the inoculums before the medium was solidified, the plates were then incubated at 30°C temperature for 3-7 days and colony counts were recorded.

Experiment No. 2 : Optimization of processing conditions for the development honey incorporated corn-Apple based extruded snacks

The best combination of Apple-corn observed under experiment-1 was further studied for the development of nutritious snacks by incorporation of honey at different concentrations. During the process moisture content, screw speed, barrel temperature and best combination

Experimental design: The central composite rotatable design (CCRD) for the four independent variables was performed. The independent variables considered were composition (A), moisture (B), screw speed(C) and Barrel temperature (D). The independent variables and variation levels are given below in Table 3.3

Response surface methodology was applied for experimental data. The results were analyzed by a multiple linear regression method to describe 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 3.4).

Table 3.4: Process variables used in the central composite rotatable design (CCRD) for four independent variables

Process variables	Code	Variables Level Codes				
		-2	-1	0	+1	+2
Composition (C-A:H)*	A	100:0	90:10	80:20	70:30	60:40
Moisture content (%)	B	12.50	15	17.50	20	22.50
Screw speed (rpm)	C	150	250	350	450	550
Barrel temperature (°C)	D	110	130	150	170	190

*Optimized level of Corn (C) + Apple (A) : Honey (H)

Table 3.5 Response surface experiment in terms of actual levels

Standard	Composition (C _A :H)	Moisture (%)	Barrel temperature (°C)	Screw speed (rpm)
1.	90:10	15.00	170	250
2.	80:20	22.50	150	350
3.	70:30	15.00	170	450
4.	90:10	15.00	130	250
5.	80:20	17.50	150	350
6.	70:30	15.00	170	250
7.	70:30	20.00	130	450
8.	70:30	20.00	170	250
9.	90:10	15.00	130	450
10.	90:10	15.00	170	450
11.	80:20	12.50	150	350
12.	80:20	17.50	150	350
13.	80:20	17.50	150	550
14.	80:20	17.50	150	350
15.	80:20	17.50	150	150
16.	80:20	17.50	150	350
17.	80:20	17.50	150	350
18.	70:30	15.00	130	450
19.	80:20	17.50	110	350
20.	90:10	20.00	130	450
21.	90:10	20.00	170	450
22.	60:40	17.50	150	350
23.	100:00	17.50	150	350
24.	70:30	15.00	130	250
25.	70:30	20.00	130	250
26.	80:20	17.50	150	350
27.	90:10	20.00	130	250
28.	90:10	20.00	170	250
29.	70:30	20.00	170	450
30.	80:20	17.50	190	350

C = Corn, A=Apple, H = Honey

Responses obtained as a result of the proposed experimental design were subjected to regression analysis in order to assess the effects of composition, moisture content, screw speed and barrel temperature on product characteristics. Second order polynomial regression models shall be established for the dependent variables to fit experimental data for each response using statistical software Design-Expert 8 (Stat-Ease Inc, Minneapolis, MN, USA).

$$y_i = b_0 + \sum_{i=1}^4 b_i x_i + \sum_{i=1}^4 b_{ii} x_i^2 + \sum_{i=1}^4 \sum_{j=1}^4 b_{ij} x_i x_j$$

where, x_i ($i = 1, 2, 3, 4$) are independent variables (Composition, Moisture, Screw speed and Barrel temperature respectively) and b_0 , b_i , b_{ii} , and b_{ij} are coefficient for intercept, linear, quadratic, and interactive effects respectively. Data shall be analyzed by multiple regression analysis and statistical significance of terms shall be examined by analysis of variance (ANOVA) for each response.

3.7 Extrudate characteristics and optimization of processing conditions

3.7.1 System extruder property

3.7.1.1 Specific mechanical energy (SME) (wh/kg). (Same as in 3.4.1.1)

3.7.2 Physical properties of extruded snacks

3.7.2.1 Bulk density (g/ml) (Same as in 3.4.2.1)

3.7.2.2 Water absorption index (WAI%) (Same as in 3.4.2.2)

3.7.2.3 Water solubility index (WSI%) (Same as in 3.4.2.3)

3.7.2.4 Expansion ratio (Same as in 3.4.2.4)

3.7.2.5 Instrumental Colour (Same as in 3.4.2.5)

3.7.2.6 Break strength (N/mm^2) (Same as in 3.4.2.6)

3.7.3 Sensory analysis of final product (Same as in 3.4.3)

3.7.4 Optimization of extrusion process variables

Numerical optimisation of the process variables was performed with the help of statistical software Design-Expert 9 (Stat-Ease Inc. Minneapolis, MN, USA). The optimization was carried out under following constraints: Expansion ratio, Specific mechanical energy, water absorption index and water solubility index were maximised while as Bulk density and Hardness were minimised. The software was used to generate optimum processing conditions and to predict the corresponding responses as well.

3.8 Proximate analysis of final product

- 3.8.1** Moisture (%) (same as in 3.3.1)
- 3.8.2** Crude protein (%) (same as in 3.3.2)
- 3.8.3** Crude fiber (same as in 3.3.3)
- 3.8.4** Dietary fiber (%) (same as in 3.3.4)
- 3.8.5** Crude fat (%) (same as in 3.3.5)
- 3.8.6** Ash (%) (same as in 3.3.6)
- 3.8.7** Total solids (%) (same as in 3.3.7)
- 3.8.8** Titrable acidity (%) (same as in 3.3.8)
- 3.8.9** Reducing sugar (%) (same as in 3.3.9)
- 3.8.10** Non-reducing sugar (%) (same as in 3.3.10)
- 3.8.11** Total sugar (%) (same as in 3.3.11)
- 3.8.12** Carbohydrate (%) (same as in 3.3.12)
- 3.8.13** Calorific value (kcal/g) (same as in 3.3.13)
- 3.8.14** Vitamin (%) (Same as in 3.3.14)
- 3.8.15** Mineral profile (%) (Same as in 3.3.15)

3.8.16 Antioxidant activity (%) (Same as in 3.3.16)

3.8.17 Water activity

Water activity was measured using water activity meter (AQUA, LAB, SN:PRE000197).

3.8.18 Pasting characteristics (Same as in 3.3.21)

Pasting properties were determined by Rapid Visco-Analyser (%) (Newport Scientific, Warriewood, Australia).

3.8.19 Betaglucan (same as in 3.3.17)

3.8.20 HMF (same as in 3.3.18)

3.8.21 Organic acids (same as in 3.3.19)

3.8.22 Colour (same as in 3.4.2.5)

3.8.23 Break strength (N/mm²) (same as in 3.4.2.6)

3.9 Storage studies of final extruded snacks

Final product was packed in high density polyethylene (HDPE) bags of 200 gauge and stored for three months under ambient conditions (25±2°C, 60-62%RH). Evaluation tests will be carried at 0, 1, 2 and 3 months for :

3.9.1 Moisture content (%) (same as in 3.3.1)

3.9.2 Water activity (same as in 3.5.17)

3.9.3 breaking strength(N/mm²) (same as in 3.4.2.6)

3.9.4 Free fatty acids (%) (same as in 3.6.4)

3.9.5 Organoleptic evaluation (same as in 3.4.3)

3.9.6 Total plate count (CFU/g) (same as in 3.6.6)

Chapter - 4

EXPERIMENTAL FINDINGS

The present investigation entitled “Utilization of honey-apple blends for the development of corn based breakfast snacks using extrusion technology “was carried out in the Division of Food Science and Technology, SKAUST-Kashmir. The results obtained during investigation are presented below:

4.1 Chemical analysis of raw materials

The data shown in the Table 4.1 depicts the chemical composition of corn flour, apple powder and honey powder. In corn flour the per cent moisture, crude protein, crude fat, crude fibre, dietary fiber and carbohydrate were found as 11.3, 8.97, 3.38, 2.6, 12.16 and 74.75 percent respectively. The percentage of moisture, crude protein, crude fat, crude fibre, dietary fiber and carbohydrate for apple powder were 14, 0.92, 0.31, 3.5, 13.5 and 82.97 respectively, whereas the percent moisture, crude protein, crude fat and carbohydrate for honey powder were 17.6, 0.084, 0.38 and 79.55. Corn flour contained 1.86% of beta glucan. Apple powder had fairly high dietary fiber content of 13.5%, and honey had highest antioxidant activity of 48% followed by corn 37%. Highest contents of calcium, potassium and sodium were found in apple, phosphorus and zinc in honey and magnesium in corn flour. Vitamins (thiamin, riboflavin and niacin) were observed highest in in corn flour however no thiamin was recorded in apple powder.

Experiment No. 1 : Optimization of processing conditions for the development of apple incorporated corn based extruded snacks

4.2 Extrusion processing

4.2.1 Experimental design

Response Surface Methodology (RSM) software Design-Expert 9 was used to investigate the effects of processing conditions on product characteristics. The independent variables included the composition (0-40% of apple powder

Table 4.1: Chemical analysis of raw materials

Parameter	Corn	Apple	Honey
Moisture (%)	11.3	14	17.6
Crude protein (%)	8.97	0.92	0.84
Crude fat (%)	3.38	0.31	0.38
Crude fiber (%)	2.6	3.5	-
Dietary fiber (%)	12.16	13.5	-
Ash (%)	1.6	1.8	1.63
Total sugar (%)	1.8	54.81	76
Reducing sugar (%)	-	12.3	74
Non reducing sugar (%)	-	42.5	2.1
Carbohydrate (%)	74.75	82.97	79.55
Beta glucan (%)	1.86	-	-
Antioxidant activity (%)	37	32.51	48
Total solids (%)	88.7	86	82.4
Acidity (%)	-	0.78	0.34
Mineral profile (mg/100g)			
Ca	7	14	8
Mg	127	16	24
K	287	452	326
P	210	39	216
Na	35	74	38
Zn	2.21	0.23	2.85
Organic acids (mg/kg)	----	-----	
Malic			1.52
Fumaric			1.38
Citric			7.61
HMF (mg/kg)	-----	-----	23.6
Calorific value (Kcal/100g)	365.3	338.35	324.98
Vitamins (mg/100g)			
Thiamine	0.385	0.00	0.23
Riboflavin	0.201	0.159	0.02
Niacin	3.63	0.927	0.16

incorporation), moisture content (12.5-22.5%), screw speed (150-550 rpm) and barrel temperature (110-190°C). Dependent variables were Specific mechanical energy (SME), Bulk density, water Absorption Index (WAI), Water Solubility Index (WSI), Expansion ratio (ER) and Breaking strength.

4.2.2 Effect of independent variables on product characteristics and specific mechanical energy (SME)

Models for all parameters were significant. None of the models showed significant lack of fit, indicating that all second order polynomial models correlated well with the measured data. Adequate precision (signal to noise ratio) greater than 4 is desirable. All the parameters showed high adequate precision (Table 4.2). A reasonable good coefficient of determination ($R^2 = 0.84, 0.89, 0.96, 0.88, 0.87, 0.92$ for SME, bulk density, expansion ratio, break strength, WAI and WSI) indicated that models developed for product responses appeared to be adequate. The predicted R-squared was found in reasonable agreement with adjusted R-squared for all the parameters.

4.3 System Parameter

4.3.1 Specific Mechanical Energy (SME)

SME is energy provided by motor drive per unit mass of material in the extruder (Akdogan, 1996). The amount of mechanical energy delivered to the extruded material plays an important role in starch conversion. Higher SME usually favours greater degree of starch gelatinization and extrudate expansion. Hence higher SME is desired for expanding products. The mean values of SME under different extrusion conditions listed in Table 4.3 ranged between 81.10 to 149.78 Wh/kg. Regression analysis was carried out to fit the mathematical models to the experimental data. The significant predicted model for SME can be described by the following equation in terms of coded levels.

$$\text{SME} = +105.58 - 5.04B - 24.16D \quad (1)$$

The significance of coefficient of fitted quadratic model was evaluated by

using F-test and P value. The analysis of variance (ANOVA) for SME given in the Table 4.4 and response surface plots depicted in Figs. 1a and 1b showed that SME decreased with the increase in moisture and temperature.

Table 4.2: Analysis of variance for the Fit of experimental data to response surface models

Term	SME	BD	ER	BS	WAI	WSI
Adequate precision	3.056	12.017	21.617	16.034	25.77	12.564
R- square	0.8492	0.8953	0.9672	0.8839	0.8791	0.9234
Adjusted R square	0.8250	0.7976	0.9365	0.8228	0.8597	0.8519
Predicted R square	0.7782	0.3971	0.8109	0.6503	0.8123	0.5588
CV (%)	9.73	12.60	3.44	14.23	6.02	12.24
Lack of fit	NS	NS	NS	NS	NS	NS

Where,

SME = specific mechanical energy.

BD = bulk density

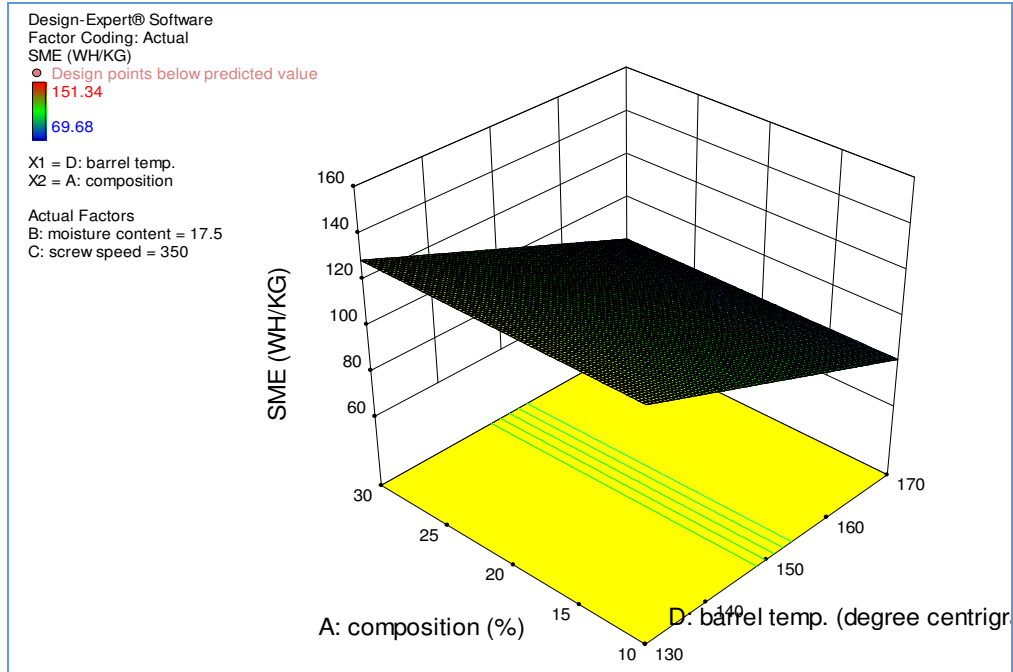
ES = expansion ratio

BS = break strength

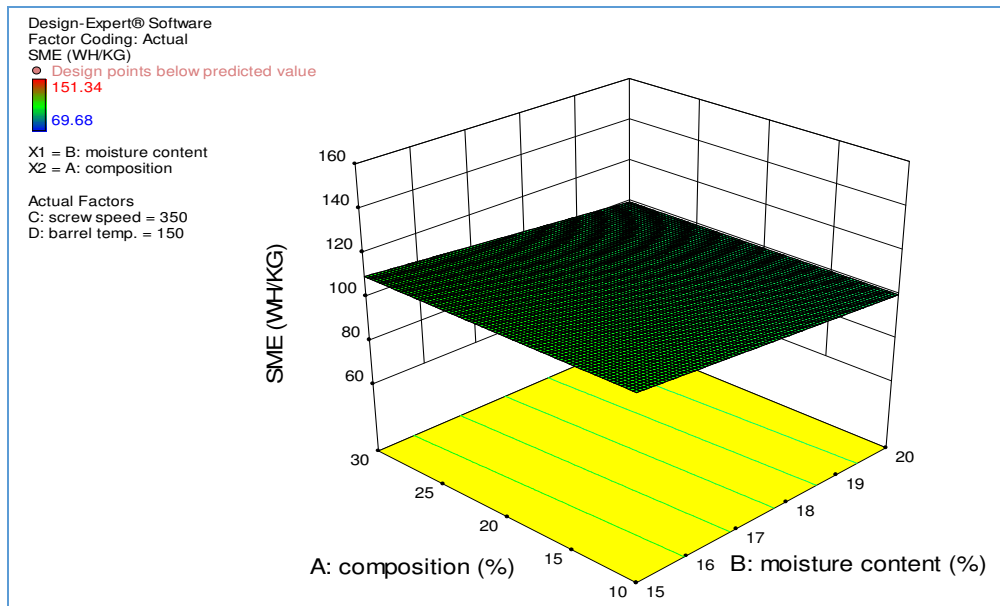
WAI = water absorption index

WSI = water solubility index

NS = non-significant



(a)



(b)

Fig. 1: (a) Response surface plot for SME as function of composition and barrel temperature. (b) Response surface plot for SME as function of composition and moisture content

Table 4.3: Effect of processing conditions on system parameter and product characteristics

S. No.	Composition C:A (%)	Moisture (%)	Screw speed (rpm)	Barrel temp. (°C)	SME (wh/kg)	Bulk density (kg/m³)	WAI (g/g)	WSI (%)	Expansion ratio	Break strength (N)
1	90:10	15	250	130	133.94	218	5.535	10.5	2.89	69.2
2	70:30	15	250	130	144.61	376	3.712	8.5	2.32	154.2
3	90:10	20	250	130	133.43	229	6.160	6.5	2.78	74.9
4	70:30	20	250	130	122.5	380	3.801	10.5	2.26	168.2
5	90:10	15	450	130	151.34	197	5.621	7	2.95	62.8
6	70:30	15	450	130	149.78	373	3.608	13	2.35	146.3
7	90:10	20	450	130	140.24	226	5.334	8	2.83	72.8
8	70:30	20	450	130	137.71	378	3.645	14.5	2.29	163.3
9	90:10	15	250	170	86.99	171	5.011	14	3.53	48.8
10	70:30	15	250	170	84.89	311	3.711	13.5	2.45	119.7
11	90:10	20	250	170	83.96	159	5.201	9.5	2.98	57.5
12	70:30	20	250	170	81.1	322	3.778	17	2.39	134.2
13	90:10	15	450	170	88.91	138	4.775	9.5	3.55	47.6
14	70:30	15	450	170	87.88	261	3.525	19	2.46	112.8
15	90:10	20	450	170	84.01	188	4.841	7.5	3.2	54.6

Contd...

Table 4.3 contd...

S. No.	Composition C:A (%)	Moisture (%)	Screw speed (rpm)	Barrel temp. (°C)	SME (wh/kg)	Bulk density (kg/m ³)	WAI (g/g)	WSI (%)	Expansion ratio	Break strength (N)
16	70:30	20	450	170	83.91	288	3.681	16	2.43	126.5
17	100;0	17.5	350	150	88.83	134	5.56	9.5	3.54	46.9
18	60:40	17.5	350	150	91.3	375	3.612	18	2.18	184.8
19	80:20	12.5	350	150	119.86	345	3.805	14.5	2.62	88.9
20	80:20	22.5	350	150	90.11	369	4.601	12	2.62	98.2
21	80:20	17.5	150	150	89.93	369.1	4.582	9	2.56	101.5
22	80:20	17.5	550	150	99.8	354	4.555	9.5	2.66	82.6
23	80:20	17.5	350	110	143.7	362	4.585	4.5	2.48	109.6
24	80:20	17.5	350	190	69.68	270	3.981	16.5	2.74	74.8
25	80:20	17.5	350	150	96.52	359	4.37	10	2.59	94.9
26	80:20	17.5	350	150	96.52	359	4.37	10	2.59	94.9
27	80:20	17.5	350	150	96.52	359	4.37	10	2.59	94.9
28	80:20	17.5	350	150	96.52	359	4.37	10	2.59	94.9
29	80:20	17.5	350	150	96.52	359	4.37	10	2.59	94.9
30	80:20	17.5	350	150	96.52	359	4.37	10	2.59	94.9

*(C:A)= Corn:Apple, SME(Wh/kg) = Specific mechanical energy, BD(kg/m³) = bulk density WAI(g/g) = Water absorption index, WSI(%) = Water solubility index, ER=Expansion ratio, BS(N) = break strength

Table 4.4: ANOVA for SME

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	105.58	14841.97	1.87	4	35.19	0.0001**
(B) Moisture	-5.04	609.84	2.10	1	5.78	0.020*
(D) Temperature	-24.16	216.60	2.10	1	132.90	0.0001**

*Significant at P<0.05

**Significant at P<0.01

4.4 Physical parameters of extruded snacks

4.4.1 Bulk density

Bulk density is major physical property of the extruded products. Bulk density considers expansion of products in all the directions in contrast to expansion ratio that considers expansion only in direction perpendicular to extrudate flow (Meng *et al.*, 2010). Bulk density of extrudates ranged between 134-380 kg/m³ (Table 4.3). The significant quadratic model obtained from regression analysis for Bulk density (BD) was developed as follows:

$$BD = +359.00 +68.54A -30.12D - 35.93A^2 - 20.55D^2 \quad (2)$$

The analysis of variance (ANOVA) given in the Table 4.5 indicated linear as well as quadratic effect of composition (A) and temperature (D) on bulk density. Response surface plots depicted in Fig. 2 indicted positive relation of composition and inverse relation of temperature with bulk density. It may be observed from Table 4.5 that F values of composition (A) and temperature (D) are 79.91 (P<0.01) and 15.44 (P<0.01) respectively indicating the direct significance of process parameters. F values for square terms A² and D² are 25.09(P<0.01) and 8.21(P<0.01) indicating that both the terms are significant.

Table 4.5: ANOVA for bulk density

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	359.00	1.810E+005	15.34	14	9.17	0.0001**
(A) composition	68.54	1.128E+005	7.67	1	79.91	0.0001**
(D) Temperature	-30.12	21780.38	7.67	1	15.44	0.0013**
(A ²) (composition ²)	-35.93	35407.68	7.17	1	25.09	0.0002**
(D ²) (Temperature ²)	-20.55	11587.85	7.17	1	8.21	0.0118*

*Significant at P<0.05

**Significant at P<0.01

4.4.2 Water absorption index (WAI)

WAI measures the water holding by starch granules after swelling in excess water, which corresponds to the weight of the gel formed. WAI depends on degree of starch damage due to gelatinization and extrusion induced fragmentation and on availability of hydrophilic groups. The WAI of extrudates ranged between 3.525 and 6.16 g/g (table 4.3). The quadratic model obtained from regression analysis for water absorption was developed as follows

$$\text{WAI} = +4.45 - 0.70A - 0.17D \quad (3)$$

The regression analysis showed that the WAI decreased with increase in composition and barrel temperature. The ANOVA for WAI given in Table 4.6 and the response surface plots depicted in Figs. 3 indicated the negative effect of composition (A) and barrel temperature (D) on WAI. Analysis of variance (Table 4.6) shows that F-values for composition (A) and barrel temperature (D) were 166.10 (P<0.01) and 9.77 (P<0.01) respectively showing that A and D are significant terms.

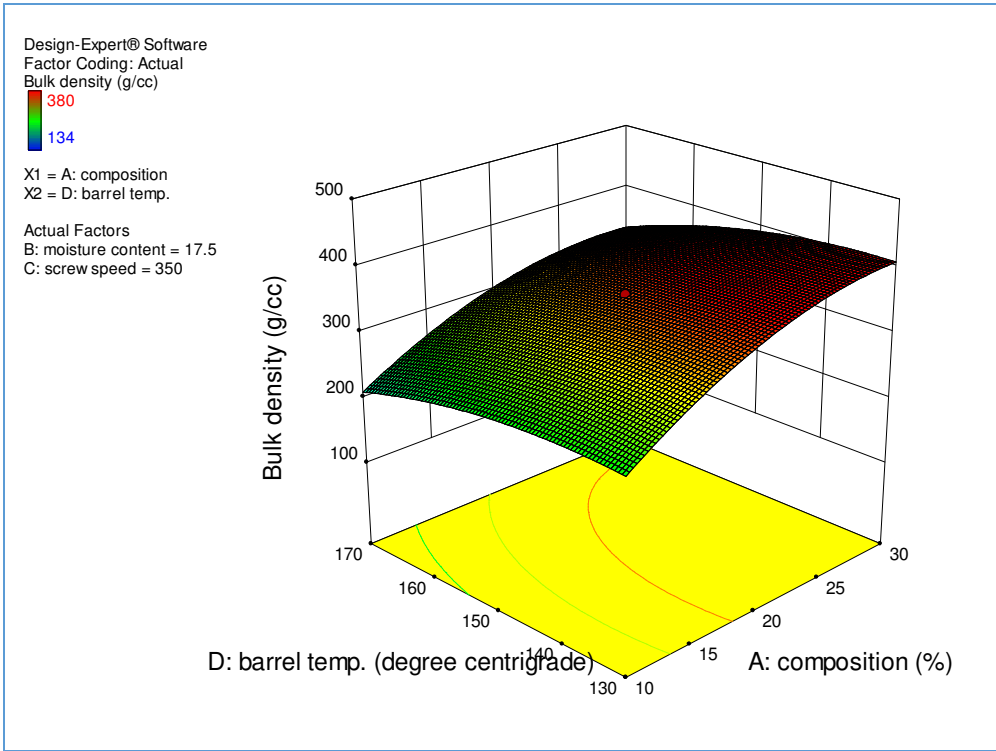


Fig. 2: Response surface plot for bulk density as function of barrel temperature and composition

Table 4.7: ANOVA for WAI

Factors	Coefficient estimate	Sum of squares	Standard error	d.f.	F-value	Prob>F
Intercept of model	4.45	13.04	0.049	4	45.44	0.0001**
(A)composition	-0.70	11.92	0.055	1	166.10	0.0001**
(D)Temperature	-0.17	0.70	0.055	1	9.77	0.0004**

**Significant at P<0.01

4.4.3 Water solubility index (WSI)

WSI measures the amount of soluble components released from the starch after extrusion. High WSI is an in vitro indicator of good starch digestibility as it implies the extent of gelatinization and dextrinization. WSI ranged from 4.5 to 19 percent (Table 4.3). The significant predicted model for WSI is given below.

$$\text{WSI} = +10 + 2.35A + 2.15D + 0.84AB + 0.91A^2 + 0.79B^2 \quad \dots (4)$$

The analysis of variance (Table 4.7) and response surface plots of WSI shown in (Fig. 4) showed the significant positive linear influence of composition (A) and barrel temperature (D) on WSI. Regression analysis also showed positive interactive effect between composition and moisture and quadratic effect of composition and feed moisture on WSI. ANOVA (Table 4.7) show that F-values for composition (A) and barrel temperature (D) were 69.95 (P<0.01) and 58.12 (P<0.01) respectively showing that A and D are significant terms. The F-value for interaction term of composition \times moisture (A \times B) is 5.99 (P<0.05) signifying that the interaction term is significant. F-values for square terms of composition (A²) and moisture (B²) are 11.98 (P<0.01) and 8.92 (P<0.01) respectively indicating both these square terms are significant.

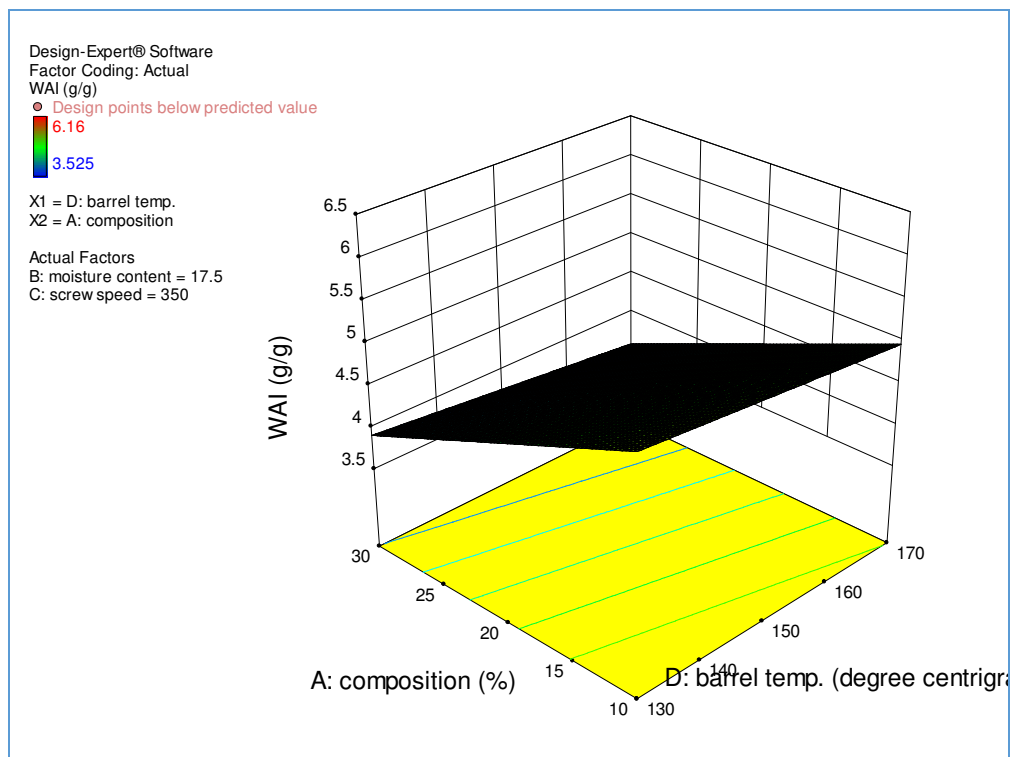


Fig. 3: Response surface plot for WAI as function of barrel temperature and composition

Table 4.7: ANOVA for WSI

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	10.00	343.85	0.56	14	12.92	0.0001**
(A) composition	2.35	133.01	0.28	1	69.95	0.0001**
(D) Temperature	2.15	110.51	0.28	1	58.12	0.0001**
(AB) Composition × moisture)	0.84	11.39	0.34	1	5.99	0.0272*
(A ²) composition ²	0.91	22.79	0.26	1	11.98	0.0035**
(B ²) moisture ²	0.79	16.97	0.26	1	8.92	0.0092**

*Significant at P<0.05

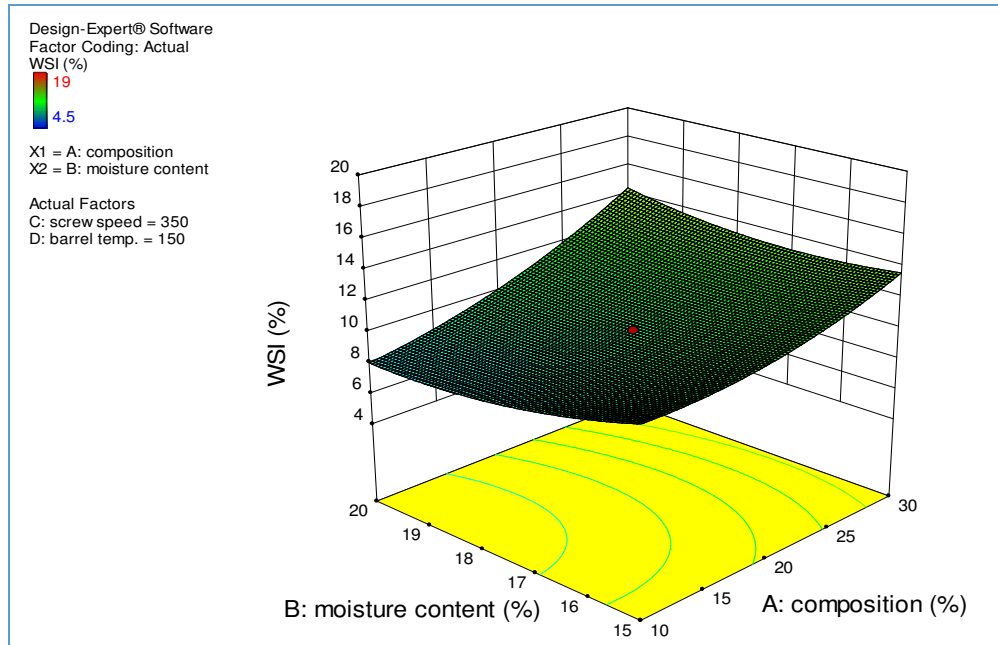
**Significant at P<0.01

4.4.4 Expansion ratio (ER)

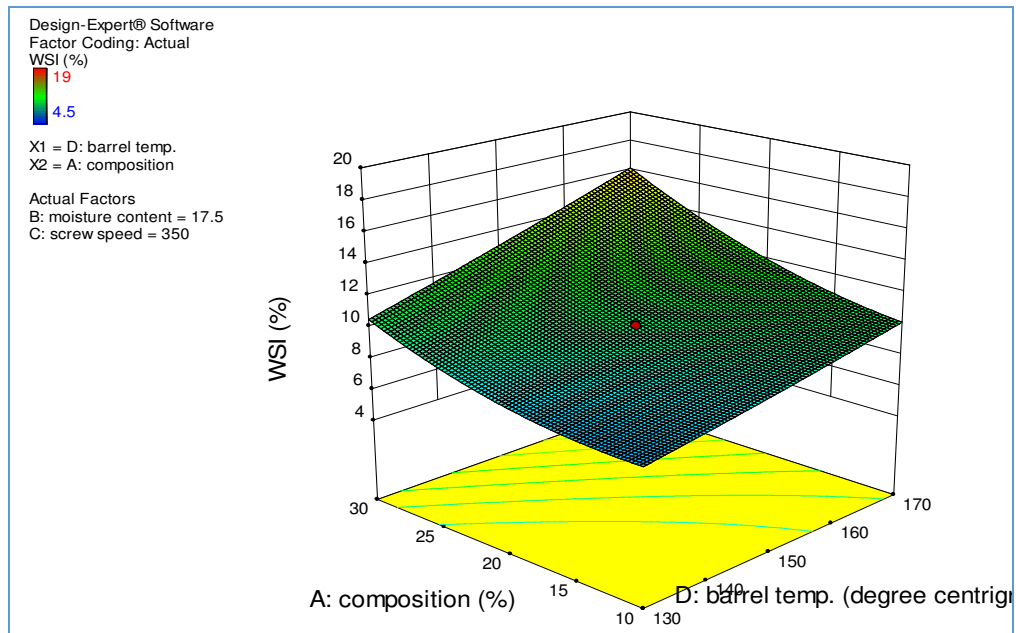
Expansion ratio indicates the extent of puffing of extruded products. During extrusion cooking, the viscoelastic mass formed is forced through the die, the sudden pressure drop causes part of the water to vaporize, giving an expanded porous structure. The mean values of expansion ratio varied between 2.18 and 3.55 (Table 4.3). The regression analysis was carried out to fit the mathematical models to the experimental data. The significant model representing expansion ratio in terms of coded independent variables is as follows.

$$ER = + 2.59 - 0.35A - 0.056B + 0.12D + 0.057AB - 0.081AD + 0.076A^2 \quad (5)$$

The analysis of variance for expansion ratio given in Table 4.8 and response surface plots (Fig. 5) showed the significant linear negative effect of composition (A), moisture (B) and positive effect of barrel temperature (D) on expansion ratio. Regression analysis also showed that ER was significantly affected by interactive effects between composition (A), moisture (B) and composition (A), barrel temperature (D). Analysis also showed quadratic effect of composition (A) on ER.



(a)



(b)

Fig. 4: (a) Response surface plot for WSI as function of composition and moisture content. (b) Response surface plot for WSI as function of composition and barrel temperature

Table 4.8: ANOVA for Expansion ratio

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	2.59	3.78	0.038	14	31.57	0.0001**
(A) composition	-0.35	3.00	0.019	1	350.49	0.0001**
(B) moisture content	-0.056	0.075	0.019	1	8.75	0.0098**
(D) Temperature	0.12	0.34	0.019	1	39.31	0.0001**
(AB) composition × moisture)	0.057	0.053	0.023	1	6.19	0.0251*
(AD) composition × temperature	-0.081	0.11	0.023	1	12.36	0.0031**
(A ²) composition ²	0.076	0.16	0.018	1	18.76	0.0006**

*Significant at P<0.05

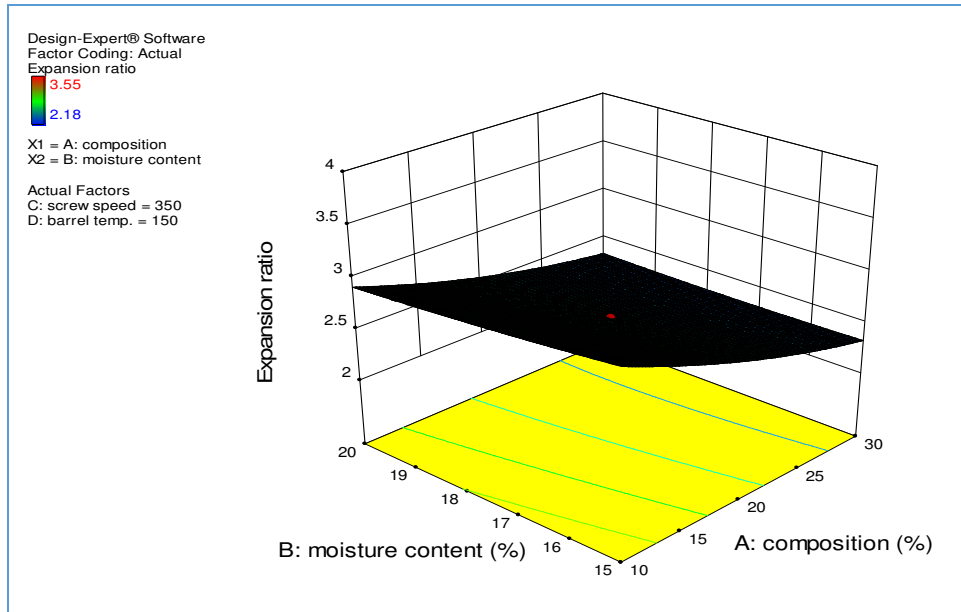
**Significant at P<0.01

4.4.5 Breaking strength

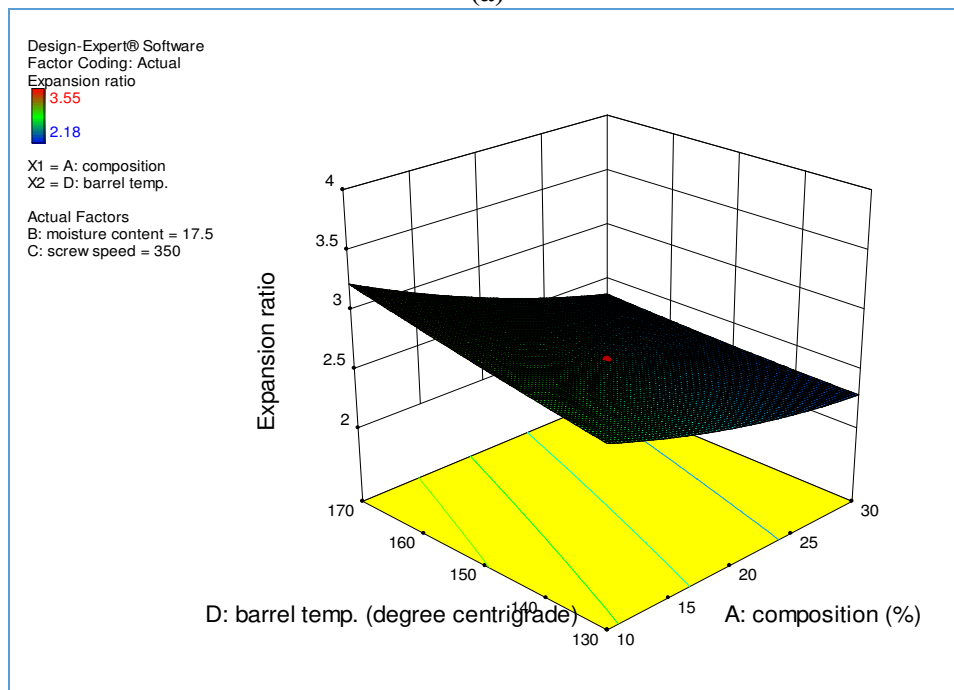
The breaking strength (BS) is the maximum force required to break or snap the snack, and is an indication of snack hardness. Mean values of breaking strength ranged between of 46.9 to 184.8 N (Table 4.3). The regression analysis was carried out to fit the mathematical models to the experimental data. The predicted model can be described by the following equation.

$$BS = +94.9 + 38.03A + 4.55B - 3.24C - 11.65D - 4.22AD + 5.64A^2 \quad (6)$$

The regression analysis (Table 4.9) and response surface plots (Fig. 6) showed the significant positive linear effect of composition and moisture, while it showed negative effect of screw speed and barrel temperature on breaking strength. Regression analysis also showed that breaking strength was significantly affected by the interactive effect of composition and barrel temperature. Analysis



(a)



(b)

Fig. 5: (a) Response surface plot for expansion ratio as function of composition and moisture content. (b) Response surface plot for expansion ratio as function of composition

also showed quadratic effect of composition on breaking strength. Since the coefficient A^2 is positive, a minimum hardness will occur in the range of composition considered in the study.

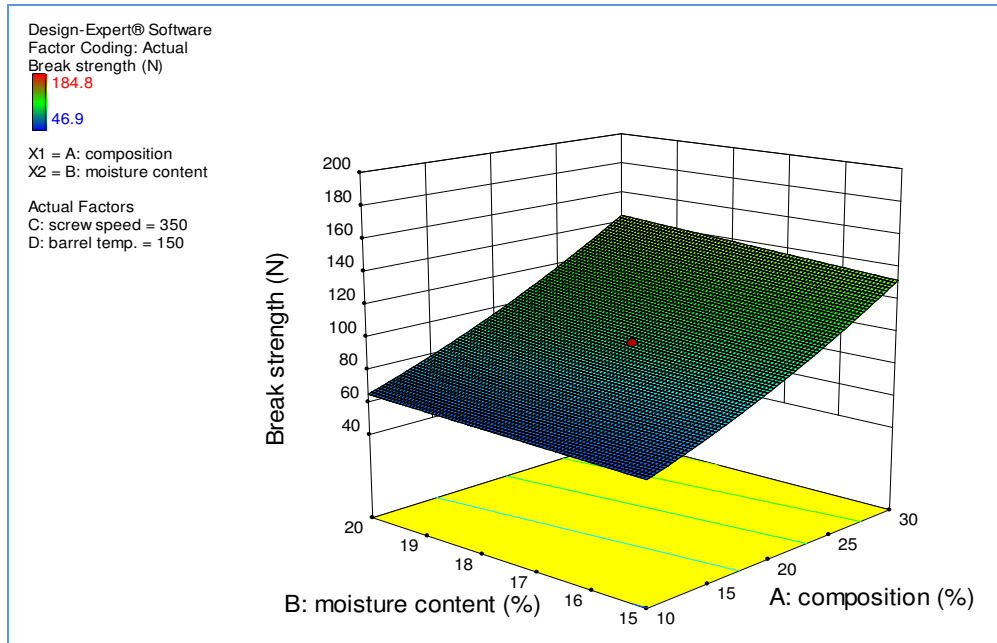
Table 4.9: ANOVA for Breaking Strength

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	94.90	400013.04	2.06	10	112.01	0.0001**
(A) composition	38.03	34716.83	1.03	1	1360.55	0.0001**
(B) moisture content	4.55	496.86	1.03	1	19.47	0.0005**
(C) screw speed	-3.24	252.20	1.03	1	9.88	0.0067**
(D) Temperature	-11.65	3257.34	1.03	1	127.65	0.0001**
AD (composition × temperature)	-4.22	285.61	1.26	1	11.19	0.0044**
A^2 (composition ²)	5.64	873.01	0.96	1	34.21	0.0001**

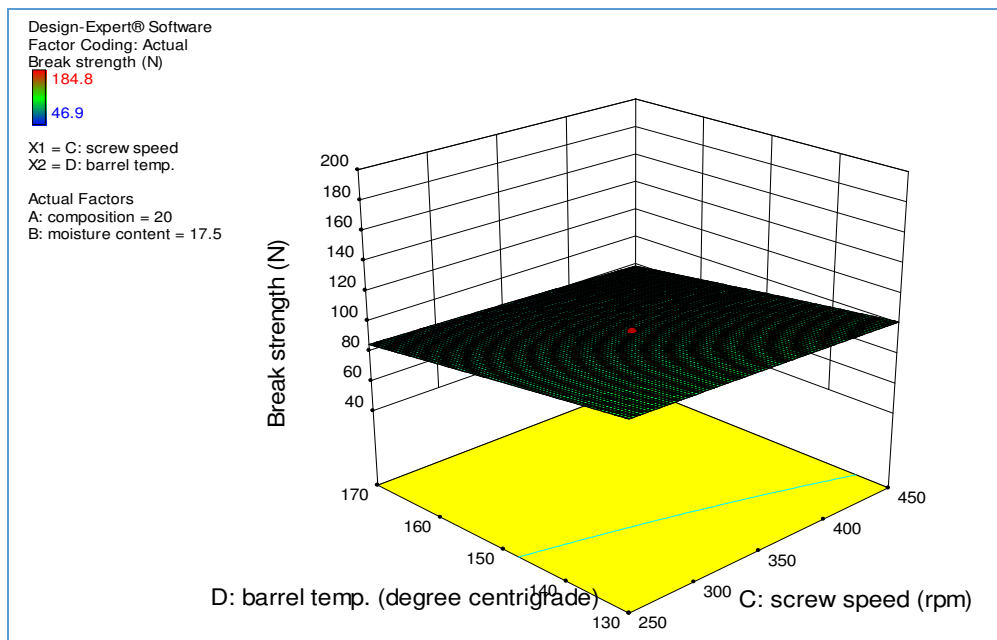
**Significant at $P < 0.01$

4.4.6 Effect of extrusion conditions on colour coordinates of apple incorporated corn based snacks

The data on mean values of colour coordinates revealed that the regression models for L^* , a^* , b^* , c^* , ΔE and hue angle were highly significant with a high correlation coefficient (R^2 0.908, 0.9859, 0.9830, 0.9850, 0.9858, 0.9826 respectively). Both a^* , b^* were negatively correlated with L^* , however they were positively correlated with each other. None of the models showed significant lack of fit, indicating that all second order polynomial models correlated well with the measured data. The predicted R-square was found in reasonable agreement with



(a)



(b)

Fig. 6: (a) Response surface plot for break strength as function of composition and moisture content. (b) Response surface plot for as break strength as function of barrel temperature and screw speed

adjusted R-square for all the parameters (Table 4.10). Adequate precision of greater than 4 is desirable. All the parameters showed high adequate precision (Table 4.10).

Table 4.10: ANOVA and model statistics for the colour parameters of corn based apple incorporated breakfast snacks

Term	Response to models					
	L*	a*	b*	c*	ΔE	Hue angle ($^{\circ}$)
R-square	0.9908	0.9859	0.9830	0.9850	0.9858	0.9826
Adjusted R-square	0.9823	0.9727	0.9672	0.9710	0.9726	0.9664
Predicted R-square	0.9472	0.9188	0.9023	0.9137	0.9184	0.9000
Adequate precision	39.226	35.138	27.28	28.975	33.801	32.821
CV	0.40	6.05	0.52	0.52	11.38	0.37
Lack of fit	NS	NS	NS	NS	NS	NS

NS: non-significant

The colour parameter, luminosity (L^*) of extrudates ranged from 54.16 to 60.58 whereas redness (a^*) and yellowness (b^*) were in range of 0.65 to 4.6 and 36.38 to 40.01 respectively. The mean values of chroma (c^*), total colour difference (ΔE) and hue angle ($^{\circ}$) were found in the range of 36.16 to 40.42, 0 to 5.89 and 81.75 to 88.87 respectively. Table 4.11; Figs. 7, 8, 9, 10, 11 and 12 demonstrates response surface plots of different colour coordinates versus two independent variables. The models developed for luminosity (L^*), redness (a^*), yellowness (b^*), chroma (c^*), hue angle, and total colour difference (ΔE) are given below in equations :

$$L^* = 55.58 - 0.16B + 0.72C - 1.56D - 0.39CD + 0.31C^2 + 0.42D^2 \quad (7)$$

$$a^* = 4.20 - 0.45C + 1.14D + 0.28B - 0.21AC - 0.25BC - 0.11A^2 - 0.098B^2 - 0.37C^2 - 0.34D^2 \quad (8)$$

$$b^* = 39.12 - 0.42C + 0.99D - 0.19AC - 0.21A^2 - 0.19B^2 - 0.38C^2 - 0.27D^2 \quad (9)$$

$$c^* = 39.34 - 0.52C + 1.02D + 0 - 0.13AC - 0.13BC - 0.13CD - 0.23A^2 - 0.21B^2 - 0.42C^2 - 0.29D^2 \quad (10)$$

$$\Delta E = 0.97 + 0.29C - 0.68D - 0.14AC + 0.25BD - 0.77CD - 0.16A^2 + 0.69C^2 + 0.87D^2 \quad (11)$$

$$\text{Hue angle} = 83.87 - 0.16B + 0.57C - 1.56D - 0.34AB + 0.28AC + 0.34BC + 0.13A^2 + 0.51C^2 + 0.56D^2 \quad (12)$$

The negative coefficients of linear terms of temperature and positive coefficients of screw speed in equation (7) indicates that luminosity decreases with an increase in barrel temperature and increased with increase in screw speed. The fitted regression equation (8) shows that with the increase in moisture and temperature, the values of redness (a^*) increased where as with the increase in screw speed these values decreased. The positive coefficients of linear terms of temperature and negative coefficients of screw speed (equations 9-10) indicated that both b^* (yellowness), and c^* (chroma) increased with increase in barrel temperature and decreased with decrease in screw speed. The negative coefficients of linear terms of temperature and positive coefficients of screw speed in equations (11, 12) indicates that total colour difference and hue angle decreased with an increase in barrel temperature and increased with increase in screw speed, An increase in hue angle was observed with decrease in moisture. The results therefore, indicate that the extrudates obtained at 170°C and 250 rpm screw speed had a minimum brightness (54.16) however, the maximum brightness(60.58) was observed in products extruded at 110 °C and 450 rpm screw speed.

Table 4.11: Effect of extrusion conditions on colour coordinates

Extrusion conditions				Product responses					
Composition (%)	Moisture (%)	Screw speed (rpm)	Temp. °C	L*	a*	b*	c*	ΔE	Hue angle
90:10	15	250	130	56.68	2.01	37.38	37.43	2.22	86.92
70:30	15	250	130	56.65	2.08	37.4	37.45	2.14	86.81
90:10	20	250	130	56.6	2.2	37.51	37.57	1.98	86.64
70:30	20	250	130	56.58	3.41	37.63	37.7	1.83	85.29
90:10	15	450	130	58.92	1.9	36.72	36.79	4.61	87.1
70:30	15	450	130	58.89	1.4	36.38	36.4	4.4	87.79
90:10	20	450	130	58.61	1.6	36.71	36.7	3.63	87.5
70:30	20	450	130	58.54	1.9	36.83	36.87	3.71	87.04
90:10	15	250	170	54.48	4.58	39.2	39.43	1.6	83.74
70:30	15	250	170	54.32	4.5	39.38	39.63	2.5	83.48
90:10	20	250	170	54.22	4.6	39.51	39.77	2.08	83.35
70:30	20	250	170	54.16	5.8	40.01	40.42	3.06	81.75
90:10	15	450	170	55.72	4.6	39.14	39.07	1.2	83.29
70:30	15	450	170	54.67	3.6	38.17	38.33	1.02	84.61
90;10	20	450	170	54.52	3.3	39.11	38.27	1.58	85.05
70;30	20	450	170	54.47	3.5	38.03	38.16	1.35	84.65
100:0	17.5	350	150	55.67	3.8	38.24	38.42	0	84.32
60:40	17.5	350	150	55.56	4.1	38.37	38.58	0.34	83.9
80:20	12.5	350	150	55.78	3.7	38.29	38.47	0.91	84.33
80:20	22.5	350	150	55.21	4.3	38.46	38.69	0.71	83.62
80:20	17.5	150	150	55.32	3.75	38.41	38.64	2.87	84.46
80:20	17.5	550	150	58.65	2.1	36.81	36.84	4.29	86.77
80:20	17.5	350	110	60.58	0.65	36.14	36.16	5.89	88.87
80:20	17.5	350	190	54.29	5.4	40.00	40.36	2.74	82.78
80:20	17.5	350	150	55.58	4.2	39.12	39.34	0.97	83.87
80:20	17.5	350	150	55.58	4.2	39.12	39.34	0.97	83.87

Table 4.12: ANOVA for L*

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	55.58	82.23	0.092	14	115.74	0.0001**
(B) Moisture	-0.070	0.59	0.046	1	11.67	0.0038**
(C) Screw speed	0.72	12.48	0.046	1	246.02	0.0001**
(D) Temperature	-1.56	58.56	0.046	1	1154.00	0.0001**
CD (screw speed × temperature)	-0.39	2.44	0.056	1	48.11	0.0001**
C ² (screw speed ²)	0.31	2.61	0.043	1	51.49	0.0001**
D ² (temperature ²)	0.42	4.86	0.043	1	95.86	0.0001**

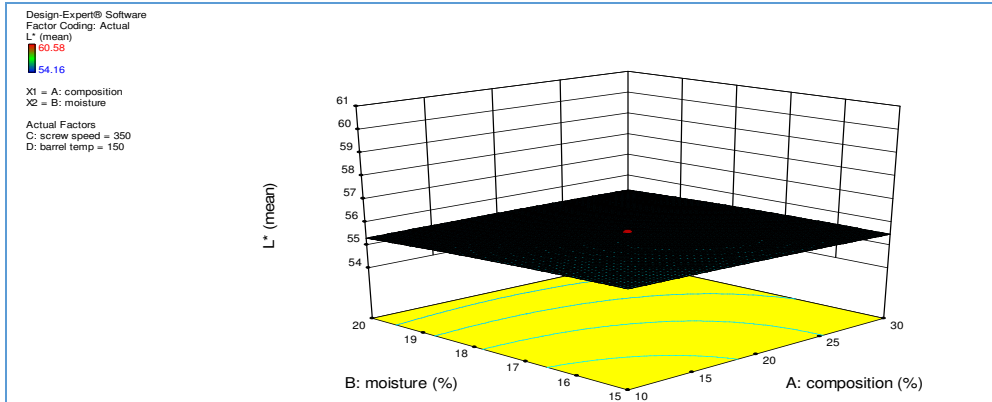
**Significant at P<0.01

Table 4.13: ANOVA for a*

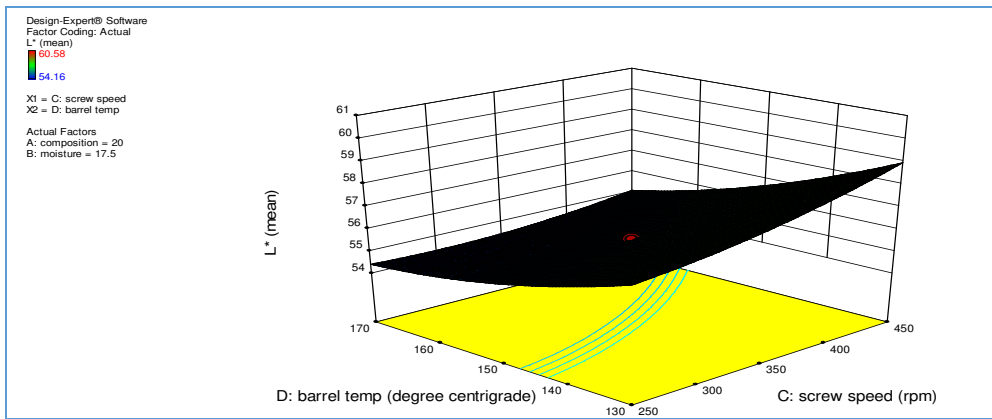
Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	4.20	46.13	0.086	14	74.89	0.0001**
(B) Moisture	0.12	0.34	0.043	1	7.64	0.0145*
(C) Screw speed	-0.45	4.75	0.043	1	108.02	0.0001**
(D)Temperature	1.14	31.465	0.043	1	715.14	0.0001**
AC	-0.21	0.72	0.052	1	16.42	0.0010**
BC	-0.25	1.02	0.052	1	23.19	0.0002**
A ²	-0.11	0.34	0.040	1	7.63	0.0145*
B ²	-0.098	0.26	0.040	1	6.00	0.0270*
C ²	-0.37	3.69	0.040	1	83.91	0.0001**
D ²	-0.34	3.21	0.040	1	72.86	0.0001**

*Significant at P<0.05

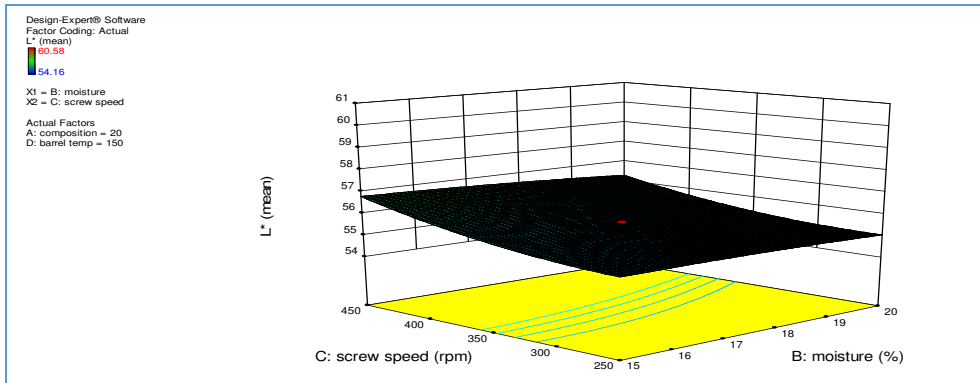
**Significant at P<0.01



(a)

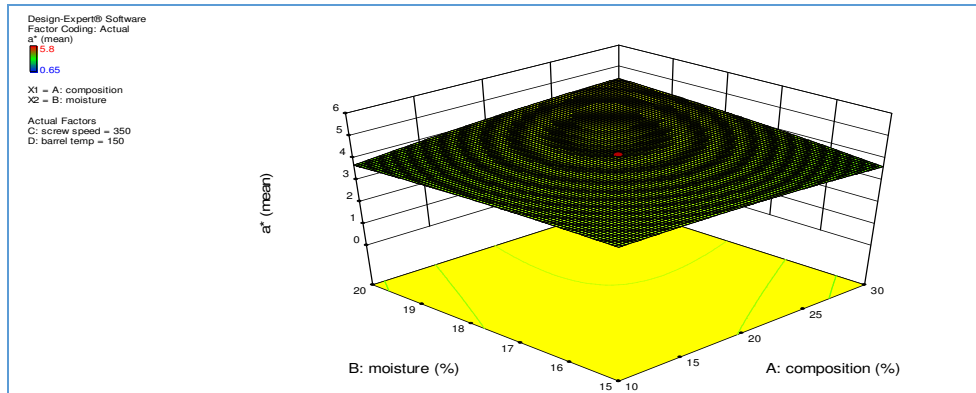


(b)

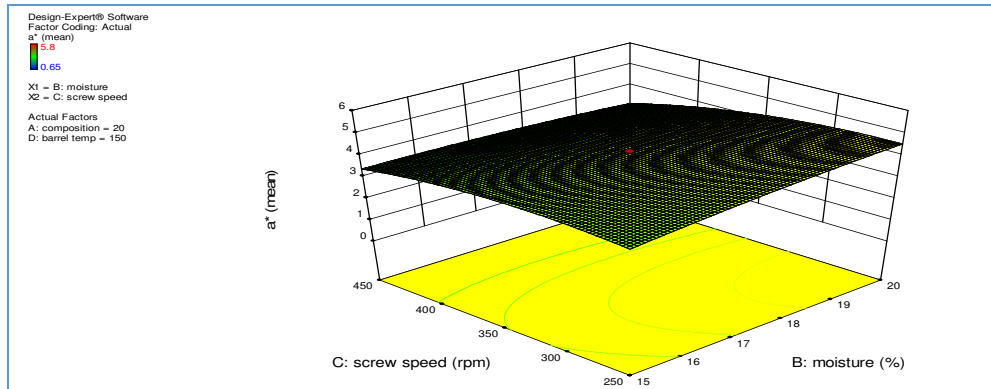


(c)

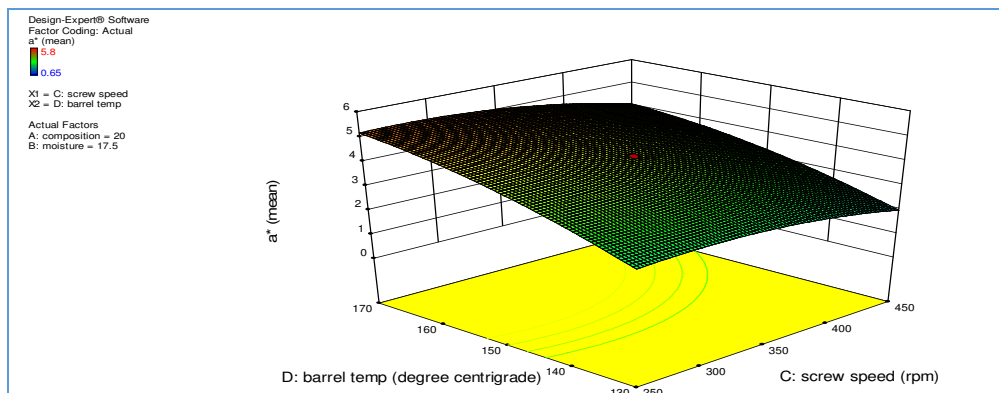
Fig. 7: (a) Response surface plot for L^* as function of moisture and composition. (b) Response surface plot for L^* as function of barrel temperature and screw speed. (c) Response surface plot for L^* as function of screw speed and moisture



(a)



(b)



(c)

Fig. 8: (a) Response surface plot for a^* as function of moisture and composition. (b) Response surface plot for a^* as function of screw speed and moisture (c) : Response surface plot for a^* as function of barrel temperature and screw speed

Table 4.14: ANOVA for b*

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	39.12	36.67	0.082	14	62.08	0.0001**
(C) Screw speed	-0.42	4.28	0.041	1	107.19	0.0001**
(D) Temperature	0.99	23.42	0.041	1	587.24	0.0001**
A ²	-0.21	1.18	0.038	1	29.52	0.0001**
B ²	-0.19	0.99	0.038	1	24.74	0.0001**
C ²	-0.38	3.98	0.038	1	99.79	0.0001**
D ²	-0.27	1.94	0.038	1	48.63	0.0001**

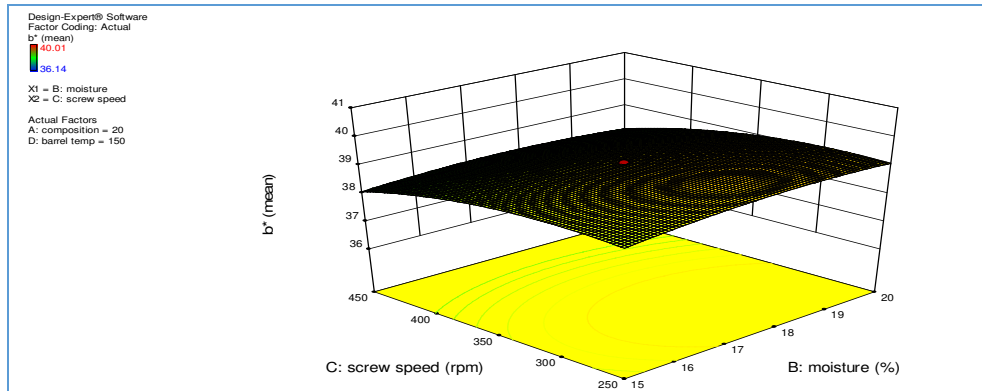
**Significant at P<0.01

Table 4.15: ANOVA for C*

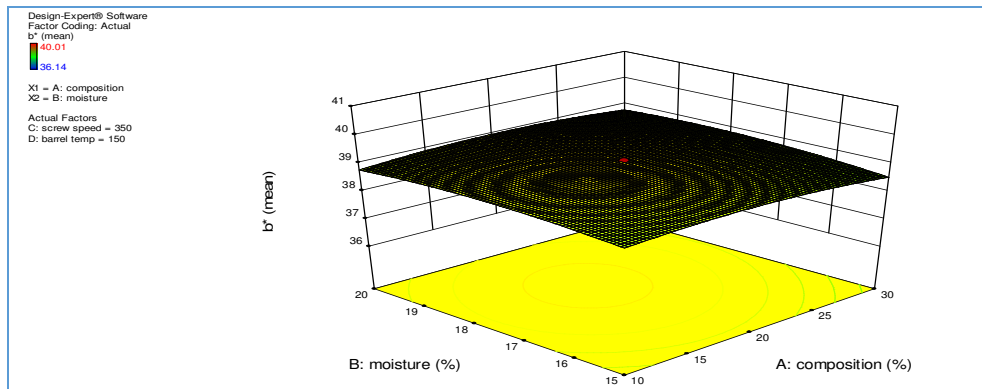
Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	39.34	40.07	0.082	14	70.45	0.0001**
(C)Screw speed	-0.52	6.42	0.041	1	157.96	0.0001**
(D) Temperature	1.02	25.15	0.410	1	619.18	0.0001**
AC	-0.13	0.27	0.050	1	6.59	0.0214*
BC	-0.13	0.28	0.050	1	6.85	0.0194*
CD	-0.13	0.26	0.050	1	6.34	0.0237**
A ²	-0.23	1.51	0.038	1	37.06	0.0001**
B ²	-0.21	1.26	0.038	1	31.00	0.0001**
C ²	-0.42	4.94	0.038	1	121.54	0.0001**
D ²	-0.29	2.38	0.038	1	58.47	0.0001**

*Significant at P<0.05

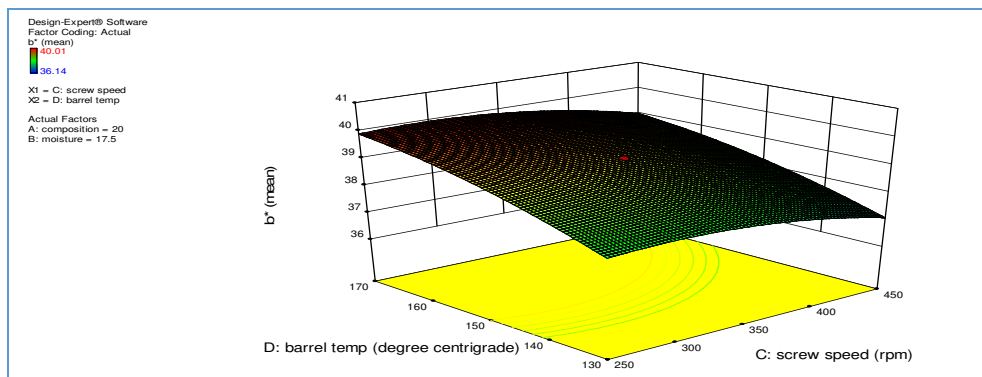
**Significant at P<0.01



(a)

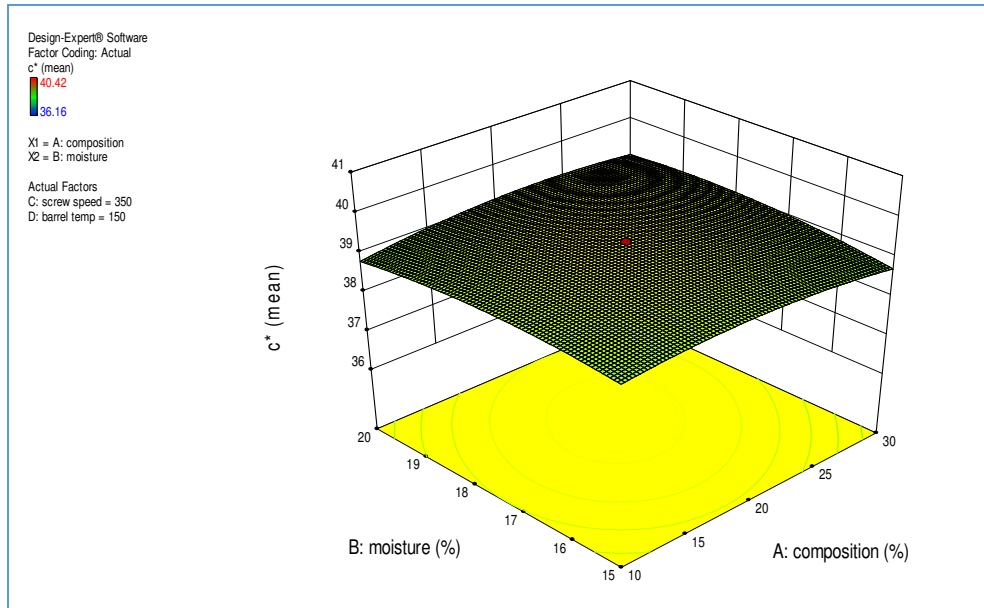


(b)

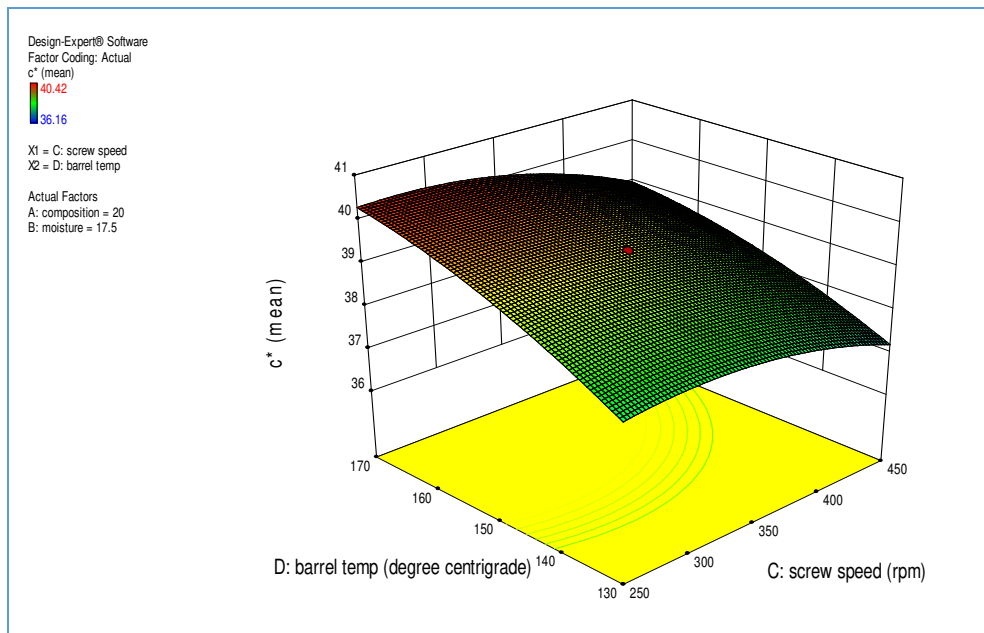


(c)

Fig. 9: (a) Response surface plot for b^* as function of screw speed and moisture. (b) Response surface plot for b^* as function of moisture and composition screw speed (c) Response surface plot for b^* as function of barrel temperature and screw speed



(a)



(b)

Fig. 10: (a) Response surface plot for c^* as function of moisture and composition screw speed and moisture. (b) Response surface plot for c^* as function of Barrel temperature and screw speed

Table 4.16: ANOVA for ΔE^*

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	0.97	58.60	0.097	14	74.55	0.0001**
(C) Screw speed	0.29	2.00	0.048	1	35.64	0.0001**
(D) Temperature	-0.68	11.25	0.048	1	200.33	0.0001**
AC	-0.14	0.30	0.059	1	5.34	0.0355*
BD	0.25	0.99	0.059	1	17.54	0.0008**
CD	-0.77	9.41	0.059	1	167.59	0.0001**
A ²	-0.16	0.74	0.045	1	13.22	0.0024**
C ²	0.69	12.98	0.045	1	231.26	0.0001**
D ²	0.87	20.85S	0.045	1	371.28	0.0001**
D ²	-0.29	2.38	0.038	1	58.47	0.0001**

*Significant at P<0.05

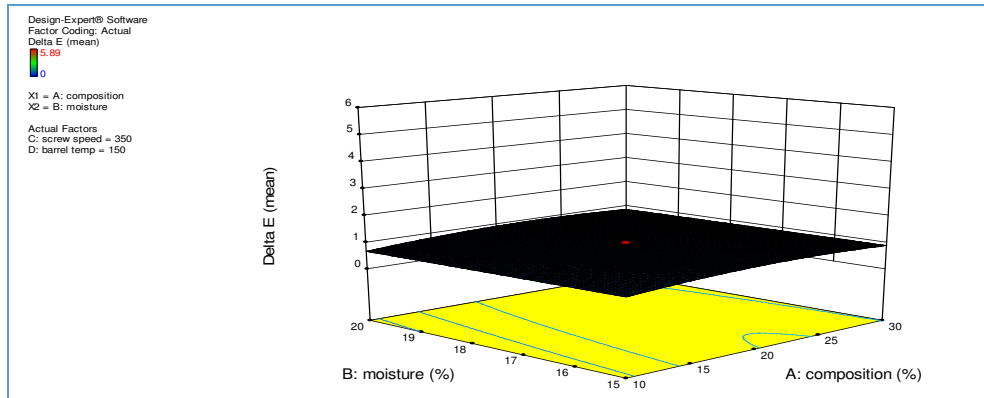
**Significant at P<0.01

Table 4.17: ANOVA for hue angle

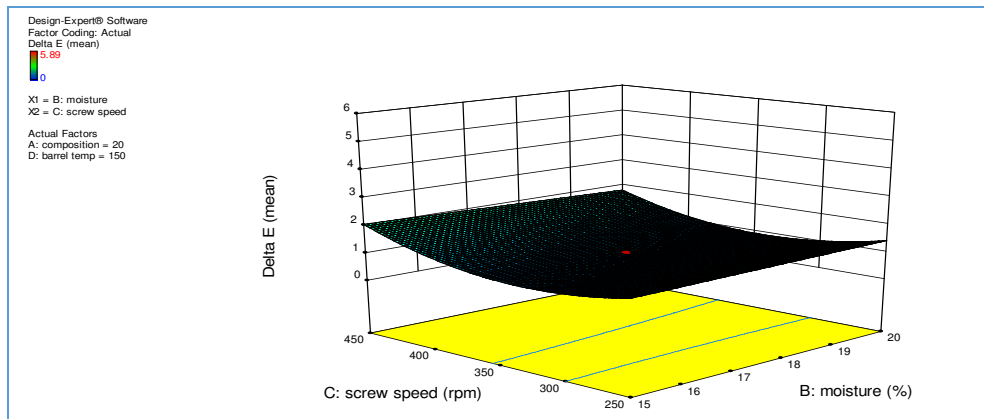
Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	83.87	85.98	0.13	14	60.62	0.0001**
B Moisture	-0.13	0.63	0.065	1	6.22	0.0248*
C Screw speed	0.57	7.79	0.065	1	76.85	0.0001**
D Temperature	-1.56	58.13	0.065	1	573.72	0.0001**
AB	-0.34	1.86	0.080	1	18.32	0.0007**
AC	0.28	1.25	0.089	1	12.33	0.032*
BC	0.34	1.80	0.080	1	17.79	0.0007**
A ²	0.13	0.48	0.061	1	4.72	0.0463*
C ²	0.51	7.08	0.061	1	69.93	0.0001**
D ²	0.56	8.62	0.061	1	85.12	0.0001**

*Significant at P<0.051

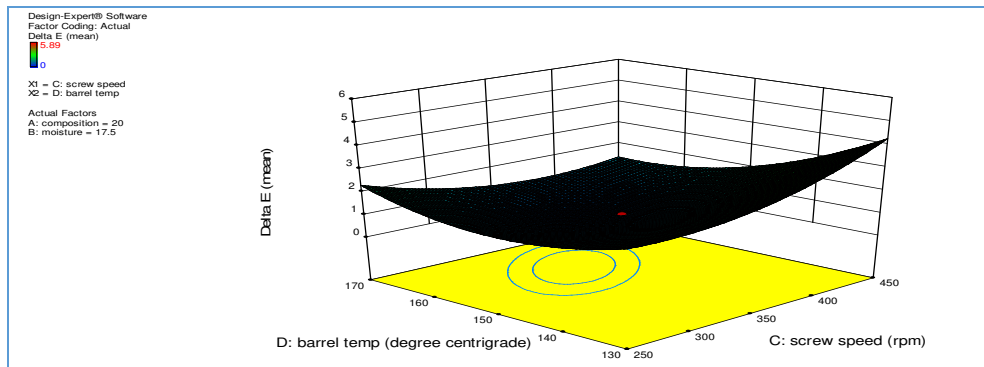
**Significant at P<0.01



(a)

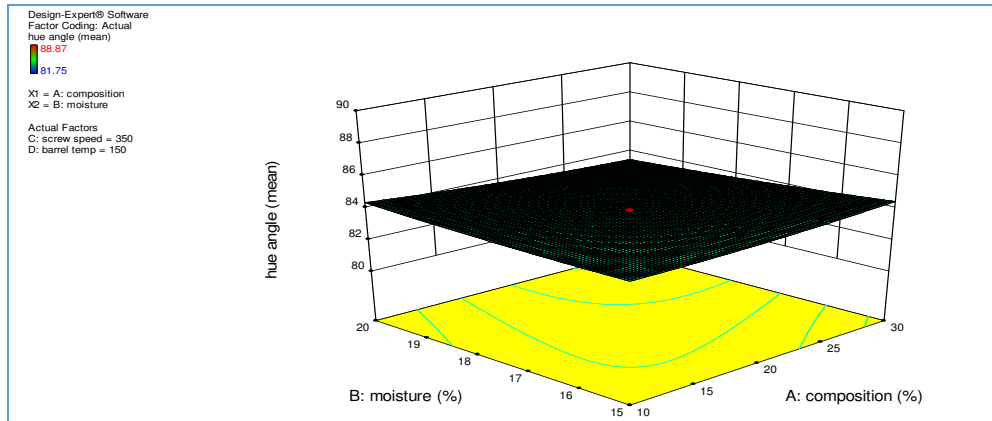


(b)

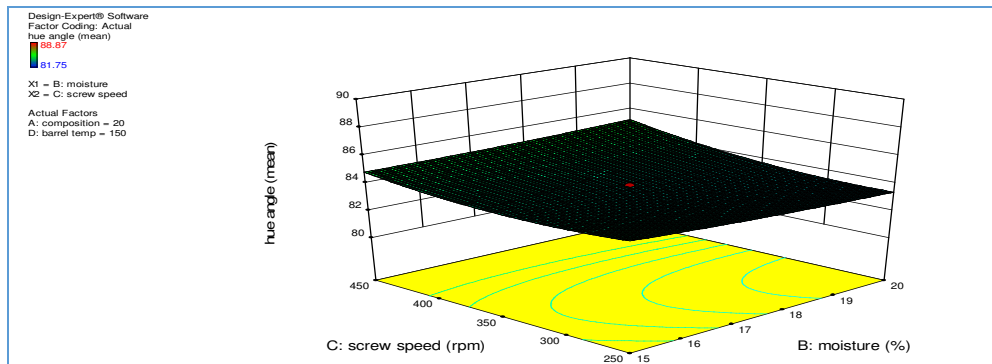


(c)

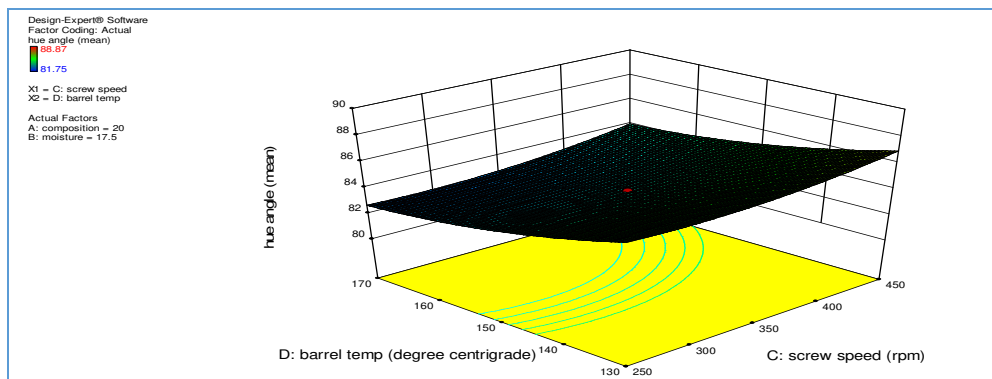
Fig. 11: (a) Response surface plot for as ΔE function of moisture and compositions (b) Response surface plot for ΔE as function of screw speed and moisture. (C) Response surface plot for ΔE as function of barrel temperature and screw speed



(a)



(b)



(c)

Fig. 12: (a) Response surface plot for hue angle as function of moisture and composition (b) Response surface plot for as function of screw speed and moisture.(C) Response surface plot for hue angle barrel temperature and screw speed

4.4.7 Sensory evaluation (overall acceptability)

The extruded samples were evaluated organoleptically for appearance, texture, flavor, colour and overall acceptability by semi-trained panel of 10 judges using 5-point scale. The overall acceptability score of 30 samples was found good. Maximum overall acceptability score (4.3) was found in extrudates obtained from following conditions: Apple powder incorporation = 10%, moisture content =15%, screw speed = 450rpm and barrel temperature 170°C.

4.5 Optimization

The highest desirability value of 0.848 was obtained (Fig 13). The optimum conditions obtained for the development of apple incorporated corn based snacks were - 10% apple powder incorporation, 15% feed moisture, 450 rpm screw speed and 170°C barrel temperature. The predicted response in terms of SME, bulk density, WAI, WSI, expansion ratio and breaking strength were 89.694 (Wh/kg), 143.200 (kg/m³), 4.796 (g/g), 9.81 (%), 3.453 and 49.479 (N), respectively (Table 4.19). The predicted response and actual response values were almost similar. It can be noted from Table 4.19 that the variation of actual response values was within 4 per cent of predicted values.

4.6 Physico-chemical properties

Table 4.20 a shows the proximate composition of optimized product.

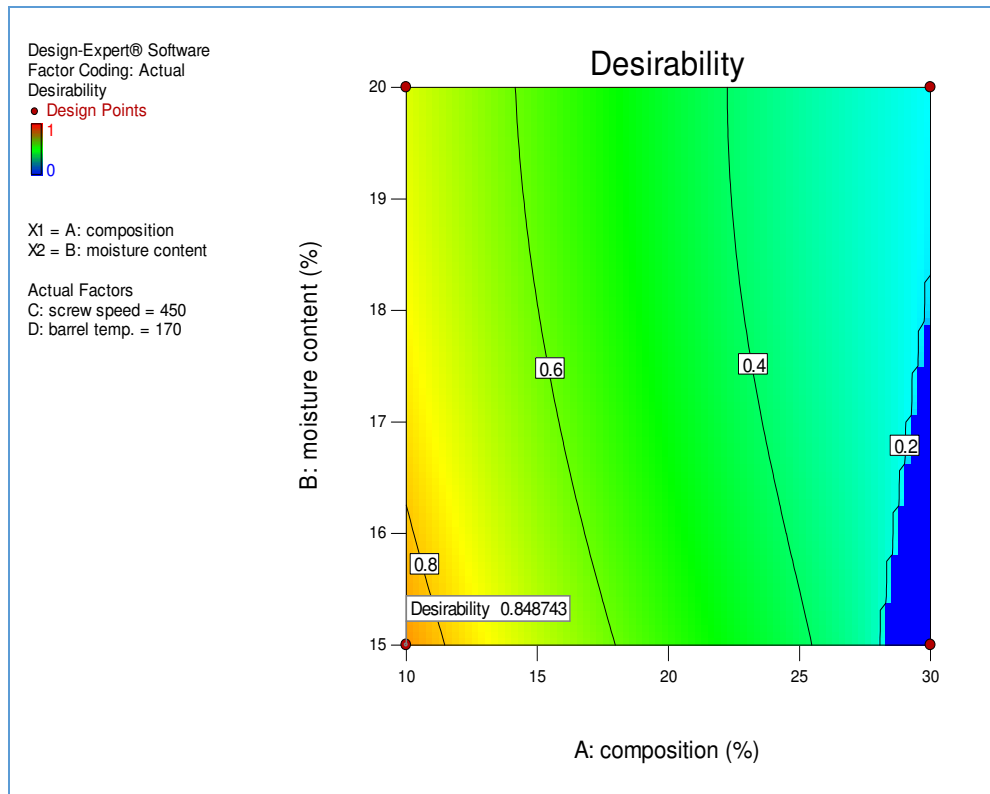


Fig. 13: Desirability function response surface for development of corn apple based extrudates



Plate 1: Optimized apple powder incorporated corn based breakfast snack

4.18: Sensory scores given by subjective method of evolution

S. No.	Composition (%) (C:A)	Moisture (%)	Screw speed (rpm)	Barrel temp. (°C)	Overall acceptability
1.	90:10	15	250	130	4.0
2.	70:30	15	250	130	2.8
3.	90:10	20	250	130	3.9
4.	70:30	20	250	130	2.6
5.	90:10	15	450	130	4.1
6.	70:30	15	450	130	2.7
7.	90:10	20	450	130	3.9
8.	70:30	20	450	130	2.7
9.	90:10	15	250	170	4.2
10.	70:30	15	250	170	3.2
11.	90:10	20	250	170	4.1
12.	70:30	20	250	170	2.9
13.	90:10	15	450	170	4.3
14.	70:30	15	450	170	3.3
15.	90:10	20	450	170	4.1
16.	70:30	20	450	170	3.0
17.	100;0	17.5	350	150	3.01
18.	60:40	17.5	350	150	2.4
19.	80:20	12.5	350	150	3.8
20.	80:20	22.5	350	150	3.4
21.	80:20	17.5	150	150	3.5
22.	80:20	17.5	550	150	3.7
23.	80:20	17.5	350	110	3.6
24.	80:20	17.5	350	190	3.3
25.	80:20	17.5	350	150	3.6
26.	80:20	17.5	350	150	3.6
27.	80:20	17.5	350	150	3.6
28.	80:20	17.5	350	150	3.5
29.	80:20	17.5	350	150	3.6
30.	80:20	17.5	350	150	3.5

Table 4.19: Predicted response levels and actual response levels

Values	SME (Wh/kg)	Bulk density (kg/m ³)	WAI (g/g)	WSI (%)	Expansion ratio	Breaking strength (N)
Predicted values	89.69	143.20	4.79	9.81	3.45	49.48
Actual values	88.91	138	4.77	9.5	3.55	47.6
Variation (%)	0.87	3.63	0.43	3.16	2.8	3.79

Table 4.20: Proximate composition of optimized product

Parameter	Optimized product
Water activity	0.42
Moisture (%)	3.36
Crude fat (%)	1.53
Crude protein (%)	6.46
Ash (%)	1.71
Crude fiber (%)	2.28
Dietary fiber (%)	13.82
Carbohydrates (%)	84.66
Acidity (%)	Not detected
Reducing sugar (%)	1.02
Non reducing sugar (%)	2.21
Total sugar (%)	3.23
Total solids (%)	88.425
Beta glucan (%)	1.728
Antioxidant activity (%)	38
Mineral profile (mg/100g)	
Calcium	7.8
Magnesium	116
Potassium	303.8
Phosphorus	193.2
Sodium	38
Zinc	2.26
Vitamins (mg/100g)	
Thiamine	0.214
Riboflavin	0.20
Niacin	2.94
Break strength	49.47
Colour	
L*	55.72
a*	4.6
b*	39.14
Calorific value (k cal/100g)	378.25

Table 4.21: Pasting properties of optimized product

Pasting Properties	Optimized product
Pasting Temperature (°C)	78.50
Pasting Time(min)	1.58
Peak Viscosity (cp)	567
Trough Viscosity (cp)	275
Final Viscosity(cp)	318
Breakdown Viscosity (cp)	290
Setback Viscosity (cp)	40

4.7 Economics of apple incorporated corn based snacks

The product formulation involved two types of costs - one fixed cost and another variable cost.

Fixed costs are those which run over lay period and only part of services of these assets are utilised in a single production period while as variable costs are those which get transformed into the ultimate production during a period season. Thus in our situation fixed costs related to machinery and equipments while as the variable cost involved expenses on chemical, raw material etc. the cost stream in respect of fixed and variable costs was drawn, break-even point was identified and margin of safety estimated.

The break-even point is a costing technique that helps in profit planning. Under break-even analysis, the break-even point is defined as volume of activity at which total sales revenue exactly equals total cost of the output produced or sold.

Margin of safety is the difference between total sale and break-even point and indicates the extent to which sales may decrease before any enterprise suffers a loss.

$$\text{Break-even point} = \frac{\text{Fixed Cost}}{\text{P/V Ratio}}$$

$$=2518891.69$$

Table 4.22: Margin of safety

Production (in units)	Total sale (in Rs.)	Total cost (in Rs.)	Profits (in Rs.)	Margin of safety (in units)	Margin of safety (in Rs.)
10000	1750000	2360000	-610000	-	-
12000	2100000	2432000	-332000	-	-
14000	2450000	2504000	-54000	-	-
14393.668	2518891.69	2518891.69	(BEP)	(BEP)	(BEP)
15000	2625000	2540000	85000	606.332	106108.31
15500	2712500	2558000	154500	1106.332	193608.31

4.8 Storage stability of snacks

The corn apple blends were extruded at pre-optimized conditions i.e. 10% apple powder incorporation, 15% moisture, 450 rpm screw speed and 170°C barrel temperature. The snacks were packed in high density polyethylene (200 gauges) bags and stored for three months under ambient conditions. The product was analysed for following parameters at an interval of 30 days.

4.8.1 Moisture content

Table 4.23 indicates significant positive effect on moisture content. Gradual increase in moisture content was observed during 3 months of storage. The moisture content of the product ranged from 3.36-4.68% during 3 months of storage.

4.8.2 Free fatty acids

Storage had a non-significant effect on the development of FFA over the period of three months. The FFA content increased only slightly from 0.061 to 0.077% (Table 4.23) in three months. Moreover the maximum value of 0.077 was within the safe limits.

4.8.3 Water activity

During the storage period of three months, the water activity of snacks increased non significantly. The mean water activity at zero months of extrude was 0.42 which increased to 0.53 after three months of storage (Table 4.23).

4.8.4 Hardness

During the three months of storage, the hardness decreased from the mean value of 48.8N to 41N (Table 4.23).

4.8.5 Total plate count

Total plate count increased non-significantly up to a period three months (Table 4.23) under ambient conditions (25 ± 2 , 60-62 %RH).

4.8.6 Overall acceptability

Storage had significant effect on the overall acceptability however, during storage period of three months, under ambient conditions (25 ± 2 , 60-62 %RH) the organoleptic properties of snacks (colour, texture, appearance, and overall acceptability) were within the acceptable range. The overall score decreased from 4.3 (very good) to 3.9 (good) on a 5 point scale during three months of storage (Table 4.23). Out of all the parameters storage had significant effect on texture, which was particularly noticed in the extrudates upon sensory evaluation. The storage was found to have a non-significant effect on the colour scores in extrudates. The scores for colour remained constant even up to 90th day of storage.

Table 4.23: Storage studies of optimized product

Storage period (3 months)	Moisture content (%)	Water activity	Free fatty acids (%)	Breaking strength (N)	Total plate count (cfu/g)	Overall acceptability
0	3.36	0.42	0.061	50	0.00	4.30
1	3.62	0.44	0.068	48	0.00	4.20
2	4.21	0.47	0.072	46	TFTC	4.00
3	4.68	0.53	0.077	41	TFTC	3.80
CD (p≤0.05)	0.123	0.019	0.002	NS	NS	0.19

TFTC = Too few to count, NS = Non significant

Experiment No. 2 : Optimization of processing conditions for the development of honey incorporated corn -apple based extruded snacks

4.9 Extrusion processing

4.9.1 Experimental design

Response Surface Methodology (RSM) (Design-Expert 9) was used to investigate the effect of processing conditions on product characteristics. The independent variables included the composition (0-40% of honey incorporation), moisture content (12.5-22.5%), screw speed (150-550 rpm) and barrel temperature (110-190°C). Response variables were specific mechanical energy (SME), bulk density, water absorption index (WAI), water solubility index (WSI), expansion ratio (ER), breaking strength and instrumental colour.

4.9.2 Effect of independent variables on product characteristics and specific mechanical energy (SME)

Models for all parameters were significant. None of the models showed significant lack of fit, indicating that all the second order polynomial models correlated well with the measured data. Adequate precision (signal to noise ratio)

greater than 4 is desirable. All the parameters showed high adequate precision (Table 4.24). A reasonable good coefficient of determination ($R^2=0.92, 0.95, 0.96, 0.94, 0.97, 0.97$) for SME, bulk density, expansion ratio, break strength, WAI and WSI indicated that the models developed for product responses appeared to be adequate. The predicted R-squared was found in reasonable agreement with adjusted R-squared for all the parameters.

Table 4.24: Analysis of variance for the fit of experimental data to response surface models

Term	SME	BD	ER	BS	WAI	WSI
Adequate precision	14.750	15.263	1.505	38.366	28.453	22.606
R- square	0.9262	0.9352	0.9656	0.9418	0.9786	0.9748
Adjusted R square	0.8623	0.8747	0.9601	0.9325	0.9586	0.9512
Predicted R square	0.5901	0.6266	0.9462	0.9106	0.8767	0.8547
CV	7.72	11.06	0.12	13.58	2.41	6.91
Lack of fit	NS	NS	NS	NS	NS	NS

NS: non-significant

4.10 System Parameter

4.10.1 Specific Mechanical Energy (SME)

The mean values of SME under different extrusion conditions ranged between 76.62 and 136.82Wh/kg. Regression analysis was carried out to fit the mathematical models to the experimental data. The significant predicted model for SME can be described by the following equation (13) in terms of coded levels.

$$SME = +89.5 - 4.90 B - 19.79D + 3.80 B^2 + 5.49 D^2 \quad (13)$$

The analysis of variance (ANOVA) for SME given in the Table 4.26 and response surface plots depicted in Fig. 14 indicated that SME decreased with the increase in moisture (B) and barrel temperature (D).

Table 4.25: Effect of processing conditions on system parameter and product characteristics

S. No.	(A) composition (CA:H)	(B) Moisture (%)	(C) Screw speed (rpm)	(D) Temp. (°C)	SME (Wh/kg)	Bulk density (kg/m³)	WAI (g/g)	WSI (%)	Expansion ratio	Breaking strength (N)
1	90:10	15	250	130	131.91	228	4.381	9.11	2.47	82.4
2	70:30	15	250	130	128.28	433	3.278	9.7	1.89	302.1
3	90:10	20	250	130	119.98	246	4.27	7.2	2.38	103.4
4	70:30	20	250	130	112.96	452	3.311	11.3	1.8	311.6
5	90:10	15	450	130	136.82	204	4.05	8.3	2.53	76.8
6	70:30	15	450	130	134.78	423	3.066	13.7	1.91	291.2
7	90:10	20	450	130	124.23	239	4.213	8.8	2.42	94.6
8	70:30	20	450	130	121.16	441	3.112	16.6	1.87	308.4
9	90:10	15	250	170	82.74	181	4.028	15.02	2.68	53.3
10	70:30	15	250	170	80.64	338	3.221	17.3	1.98	234.8
11	90:10	20	250	170	79.92	168	4.157	10.3	2.58	68.7
12	70:30	20	250	170	77.14	352	3.299	17.3	1.94	279.6
13	90:10	15	450	170	84.98	151	3.874	11.74	2.71	52.8
14	70:30	15	450	170	83.88	281	3.061	20.5	2.00	202.6
15	90:10	20	450	170	80.01	193	3.926	9.8	2.66	63.7
16	70:30	20	450	170	79.8	311	3.123	18.25	1.96	258.5

Contd...

Table 4.25 contd...

S. No.	(A) composition (CA:H)	(B) Moisture (%)	(C) Screw speed (rpm)	(D) Temp. (oC)	SME (Wh/kg)	Bulk density (kg/m ³)	WAI (g/g)	WSI (%)	Expansion ratio	Breaking strength (N)
17	100:0	17.5	350	150	84.41	139	4.64	10.3	2.7	53.1
18	60:40	17.5	350	150	87.32	428	3.102	19.8	1.78	321.4
19	80:20	12.5	350	150	110.54	339	3.376	16.6	2.26	125.3
20	80:20	22.5	350	150	86.14	417	3.785	12.6	2.23	178.3
21	80:20	17.5	150	150	85.82	417	3.592	9.6	2.22	193.6
22	80:20	17.5	550	150	91.73	393	3.508	10.3	2.29	110.5
23	80:20	17.5	350	110	133.6	407	3.616	5.7	2.21	198.8
24	80:20	17.5	350	190	76.62	225	3.413	17.4	2.32	103.8
25	80:20	17.5	350	150	89.25	401	3.488	10.8	2.24	154.6
26	80:20	17.5	350	150	89.25	401	3.488	10.8	2.24	156.6
27	80:20	17.5	350	150	89.25	401	3.488	10.8	2.24	156.6
28	80:20	17.5	350	150	89.25	401	3.488	10.8	2.24	156.6
29	80:20	17.5	350	150	89.25	401	3.488	10.8	2.24	156.6
30	80:20	17.5	350	150	89.25	401	3.488	10.8	2.24	156.6

(CA:H) = corn-apple : honey, SME (Wh/kg) = Specific mechanical energy, BD(kg/m³) = bulk density WAI(g/g) = Water absorption index, WSI(%) = Water solubility index, ER=Expansion ratio, BS(N) = break strength

Table 4.26: ANOVA for SME

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	89.25	11277.9 6	3.1	6	13.98	0.0001**
(B) Moisture	-4.90	576.53	1.55	1	10.01	0.0064**
(D) Temperature	-19.79	9399.85	1.55	1	163.17	0.0001**
B ²	3.80	396.57	1.45	1	6.88	0.192*
D ²	5.49	823.18	1.45	1	14.38	0.0018**

*Significant at P<0.051

**Significant at P<0.01

4.11 Physical properties of extrudates

4.11.1 Bulk density

Bulk density of extrudates ranged between 139 and 452 kg/m³. The significant quadratic model for the relation between bulk density and independent variables obtained in terms of coded variables is presented below (equ.14).

$$\text{Bulk density} = +401 +83.29A - 43.96 D - 38.64 A^2 - 15.01 B^2 - 30.51 D^2 \quad (14)$$

The analysis of variance (ANOVA) for bulk density given in the Table 4.27 and response surface plots depicted in Fig. 5 indicated positive relation of composition (A) and inverse relation of barrel temperature (D) with bulk density.

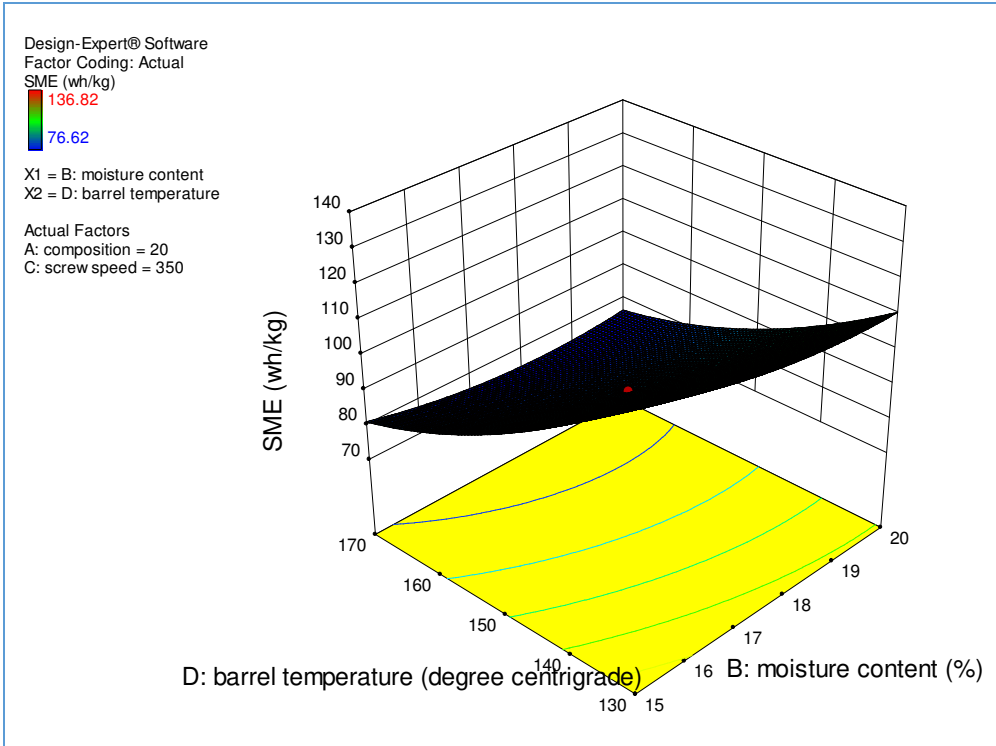


Fig. 14: Response surface plot for SME as function of barrel temperature and moisture content

Table 4.27: ANOVA for bulk density

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	401.00	2.832E+005	14.77	14	15.46	0.0001**
(A) composition	83.29	1.665E+005	7.39	1	127.70	0.0001**
(D) Temperature	-43.96	46376.04	7.39	1	35.43	0.0001**
A ²	-38.64	40942.50	6.91	1	31.28	0.0001**
B ²	-15.01	6180.00	6.91	1	4.72	0.0462*
D ²	-30.51	25532.86	6.91	1	19.51	0.0005**

*Significant at P<0.05

**Significant at P<0.01

4.11.2 Water absorption index (WAI)

The WAI of extrudates ranged between 3.061 and 4.640 g/g. The model obtained from regression analysis for water absorption index is shown below (equ.15)

$$\text{WAI} = +3.49 - 0.44A + 0.053 B - 0.070C - 0.058D + 0.054 AD + 0.099A^2 \quad (15)$$

The regression analysis showed that composition (A), barrel temperature (D) and screw speed (C) had negative linear effect on WAI while moisture content (B) had a positive linear effect. The ANOVA for WAI given in Table 4.28 and the response surface plots depicted in Fig. 16 indicated the effect of process variables on WAI.

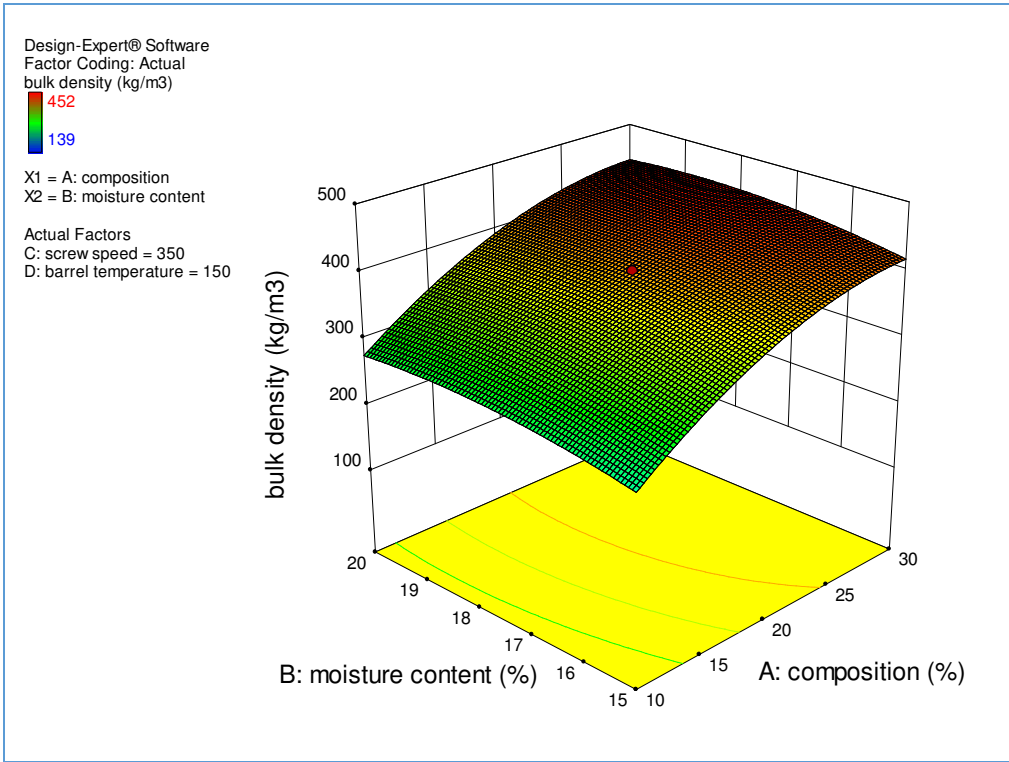


Fig. 15a: Effect of moisture content and composition on bulk density

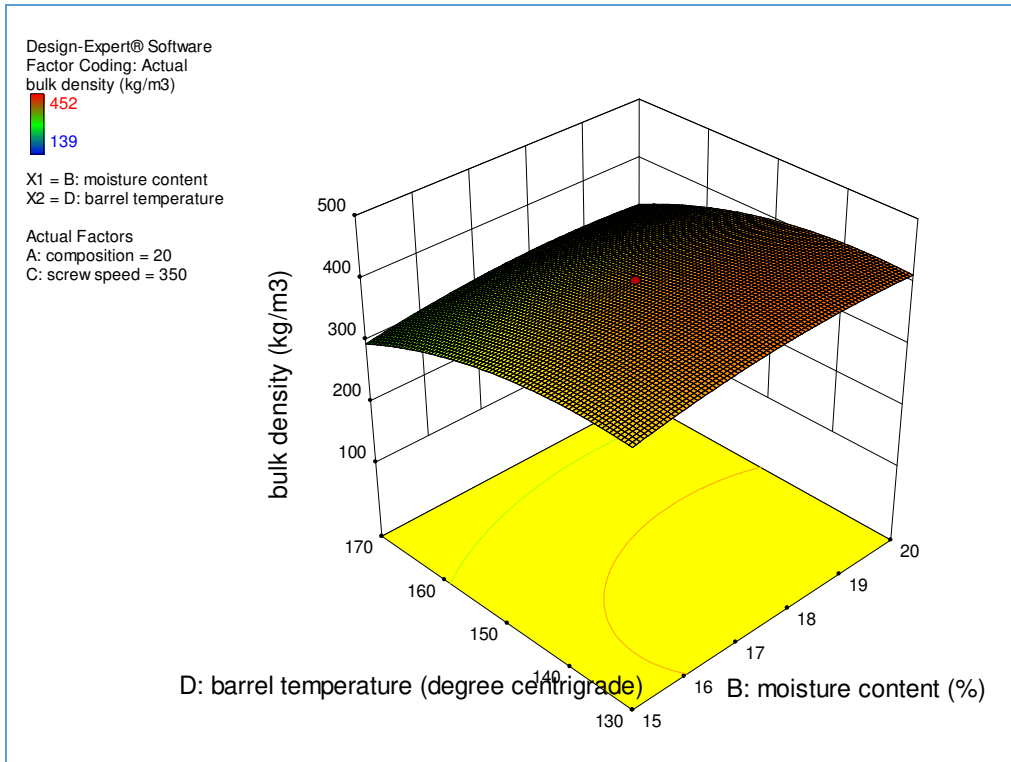


Fig. 15b: Response surface plot for bulk density as function of barrel temperature and moisture content

Table 4.28: ANOVA for WAI

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	3.49	5.19	0.036	6	48.97	0.0001**
(A) composition	-0.44	4.60	0.018	1	607.16	0.0001**
(B) Moisture content	0.053	0.067	0.018	1	8.88	0.0094**
(C) Screw speed	-0.070	0.12	0.018	1	15.63	0.0013**
(D) Temperature	-0.058	0.81	0.018	1	10.76	0.0051**
AD	0.054	0.047	0.022	1	6.19	0.0251*
A ²	0.099	0.27	0.017	1	35.46	0.0001**

*Significant at P<0.05

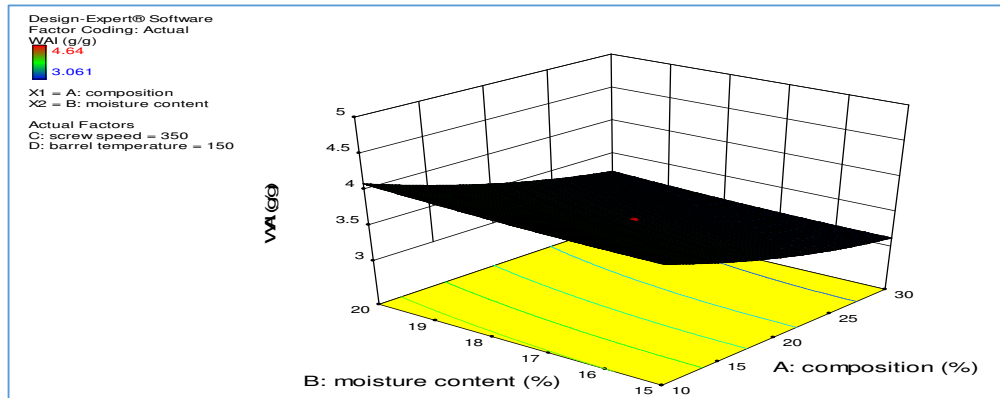
**Significant at P<0.01

4.11.3 Water solubility index (WSI)

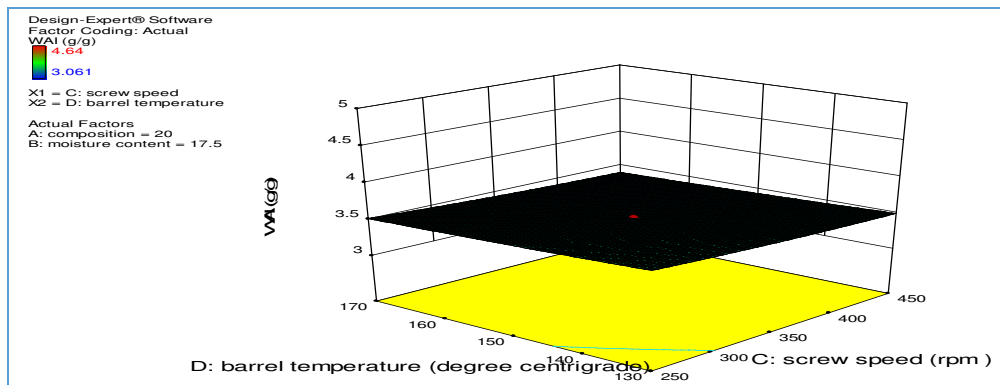
Water solubility index of extrudates ranged between 5.7 and 20.5 %. The significant predicted model for WSI in terms of independent variables (in coded levels) is given below (equ. 16)

$$\text{WSI} = +10.80 + 2.64A - 0.58B + 2.45D + 1.07A^2 + 0.95B^2 \quad (16)$$

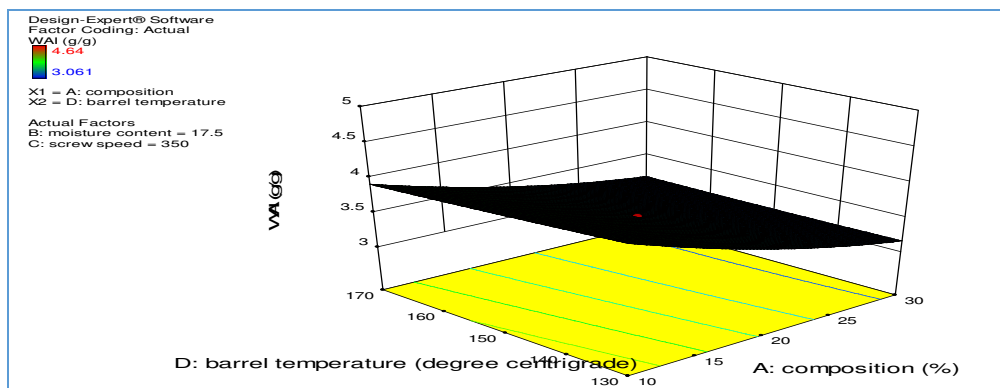
The analysis of variance (table 4.29) and response surface plots of WSI (Fig. 29.) showed the positive influence of composition (A), barrel temperature (D) and negative influence of moisture content (B) on WSI. Regression analysis also showed positive quadratic effect of composition (A) and feed moisture (B) on WSI.



(a)



(b)



(c)

Fig. 16: (a) Response surface plot for WAI as function of composition and moisture content. (b) Response surface plot for WAI as function of barrel temperature and screw speed.(C) Response surface plot for WAI as function of barrel temperature and composition

Table 4.29: ANOVA for WSI

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	10.80	425.13	0.35	14	41.40	0.0001**
A composition	2.64	167.38	0.17	1	228.20	0.0001**
D Temperature	2.45	144.55	0.17	1	197.08	0.0001**
A ²	1.67	31.16	0.16	1	42.48	0.0001**
B ²	0.95	24.93	0.16	1	33.99	0.0001**

**Significant at P<0.01

4.11.4 Expansion ratio (ER)

The mean value of expansion ratio varied between 1.78 -2.71. The significant model for expansion ratio in terms of coded independent variables is given below.

$$\text{Expansion ratio} = +2.24 -0.29A - 0.026B + 0.061 D \quad (17)$$

The analysis of variance for expansion ratio given in Table 4.30 and response surface plots (Fig. 18) indicated the significant linear positive effect of barrel temperature (D) and negative effect of composition (A) and moisture content (B) on expansion ratio.

Table 4.30: ANOVA for Expansion ratio

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	2.24	2.11	0.010	14	175.41	0.0001**
(A) Composition	-0.29	2.00	0.011	1	6663.58	0.0001**
(B) Moisture content	-0.026	0.016	0.011	1	5.33	0.0296*
(D) Temperature	0.061	0.089	0.011	1	29.54	0.0001**

*Significant at P<0.05

**Significant at P<0.01

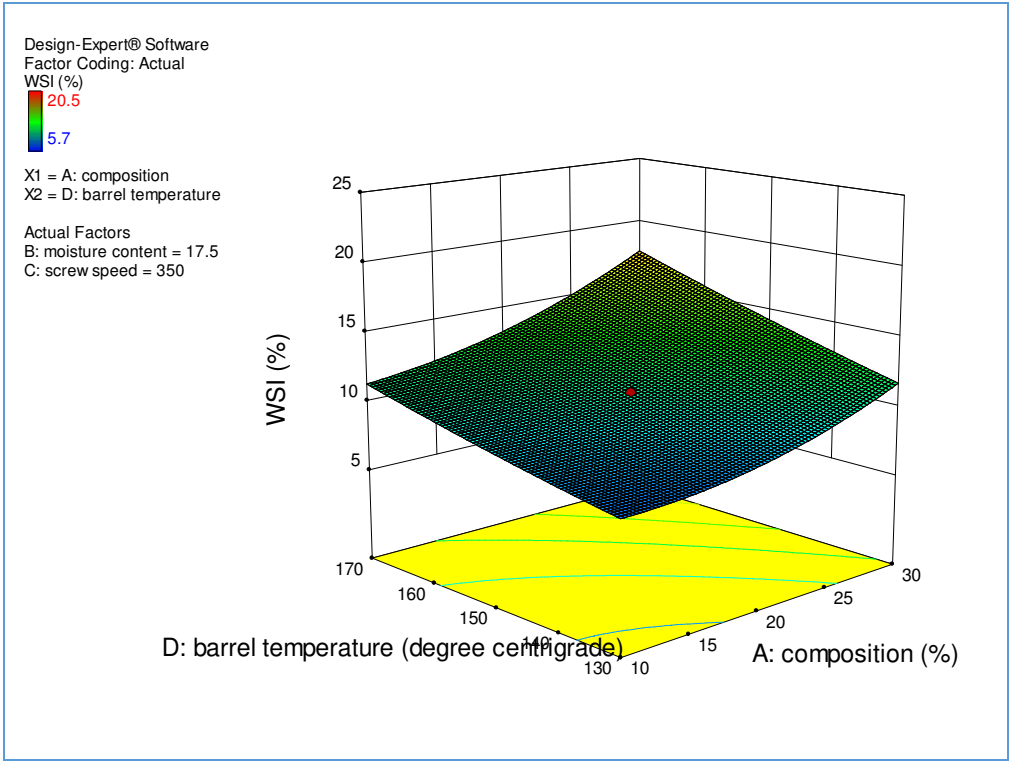
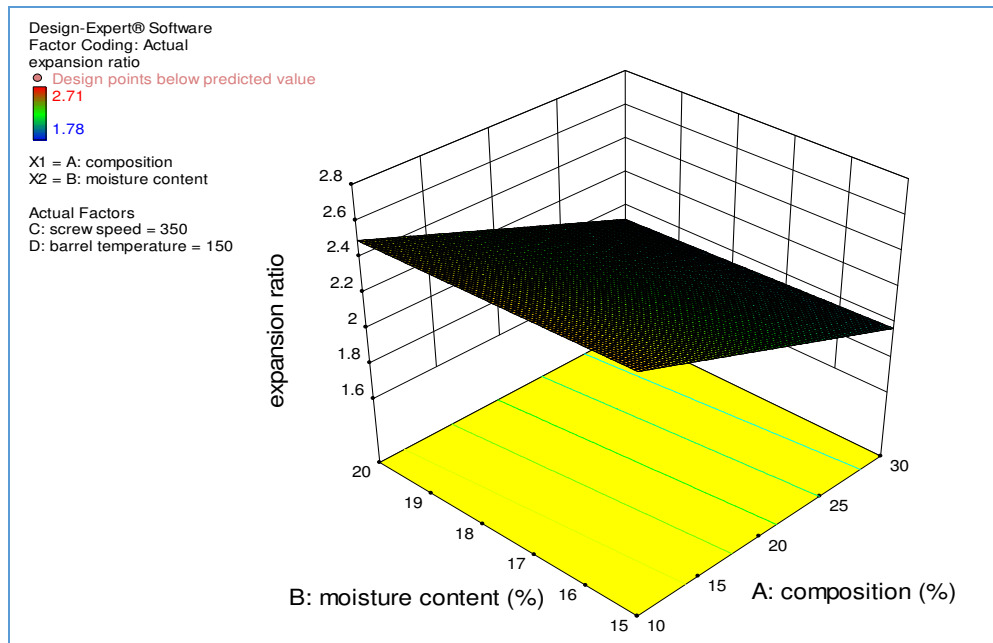
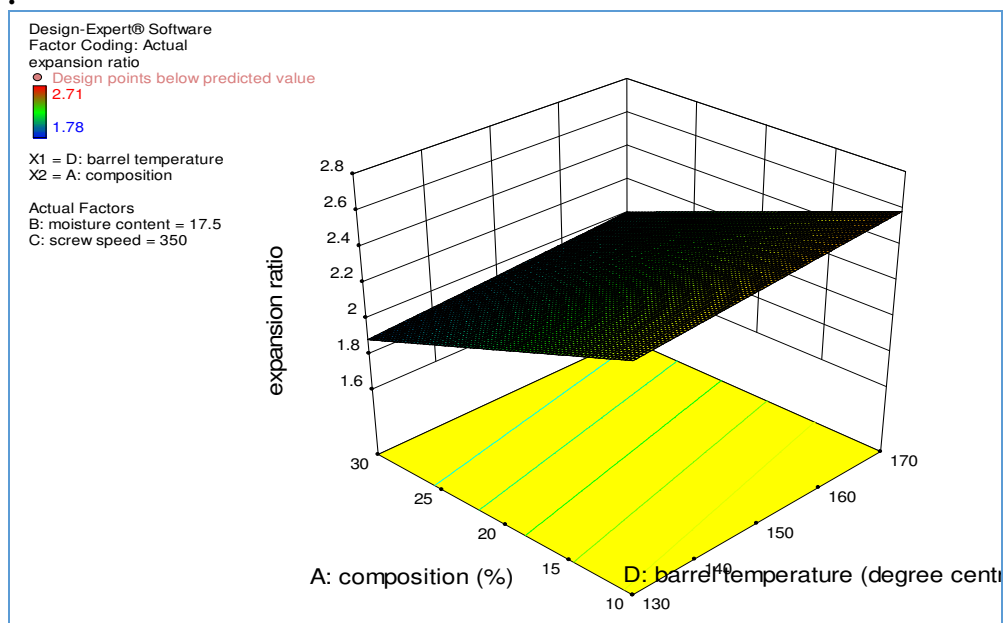


Fig. 17: Response surface plot for WSI as function of composition and barrel temperature



(a)



(b)

Fig. 18: (a) Response surface plot for expansion ratio as function of composition and moisture content (b) Response surface plot for expansion ratio as function of composition and barrel temperature

4.11.5 Breaking strength (BS)

Mean values of breaking strength ranged between of 52.8 and 321 N. The significant model developed for breaking strength in terms of coded variables is given in the following equation.

$$\text{Break strength} = +16690 + 88.74A + 12.44B - 10.56C - 22.77 D \quad (18)$$

The regression analysis (Table 4.31) and response surface plots (Fig.19) showed the significant positive linear effect of composition (A), moisture content (B) and negative effect of screw speed (C) and barrel temperature (D) on breaking strength.

Table 4.31: ANOVA for Breaking Strength

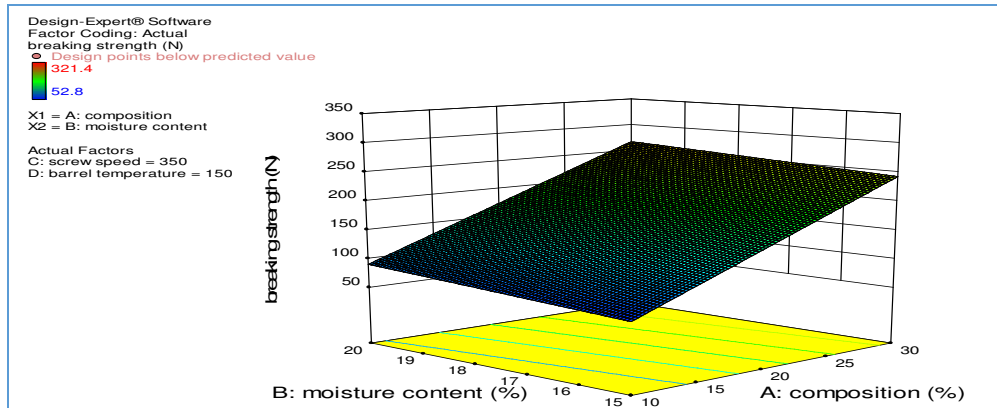
Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	166.90	2.078E+005	4.14	11	101.17	0.0001**
(A) Composition	88.74	1.890E+005	4.63	1	367.99	0.0001**
(B) Moisture content	12.44	3712.59	4.63	1	7.23	0.0126*
(C) screw speed	-10.56	2677.59	4.63	1	5.21	0.0317*
(D) Temperature	-22.77	1244.26	4.63	1	24.23	0.0001**

*Significant at P<0.05

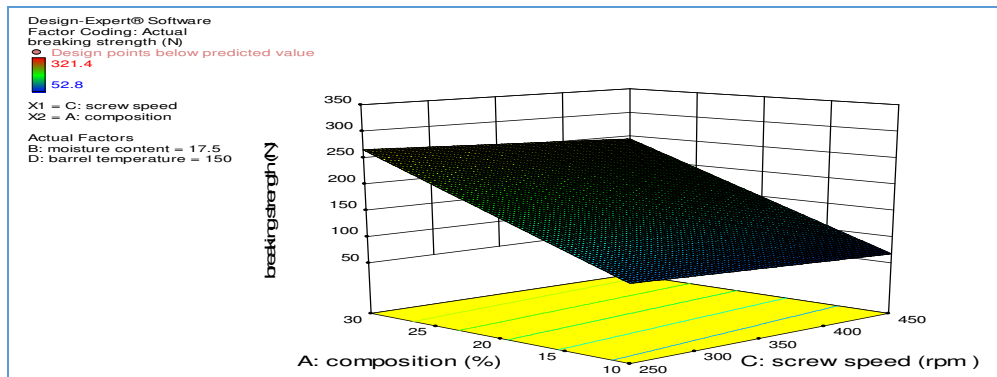
**Significant at P<0.01

4.11.6 Effect of extrusion conditions on colour coordinates of corn based apple and honey incorporated extruded snacks

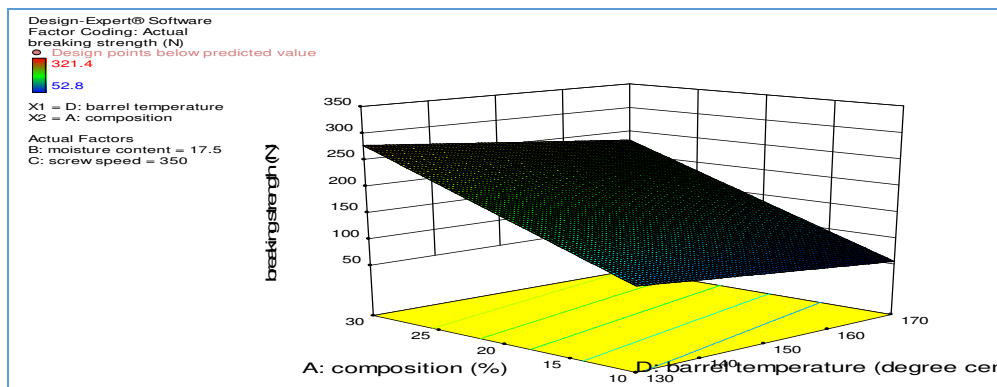
Response surface methodology revealed that the models for all the parameters (L*, a*, b*, c*, ΔE and hue angle) were significant. None of the models showed significant lack of fit (Table 4.32), indicating that all the second order polynomial models correlated well with the measured data.



(a)



(b)



(c)

Fig. 19: (a) Response surface plot for break strength as function of composition and moisture content (b) Response surface plot for as break strength as function of composition and screw speed. (c) Response surface plot for as break strength as function of composition and barrel temperature

The data on mean values of colour coordinates revealed that the regression models for L*, a*, b*, c*, ΔE and hue angle were highly significant with a high correlation coefficient (R^2 0.9691, 0.9775, 0.9383, 0.9341, 0.9048, 0.9773 respectively). The predicted R-square was found in reasonable agreement with adjusted R-square for all the parameters. Adequate precision greater than 4 is desirable. All the parameters showed high adequate precision (Table 4.32).

Table 4.32: ANOVA and model statistics for the colour parameters of corn based apple and honey incorporated breakfast snacks

Term	Response to models					
	L*	a*	b*	c*	ΔE	Hue angle (°)
R-square	0.9691	0.97775	0.9383	0.9341	0.9048	0.97773
Adjusted R-square	0.9403	0.9564	0.8808	0.8726	0.8160	0.9560
Predicted R-square	0.8236	0.8702	0.6445	0.6577	0.4517	0.8690
Adequate precision	20.831	26.294	15.272	13.411	11.906	25.187
CV	0.81	7.74	1.22	1.32	3.18	0.54
Lack of fit	NS	NS	NS	NS	NS	NS

NS: non-significant

Luminosity (L*) of extrudates ranged from 52.10 and 57.42 whereas redness (a*) and yellowness (b*) were in range of 1.02 to 6.83 and 36.83 to 42.86 respectively. Table 4.33 and Figs. 20, 21, 22, 23, 24 and 25 demonstrates response surface plots of different colour coordinates versus two independent variables. The models developed for luminosity (L*), redness (a*), yellowness (b*), chroma (c*), hue angle, and total colour difference (ΔE) are given below in equations (19 to 24) respectively.

$$L^* = 58.62 - 0.23B + 0.82C - 1.78D - 0.28AD - 0.41CD + 0.48C^2 + 0.47D^2 \quad (19)$$

$$a^* = 4.74 + 0.17B - 0.48C + 1.29D + 0.41AB - 0.21AC - 0.40BC - 0.19BD - 0.33CD - 0.16A^2 - 0.43C^2 - 0.28D^2 \quad (20)$$

$$b^* = 38.51 - 0.79C - 0.106D + 0.32A^2 + 0.46B^2 + 0.23C^2 + 0.20D^2 \quad (21)$$

$$c^* = 38.13 - 0.84C - 0.93D + 0.47A^2 + 0.61B^2 + 0.36C^2 + 0.36D^2 \quad (22)$$

$$\Delta E = 0.48 + 0.42A - 1.15D + 0.47B^2 + 0.74C^2 + 0.95D^2 \quad (23)$$

$$\text{Hue angle} = 82.98 - 0.21B + 0.60C - 1.98D - 0.61AB + 0.29AC + 0.55BC + 0.44CD + 0.29A^2 + 0.23B^2 + 0.66C^2 + 0.40D^2 \quad (24)$$

The negative coefficients of linear terms of temperature (D) and positive coefficients of screw speed (C) in equation (19) indicates that luminosity decreased with an increase in barrel temperature (D) and increased with increase in screw speed (C). The fitted regression equation (20) shows that with the increase in moisture content (B) and barrel temperature (D), the values of redness (a*) increased where as with the increase in screw speed (C) these values were decreased. The negative coefficients of linear terms of barrel temperature (D) and screw speed (C) (equations 21-22) indicated that b* (yellowness), and c* (chroma) decreased with increase in barrel temperature (D) and screw speed (C). The negative coefficients of linear terms of barrel temperature (D) and positive coefficients of screw speed (C) in equations (23-24) indicates that total colour difference (ΔE) and hue angles decreases with an increase in barrel temperature and increased with increase in screw speed (C).

Table 4.33: Effect of extrusion conditions on colour coordinates

Composition (%)	Moisture (%)	Screw speed (rpm)	Temp. (°C)	L*	a*	b*	c*	ΔE	hue angle
90:10	15	250	130	54.53	2.09	41.39	41.44	3.62	87.10
70:30	15	250	130	54.46	2.16	41.674	41.72	4.618	87.03
90:10	20	250	130	54.32	2.89	41.88	41.98	4.22	86.05
70:30	20	250	130	54.28	3.57	42.86	43.00	5.89	85.23
90:10	15	450	130	55.93	2.84	39.88	39.98	3.43	85.92
70:30	15	450	130	55.83	1.6	39.98	40.012	4.77	87.70
90:10	20	450	130	55.64	1.8	39.95	39.99	4.30	87.42
70:30	20	450	130	55.52	2.84	39.88	39.98	3.43	85.92
90:10	15	250	170	52.28	5.61	39.21	39.60	1.26	81.85
70:30	15	250	170	52.26	5.22	39.43	39.77	1.52	82.45
90:10	20	250	170	52.18	5.87	39.62	40.05	1.86	81.57
70:30	20	250	170	52.10	6.83	39.73	40.31	1.94	80.25
90:10	15	450	170	53.78	5.87	37.76	38.21	1.42	81.16
70:30	15	450	170	52.48	3.73	37.93	38.11	1.69	84.38
90:10	20	450	170	52.42	3.42	38.21	38.36	1.450	84.88
70:30	20	450	170	52.31	3.65	36.83	37.00	3.16	84.34
100:0	17.5	350	150	53.71	3.93	38.89	39.08	0.00	84.22
60:40	17.5	350	150	53.54	4.31	40.53	40.75	2.34	83.92
80:20	12.5	350	150	53.86	3.78	40.24	40.42	2.02	84.64
80:20	22.5	350	150	53.31	4.89	40.28	40.57	2.06	83.07
80:20	17.5	150	150	53.41	3.84	40.28	40.46	1.97	84.55
80:20	17.5	550	150	56.38	2.28	38.43	38.49	4.32	86.60
80:20	17.5	350	110	57.42	1.02	40.92	40.93	5.88	88.52
80:20	17.5	350	190	52.21	6.28	37.54	38.06	2.12	80.50
80:20	17.5	350	150	53.26	4.74	38.51	38.80	0.480	82.98
80:20	17.5	350	150	53.26	4.74	38.51	38.80	0.480	82.98
80:20	17.5	350	150	53.26	4.74	38.51	38.80	0.480	82.98
80:20	17.5	350	150	53.26	4.74	38.51	38.80	0.480	82.98
80:20	17.5	350	150	53.26	4.74	38.51	38.80	0.480	82.98
80:20	17.5	350	150	53.26	4.74	38.51	38.80	0.480	82.98
80:20	17.5	350	150	53.26	4.74	38.51	38.80	0.480	82.98

Table 4.34: ANOVA for L* (luminosity)

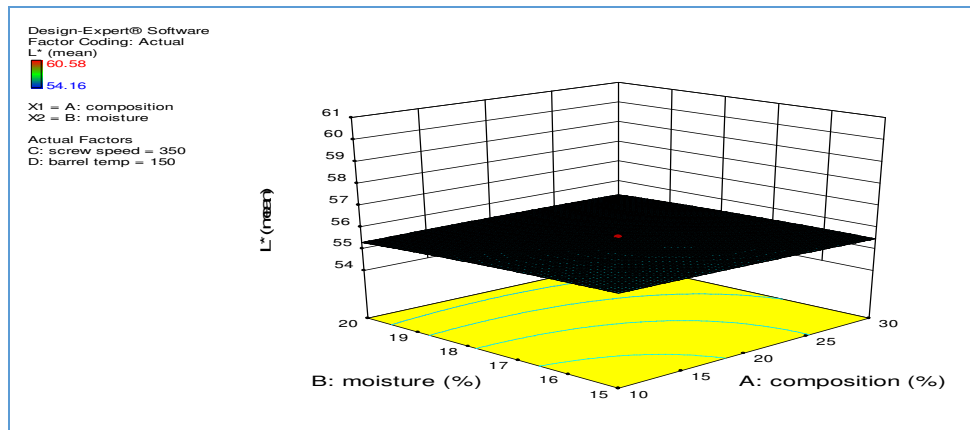
Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	58.62	109.98	0.20	14	33.62	0.0001**
(B) Moisture	-0.23	1.22	0.099	1	5.24	0.0370**
(C) Screw speed	0.82	16.27	0.099	1	69.63	0.0001**
(D) Temperature	-1.78	76.04	0.099	1	325.4	0.0001**
CD	-0.41	2.69	0.12	1	11.51	0.0040**
AD	-0.28	1.24	0.12	1	5.32	0.0351*
C ²	0.48	6.92	0.092	1	26.93	0.0001**
D ²	0.47	6.00	0.092	1	26.68	0.0001**

*Significant at P<0.05; **Significant at P<0.01

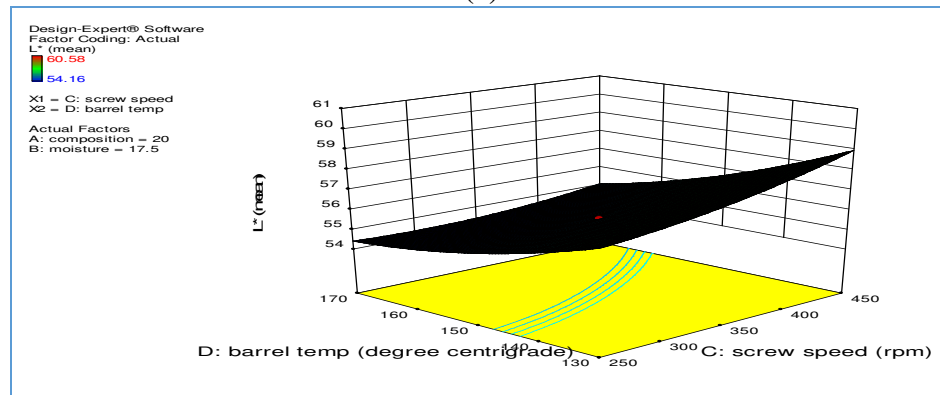
Table 4.35: ANOVA for a* (redness)

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	4.74	61.19	0.13	14	46.49	0.0001**
(B) Moisture	0.17	0.66	0.063	1	6.99	0.0184*
(C) Screw speed	-0.48	5.62	0.063	1	59.75	0.0001**
(D)Temperature	1.29	39.87	0.063	1	424.04	0.0001**
AB	0.41	2.73	0.077	1	29.05	0.0001**
AC	-0.21	0.74	0.077	1	7.82	0.0135**
BC	-0.40	2.57	0.077	1	27.32	0.0001**
BD	-0.19	0.59	0.077	1	6.27	0.0243*
CD	-0.33	1.71	0.077	1	18.19	0.0001**
A ²	-0.16	0.72	0.059	1	7.66	0.0144*
C ²	-0.43	5.00	0.059	1	53.20	0.0001**
D ²	-0.28	2.14	0.059	1	22.79	0.0002**

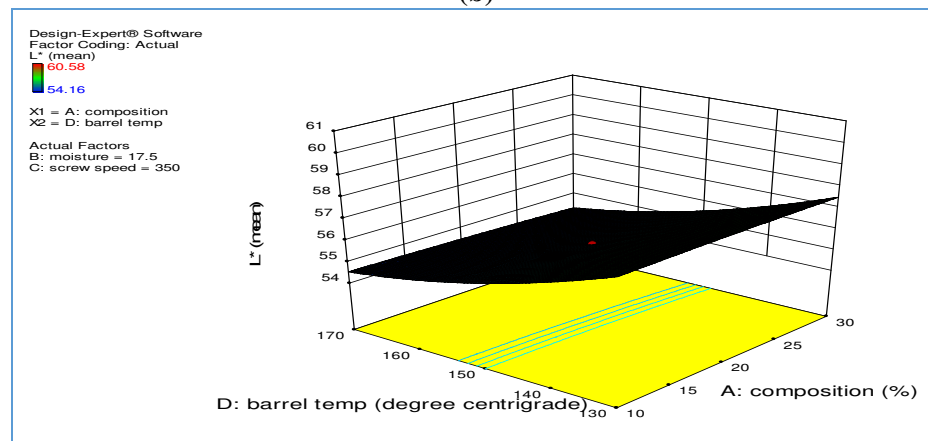
*Significant at P<0.05; **Significant at P<0.01



(a)

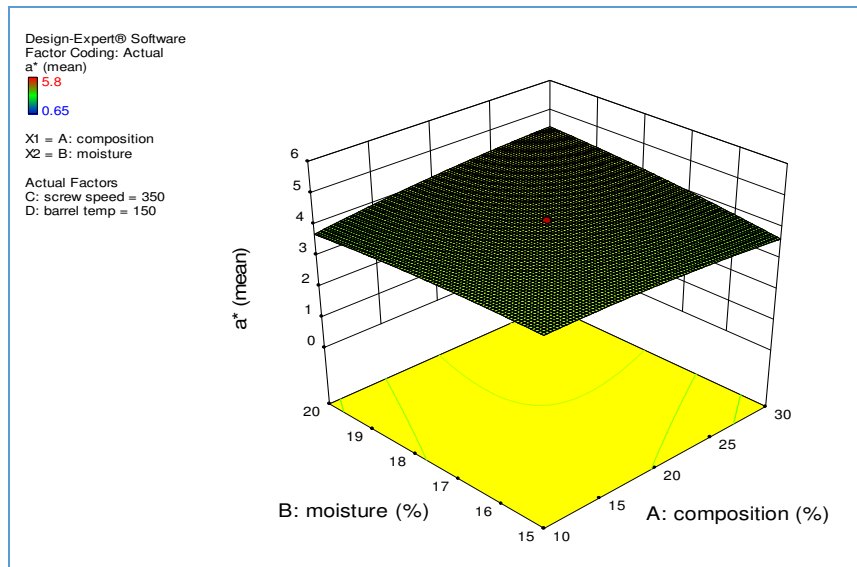


(b)

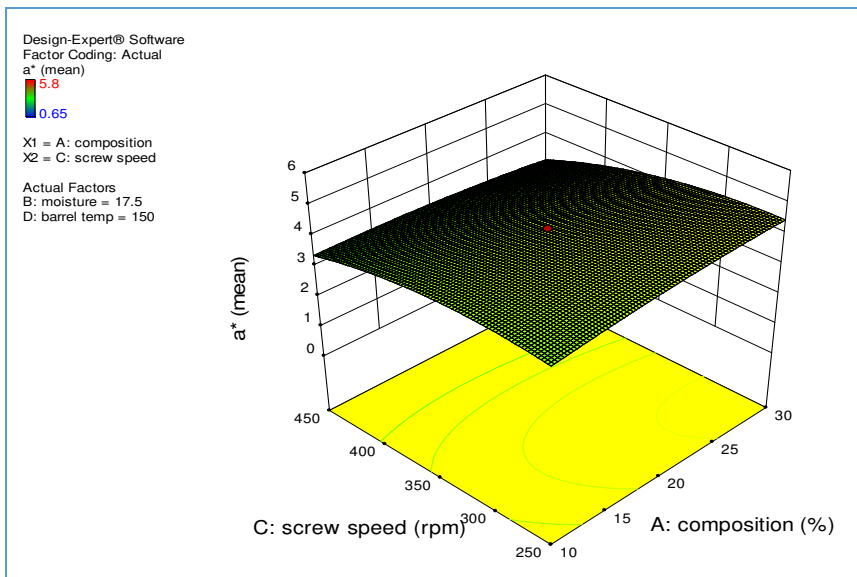


(c)

Fig. 20: (a) Response surface plot for L^* as function of moisture and composition. (b) Response surface plot for L^* as function of barrel temperature and screw speed. (c) Response surface plot for L^* as function of barrel temperature and screw speed



(a)

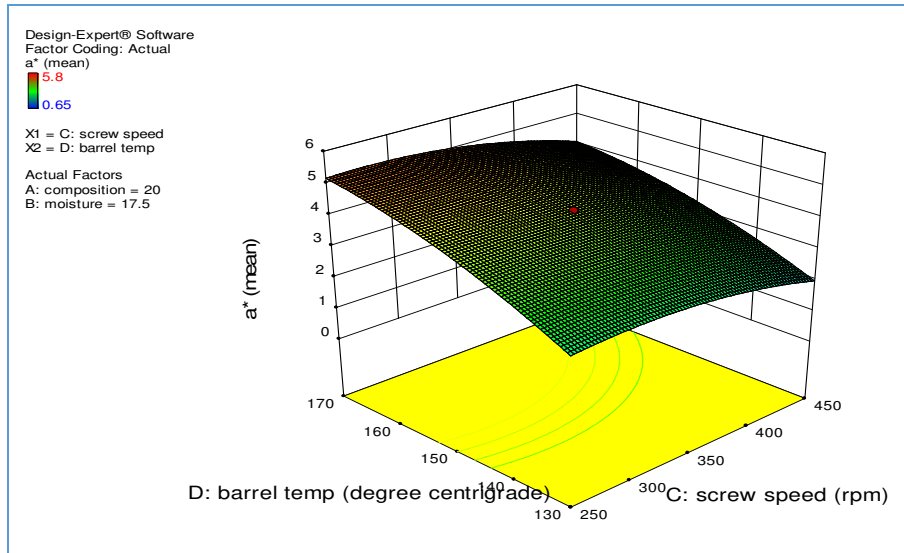


(b)

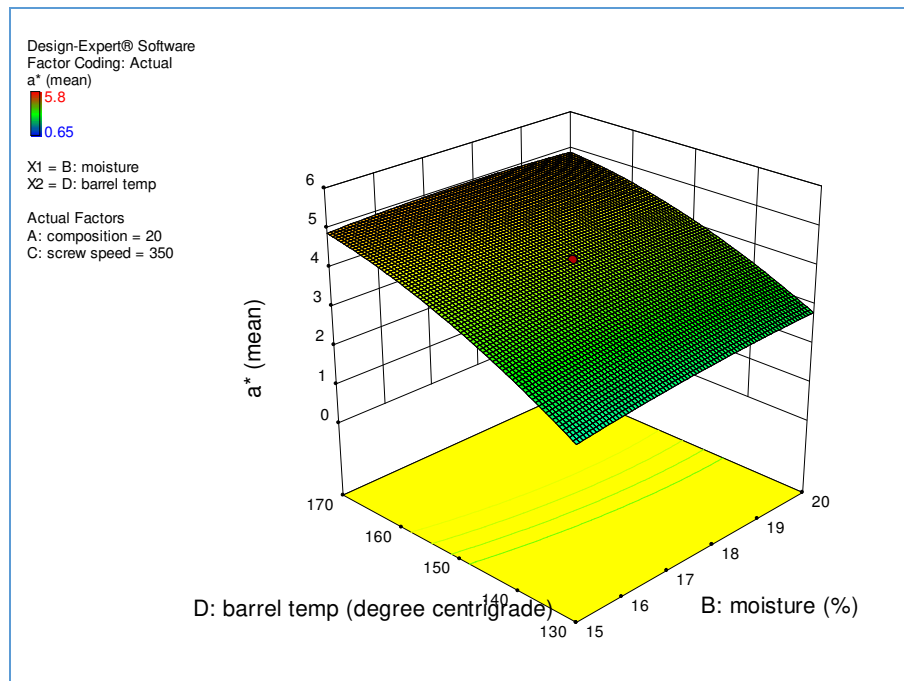
Fig. 21: (a) Response surface plot for a* as function of moisture and composition. (b) Response surface plot for a* as function of screw speed and moisture (c) Response surface plot for a* as function of barrel temperature and screw speeds (d) Response surface plot for a* as function of barrel temperature and moisture

Contd..

Fig. 21: Contd....



(c)



(d)

Table 4.36: ANOVA for b* (yellowness)

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	38.51	0.20	52.98	14	16.29	0.0001**
(C) Screw speed	-0.79	0.098	15.15	1	65.21	0.0001**
(D) Temperature	-1.06	0.098	27.16	1	116.88	0.0001**
A ²	0.32	0.092	2.82	1	12.14	0.0033**
B ²	0.46	0.092	5.76	1	24.79	0.0002**
C ²	0.23	0.092	1.48	1	6.35	0.0235*
D ²	0.20	0.092	1.11	1	4.76	0.0455*

*Significant at P<0.051

**Significant at P<0.01

Table 4.37: ANOVA for c* (chroma)

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	38.13	57.57	0.21	14	15.18	0.0001**
(C)Screw speed	-0.84	16.95	0.11	1	62.59	0.0001**
(D) Temperature	-0.93	20.96	0.11	1	77.40	0.0001**
A ²	0.47	5.96	0.099	1	22.01	0.0003**
B ²	0.61	10.24	0.099	1	37.83	0.0001**
C ²	0.30	3.48	0.099	1	12.85	0.0027**
D ²	0.36	3.53	0.099	1	13.21	0.0024**

**Significant at P<0.01

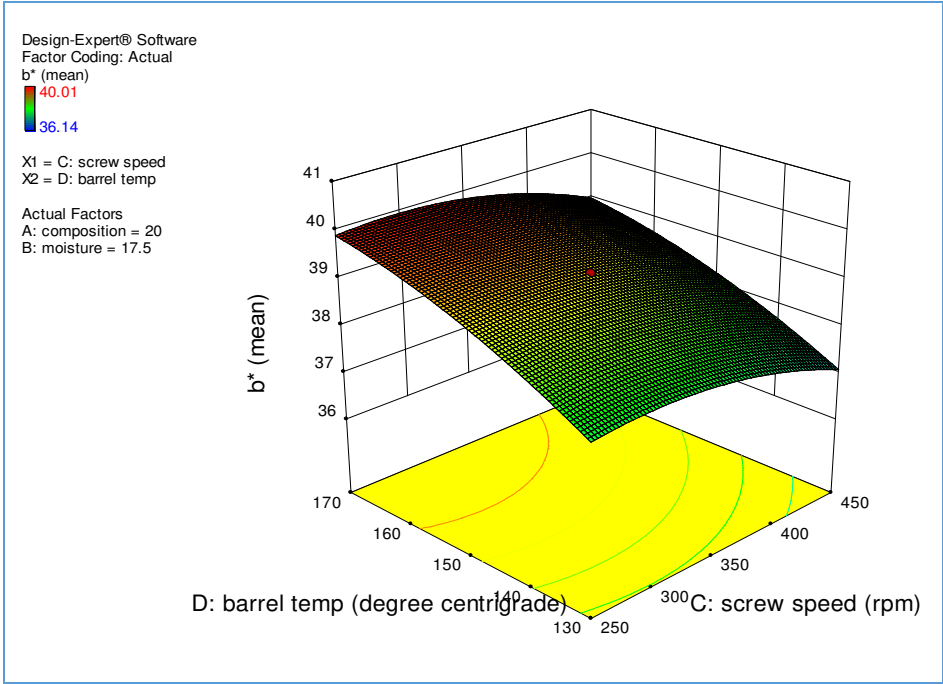


Fig. 22: Response surface plot for b* as function of barrel temperature and screw speed

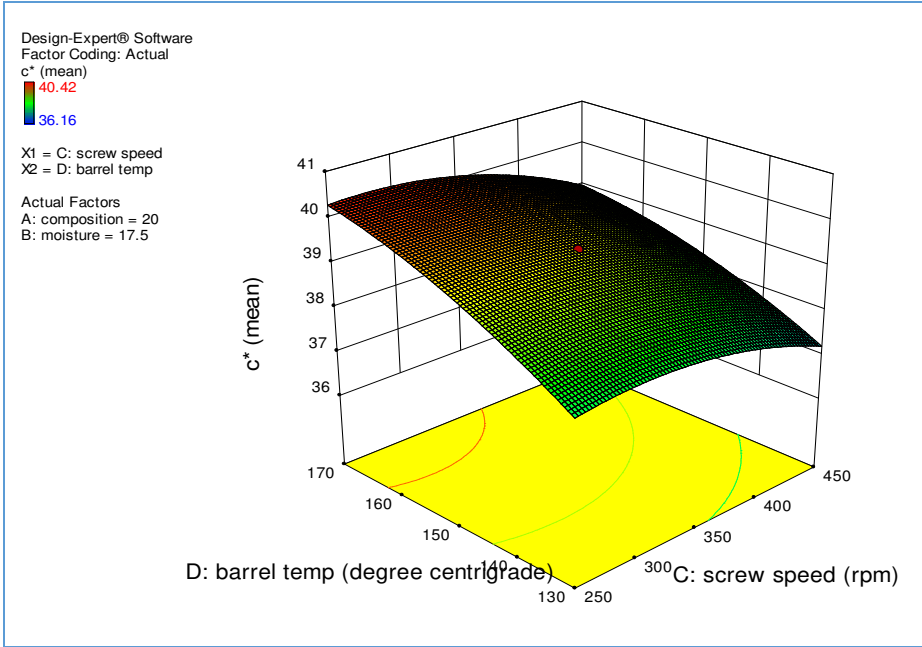


Fig. 23: Response surface plot for c* as function of barrel temperature and screw speed

Table 4.38: ANOVA for ΔE^* (total colour difference)

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	0.48	75.22	0.30	14	10.18	0.0001**
(A) composition	0.042	4.23	0.15	1	8.02	0.0126*
(D) Temperature	-1.15	31.60	0.15	1	59.90	0.0001**
B ²	0.47	5.93	0.14	1	11.24	0.0004**
C ²	0.74	15.07	0.14	1	28.57	0.0001**
D ²	0.95	25.02	0.14	1	47.42	0.0001**

*Significant at P<0.05

**Significant at P<0.01

Table 4.39: ANOVA for hue angle

Factors	Coefficient estimate	Sum of squares	Standard error	df	F-value	Prob>F
Intercept of model	82.98	135.81	0.19	14	46.05	0.0001**
(B) Moisture	-0.21	1.07	0.094	1	5.08	0.0345*
(C) Screw speed	0.60	8.51	0.094	1	40.39	0.0001**
(D) Temperature	-1.98	94.13	0.094	1	446.85	0.0001**
AB	-0.61	5.89	0.11	1	27.97	0.0001**
AC	0.29	1.31	0.11	1	6.20	0.0250*
BC	0.55	4.76	0.11	1	22.61	0.0003**
CD	0.44	3.14	0.11	1	14.91	0.0323*
A ²	0.29	2.23	0.088	1	10.58	0.0053**
B ²	0.23	1.47	0.088	1	6.97	0.0186*
C ²	0.61	12.00	0.088	1	56.95	0.0001**
D ²	0.40	4.28	0.088	1	20.33	0.0004**

*Significant at P<0.05

**Significant at P<0.01

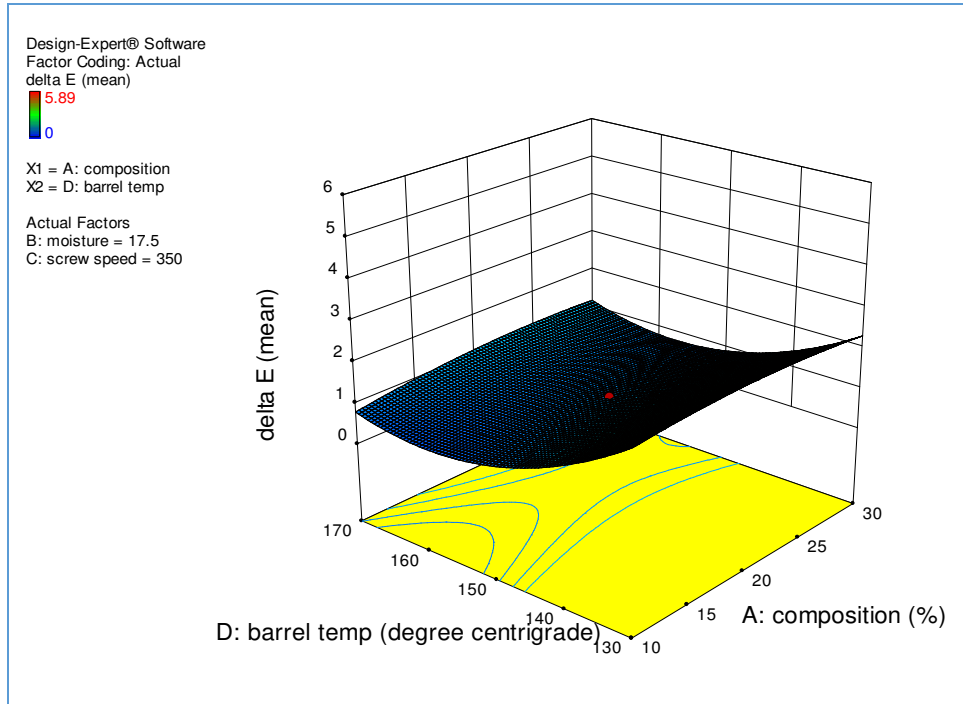
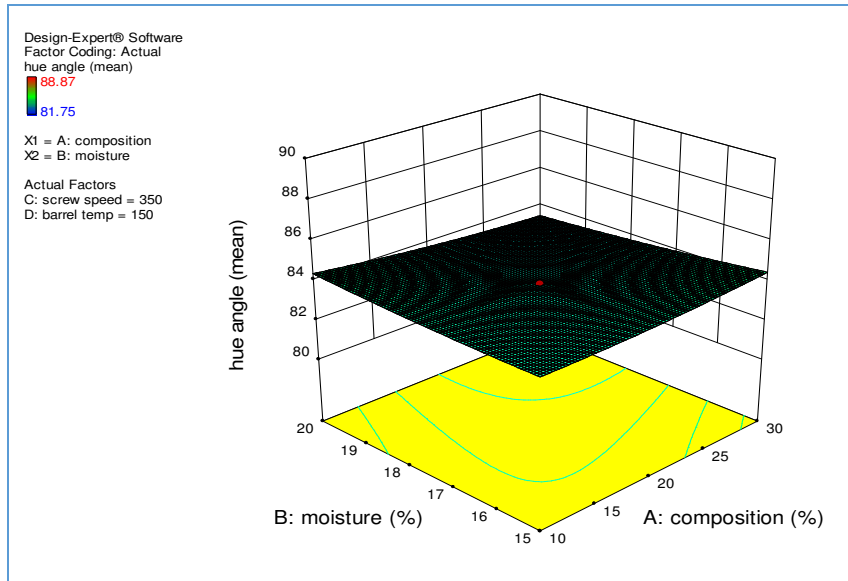
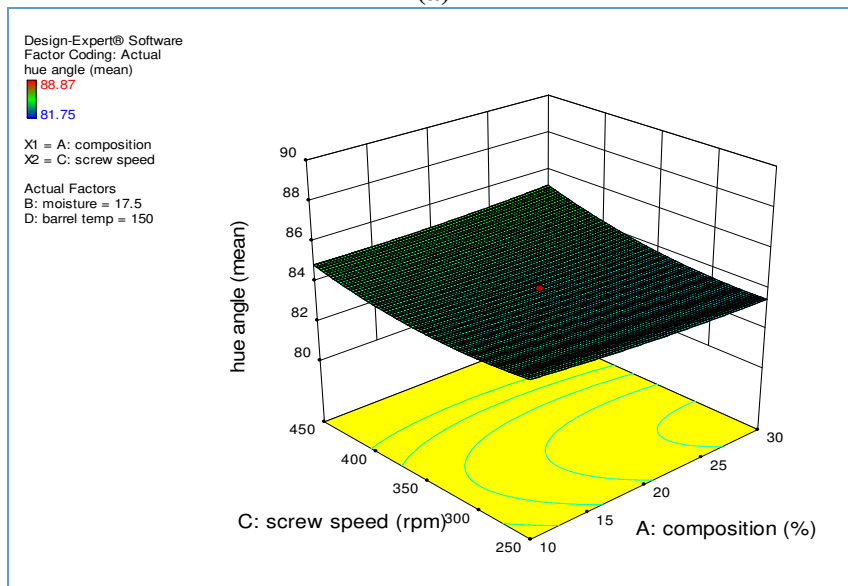


Fig. 24: Response surface plot for as ΔE function of barrel temperature and composition



(a)

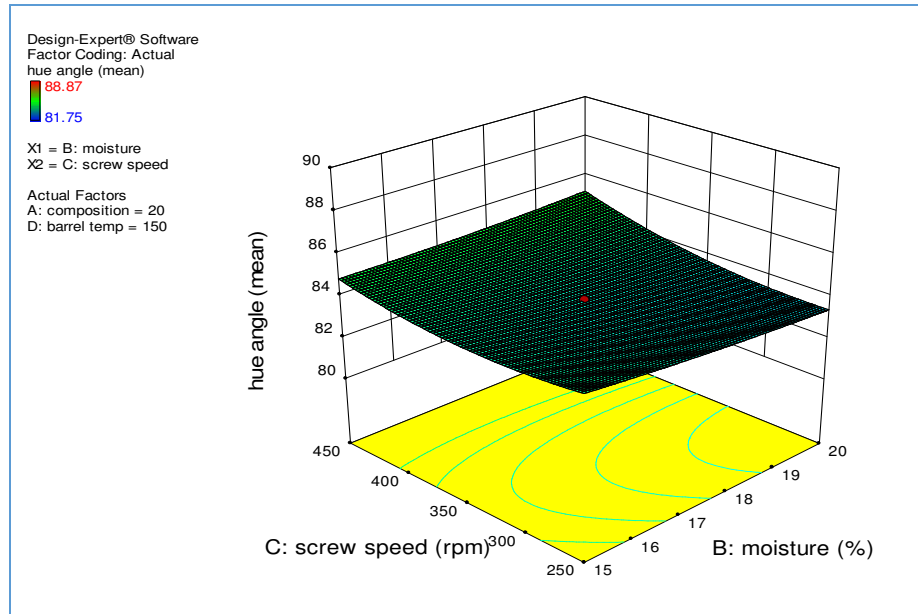


(b)

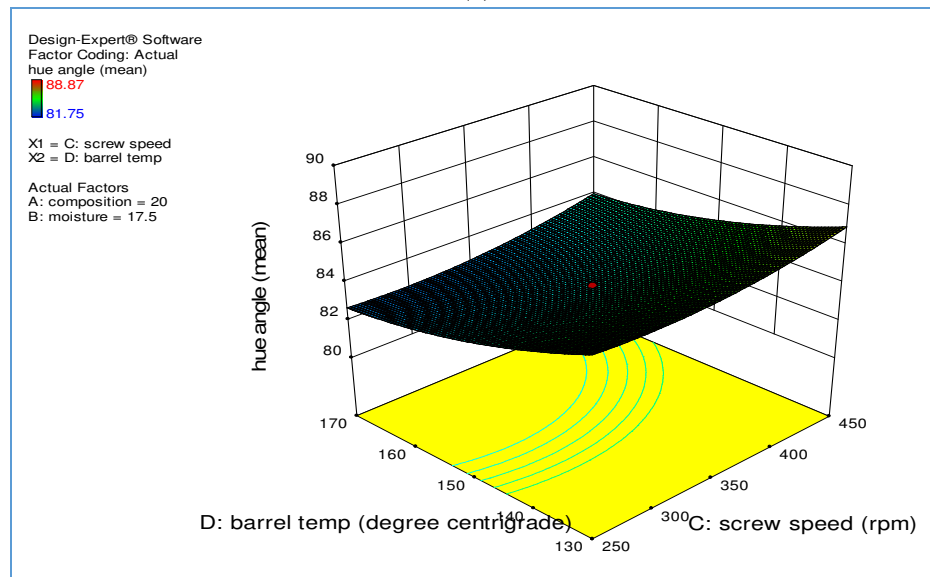
Fig. 25: (a) Response surface plot for hue angle as function of composition and moisture (b) Response surface plot for hue angle as function of hue angle composition and screw speed. (c) Response surface plot for hue angle as function of hue angle moisture and screw speed. (d) Response surface plot for hue angle as function of hue angle barrel temperature and screw speed

Contd...

Fig. 25 Contd...



(c)



(d)

4.11.7 Sensory evaluation (overall acceptability)

The extruded samples (honey + corn-apple) were evaluated organoleptically for appearance, texture, flavor, colour and overall acceptability by semi trained panel of 10 judges using 5-point scale. The overall acceptability score of 30 samples was found good. Maximum overall acceptability score (4.5) was found in extrudates obtained from following conditions: Apple powder incorporation = 10%, moisture content =15%, screw speed = 450rpm and barrel temperature 170°C.

4.12 Optimization of final product (corn based apple and honey incorporated breakfast snacks)

The highest desirability value of 0.865 was obtained (Fig 20). The optimum conditions for development of final product were - composition (honey incorporation) - 10%, feed moisture-15%, screw speed - 450 rpm and barrel temperature - 170°C. The predicted response in terms of SME, bulk density, WAI, WSI, expansion ratio and breaking strength were 83.572 Wh/kg, 156.333 kg/m³, 3.822 g/g, 12.13 %, 2.636 and 54.388 N (table 4.118).while as the actual response in terms of SME, bulk density, WAI, WSI, expansion ratio and breaking strength were 84.98 Wh/kg, 151 kg/m³, 3.874 g/g, 11.74 %, 2.71and 52.8 N. The predicted response and actual response values were almost similar and the variation of actual response values was within 4 per cent of predicted values.

4.13 Physicochemical characteristics of corn based apple and honey incorporated breakfast snacks

Table 4.42 and 4.43 shows the physicochemical characteristics of final product.



Plate 2: Optimized honey powder incorporated corn-apple based breakfast snack

Table 4.40: Sensory scores of extrudates produced at different process conditions

S. No.	Composition (%)	Moisture (%)	Screw speed (rpm)	Barrel temp. (°C)	Overall acceptability
1	90:10	15	250	130	4.2
2	70:30	15	250	130	3.0
3	90:10	20	250	130	4.1
4	70:30	20	250	130	2.8
5	90:10	15	450	130	4.3
6	70:30	15	450	130	3.0
7	90:10	20	450	130	4.1
8	70:30	20	450	130	2.9
9	90:10	15	250	170	4.5
10	70:30	15	250	170	3.3
11	90:10	20	250	170	4.4
12	70:30	20	250	170	3.1
13	90:10	15	450	170	4.6
14	70:30	15	450	170	3.4
15	90:10	20	450	170	4.4
16	70:30	20	450	170	3.2
17	100;0	17.5	350	150	3.05
18	60:40	17.5	350	150	2.6
19	80:20	12.5	350	150	4.0
20	80:20	22.5	350	150	3.5
21	80:20	17.5	150	150	3.6
22	80:20	17.5	550	150	3.9
23	80:20	17.5	350	110	3.7
24	80:20	17.5	350	190	3.5
25	80:20	17.5	350	150	3.8
26	80:20	17.5	350	150	3.8
27	80:20	17.5	350	150	3.8
28	80:20	17.5	350	150	3.8
29	80:20	17.5	350	150	3.8
30	80:20	17.5	350	150	3.8

Table 4.41: Predicted response levels and actual response levels

Values	SME (Wh/kg)	Bulk density (kg/m ³)	WAI (g/g)	WSI (%)	Expansion ratio	Breaking strength (N)
Predicted values	83.572	156.333	3.822	12.13	2.636	54.388
Actual values	84.98	151	3.874	11.74	2.71	52.8
Variation (%)	1.68	3.41	1.36	3.315	2.80	2.91

Table 4.42: Physicochemical characteristics of final product

Parameter	Final product (honey+corn- apple)
Water activity	0.47
Moisture (%)	3.53
Break strength (N)	52.8
Crude fat (%)	1.1
Crude protein (%)	3.325
Ash (%)	1.705
Crude fiber (%)	2.053
Dietary fiber (%)	12.439
Carbohydrates (%)	90.34
Acidity (%)	Not detected
Reducing sugar (%)	3.2
Non reducing sugar (%)	0.6
Total sugar (%)	3.8
HMF (mg/kg)	2.39
Total solids (%)	88.425
β-glucan (%)	1.738
Antioxidant activity (%)	40
Mineral profile (mg/100g)	
Calcium	7.88
Magnesium	107.2
Potassium	306.04
Phosphorus	195.2
Sodium	37.62
Zinc	2.319
Vitamins (mg/100g)	
Thiamine	0.133
Riboflavin	0.19
Niacin	2.352
Calorific value (k cal/100g)	384.56
Colour	
L*	53.78
a*	5.87
b*	37.76

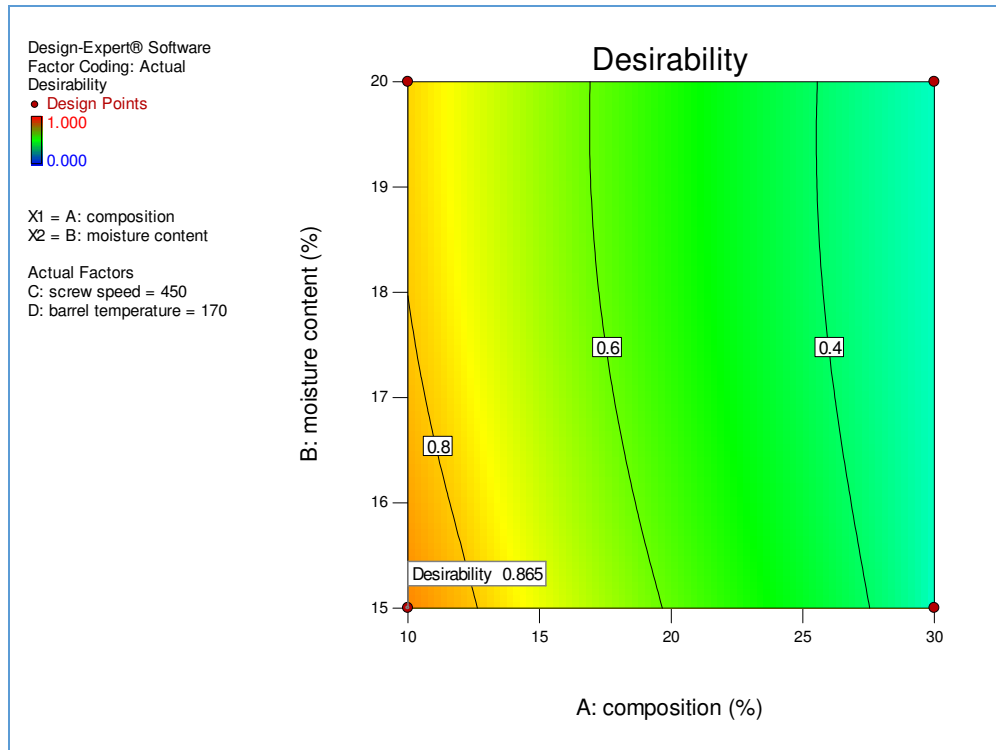


Fig. 26: Desirability function response surface for development of honey incorporated corn-apple based extrudates

Table. 4.43: Pasting Properties of Final product (honey + corn-apple)

Pasting properties of final product	Final product
Pasting Temperature (°C)	80.02
Pasting Time(min)	3.80
Peak Viscosity (cp)	298
Trough Viscosity (cp)	258
Final Viscosity(cp)	290
Breakdown Viscosity (cp)	40
Setback Viscosity (cp)	32

4.14 Economics of corn based apple and honey incorporated breakfast snacks

Break-even point =fixed cost/P/V Ratio

= 2607561.93

Table 4.44: Margin of safety

Production (in units)	Total sale (in Rs.)	Total cost (in Rs.)	Profits (in Rs.)	Margin of safety (in units)	Margin of safety (in Rs)
10000	1850000	2360000	-610000	-	-
12000	21220000	2432000	-332000	-	-
14000	2590000	2504000	-54000	-	-
14094.9241	2607561.93	2607561.93	(BEP)	(BEP)	(BEP)
14500	2682500	2623500	59000	405.07	15938.07
15000	2775000	2645000	80000	905.07	37438.07

4.15 Storage Stability of corn based apple and honey incorporated breakfast snacks

The blends of honey + corn-apple were extruded at pre-optimised conditions i.e. 10% honey, 15%moisture content, 450 rpm screw speed and 170 °C barrel temperature. The extrudates were packed in high density polyethylene bags and kept for three months under ambient conditions for storage studies (25±2°C, RH=60-62%). The product was analysed for following parameters at an interval of one month.

4.15.1 Moisture content

Significant increase in moisture content was observed during 3 months of storage. The moisture content of the product ranged from 3.53 to 5.32 per cent (Table 4.45) during 3 months of storage.

4.15.2 Free fatty acids (FFA)

Storage had a non-significant effect on the development of FFA over the period of three months The FFA content increased from 0.062 to 0.079 % (Table 4.45) in three months of storage.

4.15.3 Water Activity

During the storage period of three months, the water activity of snacks increased slightly. The mean water activity on the 0th was 0.47 which increased to 0.57 after three months of storage (Table 4.45).

4.15.4 Break strength

During the three months of storage, the hardness decreased from the mean value of 52.8N to 48.3 N (Table 4.45).

4.15.5 Total plate count (TPC)

Up to 3 months of storage period (Table 4.18) no significant growth of microbes was observed. After the first month of storage, TPC was observed to be 0, however after 2 and 3 months of storage, TPC was too few to count.

4.15.6 Overall acceptability

The sensory evaluation of the extrudates was carried out every month during storage. Extrudates showed significant decrease in overall acceptability during three months of storage. The sensory evaluation of extruded snacked revealed that overall acceptability showed significant change during the storage period of three months, however extrudated were still acceptable.

Table 4.45: Storage studies of final product

Storage period (3 months)	Moisture content (%)	Water activity	Free fatty acids (%)	Breaking strength (N)	Total plate count (CFU/g)	Overall acceptability
0	3.53	0.47	0.062	52.8	0.00	4.6
1	3.64	0.49	0.069	51.7	0.00	4.6
2	4.71	0.53	0.074	50.4	TFTC	4.2
3	5.32	0.57	0.079	48.3	TFTC	3.9
CD (p≤0.05)	0.127	0.02	0.002	NS	NS	0.199

TFTC = Too few to count NS = Non significant

Chapter - 5

DISCUSSION

The results of experiment *obtained in the present investigation entitled* “Utilization of honey-apple blends for the development of corn based breakfast snacks Using Extrusion Technology” described in the preceding chapter has been discussed here with suitable reasoning.

Experiment No. 1: Optimization of processing conditions for the development of apple incorporated corn based extruded snacks

5.1 System parameters

5.1.1 Specific Mechanical Energy (SME)

Temperature and moisture content had significant negative effects on SME. The negative coefficient of moisture content and barrel temperature indicated that SME decreased with increase in temperature and moisture content. The decrease of SME with increase of feed moisture is due to the fact that higher moisture produces a lubricating effect resulting in reduced use of energy and consequently lower SME (Jin *et al.*, 1994). The decrease of SME with increasing temperature could be attributed to the enhanced gelatinization of starch at higher barrel temperature, higher temperature facilitates transformation of solid flow to viscoelastic flow and reduces melt viscosity, which resulted in drop of SME. These results are in agreement with the results of Altan *et al.* (2008) in wheat, corn and barley extrudate.

5.2 Physical properties of extruded snacks

5.2.1 Bulk density (BD)

Composition had a significant positive effect on bulk density while temperature had a significant negative effect on bulk density. Increasing concentration of apple powder in corn-apple blends significantly increased the bulk density of extrudates. According to Seker (2005) interactions of starch with

apple powder could decrease the free expansion of amylopectin chains and inhibit the release of water vapor, thus limiting expansion and increasing density. Decrease in bulk density with increasing concentration of fruit powder has also been reported by Altan *et al.* (2008) in extruded mixtures of barley and grape. At lower temperatures enough vapor pressure is not generated to break the cell walls, escape of vapours, thus collapsing the extrudates and increasing bulk density. Furthermore, increased starch gelatinization at higher temperature enables more entrapment of water inside the pellets and ultimately results in increased expansion and reduced bulk density of the extrudates. The results found to be in reasonable agreement with the findings of Dehghan-Shoar *et al.* (2010) for the directly expanded extruded snacks.

5.2.2 Water Absorption Index (WAI)

The response surface plots demonstrates that WAI decreased with the increase in composition and barrel temperature. WAI decreased significantly as the percentage of apple powder increased. Lower WAI with increasing apple powder concentration may be attributed to the reduction in starch content with increasing percentage of apple powder, as a result, less of the starch may be available for gelatinization, subsequently reducing WAI. Singh and Sekhon (2007) reported a decrease in WAI of extruded rice due to dilution of starch by addition of pea grits to rice. Higher thermal temperature may lead to enhancement in the extent of starch degradation and increased dextrinization which resulted in decreased WAI. Similar results were reported by Hagenimana *et al.* (2006) in evaluation of rice flour modified by extrusion cooking.

5.2.3 Water Solubility Index (WSI)

The response surface plots of WSI showed the positive influence of composition and barrel temperature. The significant increase in WSI with increasing apple powder concentration may due to disintegration of starch granules and formation of low molecular weight compounds during extrusion,

leading to increase in soluble components. Collona *et al.*,(1989) related increase in WSI to formation of low molecular weight components, which can be separated quite easily from each other under severe processing conditions. Singh *et al.* (2001) reported an increase in WSI when temperature was increased, during extrusion processing of sweet corn grits. WSI increased with increasing temperature, at higher temperatures degradation of starch and pectin may increase, thereby releasing low molecular weight components, this in turn increases their solubility in water. Also, at low moisture content, more friction may have occurred inside the extruder, causing high mechanical damage and an increased WSI. These findings are in agreement with the results reported by Singh *et al.* (2001) for extrusion cooking of sweet corn.

5.2.4 Expansion Ratio (ER)

The response surface plots of ER indicated the negative influence of composition, moisture content and positive influence of barrel temperature on expansion ratio. The reduced expansion of the extrudates upon addition of apple powder might be due to the competition set by apple powder for moisture during the extrusion process affecting the degree of gelatinization. Similar results were reported by Yanniotis *et al.* (1987). At higher temperatures, the viscoelastic properties might have improved, generating a sufficient vapor pressure to expand the snacks properly. This increase in vapor pressure may be due to formation of large amount of small resulting in increase in pressure and breakage of cell walls thus allowing water vapor to escape and snacks to expand. Similar results have been reported by Aguilar-Palazuelos *et al.* (2006), working with 3G snacks made from a mixture of potato starch, quality protein maize (QPM), and soybean meal. Launay and Lisch (1983) reported that the increased temperature would yield a lower melt viscosity and increased longitudinal expansion. Similar observations were reported by Chinnaswamy and Hanna (1988), Ali *et al.* (1996) and Hagenimana *et al.* (2006) for the effect of temperature on product expansion of corn starch, corn grits and rice flour. The decrease in ER with increase in moisture

content attributed to the effect of moisture content on viscoelastic properties. The increased moisture is believed to affect the viscoelastic properties and collapsing of air bubbles inside the pellets thereby causing a decrease in expansion. Similar results were reported by Escalante-Aburto *et al.* (2013) in direct expanded snack foods obtained from nixtamalized blue corn flours. Also, this is consistent with the results reported by Ding *et al.* (2006) in directly expanded snacks made from wheat.

5.2.5 Breaking Strength (BS)

Breaking strength was significantly affected by level of apple powder incorporation, moisture content, screw speed and barrel temperature. Composition and moisture had positive influence on breaking strength while screw speed and barrel temperature had a negative effect on breaking strength. The significant increase in BS of extrudate with increase in the level of apple powder may be attributed to reduced expansion due to high fibre content of apple powder. Similar results were reported by Normell *et al.* (2009) for soy protein fortified extrudates. Increase in BS with increasing moisture content might be due to the reduced expansion caused by collapse of air bubbles inside the pallet at high moisture content. Similar trends have also been reported by Lee *et al.* (2002). The effect of screw speed on hardness might be through its influence on extrudate expansion. The decrease in hardness with increasing screw speed has also been reported by Altan *et al.* (2008) in corn- and barley-based extrudates. Breaking strength had a negative correlation with barrel temperature, when extrusion was performed at high temperatures extrudates became more brittle, offering lower breaking strength, further decrease in hardness with increasing barrel temperature is in line with the results of bulk density where reduced density was observed. A low-density product naturally offers low breaking strength.

5.2.6 Colour

L* (luminosity) values of extrudates decreased with the addition of apple

powder. This behavior may occur because dietary fiber content is increased by increasing apple powder concentration. Holguín-Acuña *et al.* (2008) reported that L* colour values decreased by the addition of fiber in extruded products made from corn and oat. The negative coefficient of linear term of moisture indicates that luminosity decreases with an increase in moisture content. Similar trend was reported by Syed *et al.* (2014), while conducting the study on the refabricated rice by extrusion technology. Barrel temperature showed significant negative effect on L* value of the extrudates. This was probably due to presence of sugars which could have suffered caramelization and/or Maillard reactions and thus darkening the product. The increase in L* with increase in screw speed may be due to lesser residence/extrusion time at higher screw speed that resulted in lower degradation of the pigments (Yu *et al.*, 2012).

With increasing apple powder concentration, the a* (redness) and b* (yellowness) values increased due to presence of yellow-orange pigments in apple powder. Both the a* and b* values were more pronounced at higher temperature due to browning caused by pigment decomposition and caramelization of sugars at high extrusion temperature (Hagenimana, 1999). Yang *et al.* (1998) working on samples of corn starch and potato, conjugated with amino acids, reported that the yellow colour of corn largely contributes to the increase of the parameter b*, and concluded that these values may be increased by Maillard browning reactions. Both a* and b* decreased with the increase in the screw speed. The reason being, with increasing screw speed, there may be reduction in the residence time and, hence, reduction in the extrudate pigment decomposition (Jin *et al.*, 1994).

C* (chroma) value, it is the quantification of colour saturation. The reason for positive effect of temperature is that higher temperature accelerates the Maillard reaction, turning the food more saturated because of the generation of coloured compounds (Bemiller and Whisler, 1996). Hue angle is the colour expressed in degrees, which corresponds to pure red at 0°, to yellow at 90°, to green at 180°, and to blue at 270°. The moisture content of the blend and barrel

temperature and screw speed had significant effect on the hue of the extrudates. The hue angle of the extrudates varied from 81.75° to 87.1°. The lower angle relates to red colouration and higher angle corresponds to yellowish tinge. Colour difference (ΔE) is used to represent the colour change between the unprocessed and processed flours (effect of processing). In this study ΔE ranged from 0.97-5.89, values of ΔE for all the extrudates increased significantly ($P < 0.001$) as the screw speed increased and temperature decreased.

5.3 Storage studies of apple incorporated corn based snacks

5.3.1 Moisture content

With the advancement of storage period, an increase in moisture content was observed in extruded samples. Increase in the moisture content from 3.5-5% was reported in Thai rice (Charunuch *et al.*, 2008). The increase in moisture content may be due to hygroscopic nature of extrudates (Butt *et al.*, 2004). Due to the hygroscopic nature of the snacks and inefficient barrier properties, breakfast snacks absorbed moisture from environment (Butt *et al.*, 2004).

5.3.2 Water activity

During the storage period of three months, the water activity of snacks increased. Belitz *et al.* (2009) reported that the water activity below 0.3 largely protects food products against lipid oxidation, non-enzymatic browning, enzymatic activity and microbial spoilage. The slight increase of water activity in extrudates may possibly be due to the change in humidity of the surrounding environment (Syed *et al.*, 2014).

5.3.3 Free -fatty acids (FFA)

The FFA content increased during the storage period of three months, however the increase in FFA was within the permissible limits. It is reported that extrusion denatures enzymes responsible for oxidation of lipids (Camire *et al.*, 2007). Also lipids embedded within starch are less susceptible to oxidation and Miallard's reaction products produced during extrusion processing posses

antioxidant properties (Arora and Camire, 1994) which may have resulted in prevention of lipid oxidation.

5.3.4 Total plate count

Storage had a non-significant effect on the total plate count Owing to low water activity of the snacks and high temperature thermal processing. Frazier and Westhoff (1988) stated the reason for low total plate count of extruded snacks to be due to low moisture content of product. TPC was too few to count during the three months of storage, ensuring microbiologically safe extrudates.

5.3.5 Breaking - strength

Break strength is associated with the expansion and cell structure of the product. During the three months of storage period, a decrease in the break strength of extrudates was observed. Moisture gain by extrudates during the storage period cause decrease in breaking strength and eventually decrease in the force required to break the product. Dar *et al.* (2014), have reported a decrease in breaking strength of extrudates and ascribed this to moisture gain and increased starch bonding in extrudates.

5.3.6 Overall acceptability

Organoleptic properties are important for estimating eating quality and acceptability of the product in terms of texture, flavor and mouth feel.. During storage period of three months, the overall acceptability of snacks showed a significant decrease, however it was still in the acceptable range. Pradeep *et al.* (2013) have reported that overall acceptability of RTE nutritious snacks packed in LDPE was within the acceptable range over the period of 90 days. Sharrma (2012) has also reported overall acceptability of rice based snack was within the acceptable range over the 90 days of storage.

Experiment No. 2: Optimization of processing conditions for the development of honey incorporated corn -apple based extruded snacks

5.4 System Parameters

5.4.1 Specific mechanical energy (SME)

The negative coefficients of the linear terms of moisture and barrel temperature indicates that SME decreases with increase in these variables. At high moisture content a lubricating effect is produced within the dough which reduces the friction of screws, resulting in less torque and subsequently reduced SME. Similar results were reported by Govindsamy *et al.* (1997). Higher temperature favours the reduction of melt viscosity, flow characteristics of melt transform from solid flow to viscoelastic flow, which leads to reduction of torque and consequently lower SME (Ruiz *et al.*, 2008). Ryu and Ng (2001) have reported that higher temperature at the die exit lowered the SME of wheat flour and whole corn meal. Lin *et al.* (2000) found that increasing water content and temperature led to decreasing torque and pressure during the extrusion process of soy protein.

5.5 Physical properties of extruded snacks

5.5.1 Bulk density (BD)

Composition had significant ($P < 0.001$) positive effect on bulk density while temperature had significant negative effect. The bulk density of extrudates increased with the increased concentration of honey powder in the blends. Sopade and Le Grys (1991), Hsieh *et al.* (1993), Ryu *et al.* (1993) and Fan *et al.* (1996). The presence of sugar tended to reduce the availability of water or water activity, which effect the bulk density of extrudate (Moore *et al.*, 1990). With the increase in temperature, the bulk density decreased. Fletcher *et al.* (1985), Lawton *et al.* (1985) and Mercier and Fillet (1975) reported that with an increase in the die temperature, there was increase in degree of superheating of water in the extruder encouraging bubble formation with decrease in melt viscosity, leading to increased expansion and decreased bulk density. Case *et al.* (1992) with advance

in gelatinization, the volume of extruded product increases resulting in decrease in bulk density which is in agreement with our observations.

5.5.2 Water absorption index (WAI)

Composition, screw speed and temperature had significant ($P < 0.001$) negative effect on WAI while moisture content had significant ($P < 0.001$) positive effect. The binding of water due to addition of honey might have limited the availability of water, thus lower WAI. Yanniotis *et al.* (2007) reported that any increase in non-starch component results in extrudates with lower water absorption capacity. Yagcı and Goguş (2008) reported that at high moisture content, the starch viscosity might have decreased, allowing internal mixing and uniform heating which may account for the enhanced water absorption associated to starch gelatinization. Higher screw speeds caused decrease in WAI, probably due to the high shearing action produced at higher screw speed, which may have resulted in depolymerization of starch granules. The increase in WAI with increasing moisture content is in accordance with the observations reported by Ding *et al.* (2005) and Singh *et al.* (2007). Higher temperatures result in more dextrinization in comparison to gelatinization which in turn leads to lower WAI. Similar results have also been reported by Valentina *et al.* (2010).

5.5.3 Water solubility index (WSI)

WSI was significantly affected by composition and temperature. composition and temperature had significant positive effect on WSI. The increase in WSI with increase in honey proportion may be due to restriction on starch gelatinization by limited water availability so it promoted more dextrinization in comparison to gelatinization. These results are in alignment with that of Fan *et al.* (1996). Increasing temperature would increase the degree of starch gelatinization that may increase the amount of soluble starch resulting in an increase in WSI. Ilo *et al.* (1996) reported that the degree of gelatinization of extruded maize grits increased with increasing product temperature.

5.5.4 Expansion ratio (ER)

Expansion ratio was found to be significantly ($P < 0.001$) affected by the level of honey powder incorporation, moisture content and barrel temperature. Composition and moisture had significant negative linear effect on expansion while temperature had a significant positive influence. With increased concentration of honey powder resulted in reduced the expansion of extrudates. Jin *et al.* (1994) and Barret *et al.* (1995) reported that the presence of sugar reduced the availability of water, resulting in abbreviated gelatinization and thus decreased expansion of extrudates. Expansion ratio was also found to get decreased with the increase in moisture content. Alvarez-Martinez *et al.* (1988) suggested that the excess of water may greatly reduce elastic characteristics of amylopectin network thereby decreasing sectional expansion. The positive effect of barrel temperature might be due to augmented vapour pressure generation at higher temperatures which favors sufficient bubble formation and greater expansion. The results found in this study agree with those reported by Dehghan *et al.* (2010) for the directly expanded extruded snacks made from rice flour, wheat bran, and corn grits, and enriched with tomato lycopene. These authors believed that as temperature was increased, a higher amount of moisture was lost from the product at the outlet of the extruder die, becoming a less dense product.

5.5.5 Break strength (BS)

Breaking strength of extrudates was increased significantly with the increase in composition, moisture content whereas, with the increase in temperature and screw speed, breaking strength was decreased. It is possible that the higher levels of sugar in the formulation as a result of the honey powder may have contributed to the increase in density and reduction in cell size of the extrudates that resulted in increased hardness. This is consistent with the findings of Barrett *et al.* (1995) who reported that increasing sucrose content increases the density and reduces the cell size resulting in a progressive increase in compressive resistance. Water function as a plasticizer in extruder for the starch based material,

which reduces viscosity and compresses bubble growth. The compressed bubble growth results in dense products. Similar results were reported by Huth *et al.* (2000). It is expected that increasing temperature as well as screw speed would decrease 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 offers low hardness. Bhattacharya and Hanna (1987) also reported that a higher degree of gelatinization caused greater expansion but lower breaking strength. Similar trends have been reported previously by Ding *et al.* (2005) in barley-tomato pomace blended extrudates and Lin *et al.* (2000), Altan *et al.* (2008) and Menget *et al.* (2010) in corn, barley and chickpea based extrudates respectively.

5.6 Colour

When the level honey powder was increased, the values of L* (luminosity) tend to decrease. The increased darkening of extrudates with addition of honey powder might be due to presence of mono- and disaccharides in honey, which may have underwent enhanced caramelization and maillards reaction. (Maga and Kim, 1989). However, the luminosity of extrudates increased with decrease in moisture content. These results are in accordance with the results shown by Gutkoski and EL-Dash (1999). L* value of extrudates increased at higher screw speeds, probably due to lower residence time at higher screw speeds (Jin *et al.* 1994). The reduction in L* values of the extrudates on increasing temperature may be attributed to the occurrence of Maillard reaction at high temperatures (Sacchetti *et al.*, 2004).

The positive coefficients of linear terms of composition, temperature and moisture indicated that with the increase in these variables a* (redness) value increased, while as the negative coefficients of screw speed indicates that a* values decreased with increase in screw speed. This may be due to the occurrence of browning reaction (caramellization of sugars), taking place during extrusion due to processing honey (Maga and Kim, 1989). The process conditions

normally used in the thermoplastic extrusion (high temperature and low moisture content) are known to favour the reaction between reducing sugars and amino acids, that results in either colour degradation or formation of desirable colour compounds (Mercier *et al.*, 1989). Increase in temperature and screw speed decreased the b^* value of the product, whereas increase in feed proportion increased the b^* value of the product. Similar observations were recorded by Juvii *et al.* (2012).

Chroma or saturation or colourfulness is the difference between the colour against the gray. It describes the vividness or dullness of a colour. The c^* value increased with the fall in temperature, due to increase in the coordinate b^* . Hue is the first element in the colour-order system by which we distinguish red from green, blue from yellow, etc. Hue angle ranged from 37.00 to 43.00. The total colour difference values (ΔE) increased with composition and moisture content whereas high temperature resulted in decrease in ΔE .

5.7 Storage studies of honey incorporated corn-apple based breakfast snacks

5.7.1 Moisture content

Gradual increase in moisture content was observed during 3 months of storage. The increase in moisture content during storage was due to the hygroscopic nature of snacks. Cheng *et al.* (2011) observed significant increase of moisture content in mung bean snacks during storage. Butt *et al.* (2004) observed an increase in moisture content in breakfast cereals during a storage period of six months

5.7.2 Water activity

The water activity of snacks increased during the storage period of three months, this increase of water activity might be due to humid environmental conditions. Labuza *et al.* (1980) reported non-significant increase of water activity in stored food products.

5.7.3 Free fatty acids (FFA)

The FFA increased during the storage time of three months. The increase in FFA was presumably due to the enzyme activity of lipase upon fats, which leads to generation of free fatty acids in presence of a catalyst like moisture, light or heat (Camire *et al.*, 2007). The similar increase in FFA was observed by Uma *et al.* (2011).

5.7.4 Total plate count

No significant increase was found in TPC of extrudates during the storage period of three months. The reason for low total plate count of extruded snacks might be due to low moisture content of product (Frazier and Westhoff, 1988).

5.7.5 Breaking - strength

The breaking strength of the extrudates was observed to decrease during a period of three month. The decrease in hardness might be related to gain in moisture of extrudates. Charunuch *et al.* (2008) also reported decrease in hardness of iron fortified extruded Thai rice snacks stored for 4 months.

5.7.6 Sensory analysis

Storage period had significant effect on the organoleptic properties of the snacks. During the entire period of three months of storage, overall acceptability of snacks was within acceptable range. Butt *et al.* (2004) observed that sensory properties were almost same throughout six months storage and there was a non-significant difference in various treatments. Pathania (2013) reported that the extruded instant mixes developed from combination of cereal: pulses: groundnuts were in acceptable range after six months of storage.

Chapter – 6

SUMMARY AND CONCLUSION

The present investigation entitled “Utilization of honey-apple blends for the development of corn based breakfast snacks using extrusion technology “was carried out in the Division of Food Science and Technology, SKAUST-Kashmir. Experimental procedures are given in chapter 3 under Materials and Methods. The extrusion experiment was designed and conducted according to response surface methodology (RSM) having composition, moisture, screw speed and barrel temperature as independent variables and their effects on product responses-SME, bulk density, WAI, WSI, expansion index, instrumental colour and breaking strength were studied. Sensory evaluation and storage studies of extruded snacks were also studied. The best processing condition for development of extrudates was selected by numerical optimization. The results of investigation are summarized below:

The corn (C-6) variety procured from Division of Genetics and Plant Breeding, SKUAST-Kashmir, was milled in mill (Model 3303, Perten Sweden) in the Division of Food Science and Technology. Culled apples (CV: Red delicious) and honey powder were procured from the local market. Culled apples were dehydrated in tray dryer ((NSW-154)) and ground in grinder (Black and FG-550) to form powder, sieved and stored under ambient conditions ($25\pm 2^{\circ}\text{C}$, 60-62%RH) in high density polyethylene (HDPE)until used. Central composite rotatable design was used to obtain the design for experiment. The design generated 30 runs (processing conditions). The independent variables selected in first extrusion process were composition (0-40%). Moisture content (12.5-22.5%), screw speed (150-550 rpm) and barrel temperature (110-190 °C). Extrusion processing at each condition was performed for corn-apple blends to get extruded product. Thirty extruded samples were analysed for SME, WAI, WSI, bulk density, expansion index, instrumental colour and breaking strength. Corn flour was replaced with water apple powder in first set at 0 to 40% levels and the

optimized corn-apple blend (90:10) was replaced with honey powder in the next experiment.

Both individual flours and their blends were physico-chemically analysed (moisture, crude protein, crude fat, crude fiber, dietary fiber, carbohydrates, acidity, ash, β -glucan, reducing sugars, non-reducing sugars, total sugars antioxidant activity, total solids, minerals, organic acids, calorific value and vitamins). In corn flour the per cent moisture, crude protein, crude fat, crude fibre, dietary fiber and carbohydrate were found as 11.3, 8.97, 3.38, 2.6, 12.16 and 74.75 percent respectively. The percentage of moisture, crude protein, crude fat, crude fibre, dietary fiber and carbohydrate for apple powder were 14, 0.92, 0.31, 3.5, 13.5 and 82.97 respectively, whereas the percent moisture, crude protein, crude fat and carbohydrate for honey powder were 17.6, 0.084, 0.38 and 79.55. Corn flour contained 1.86% of beta glucan. Apple powder had fairly high dietary fiber content of 13.5%, and honey had highest antioxidant activity of 48% followed by corn 37%. Highest contents of calcium, potassium and sodium were found in apple, phosphorus and zinc in honey and magnesium in corn flour. Vitamins (thiamin, riboflavin, and niacin) were observed highest in in corn flour however no thiamin was recorded in apple powder. In this study it is observed that the incorporation of apple and honey powders has an impact on the physical characteristics of extrudates impacting on expansion and density that contribute to the organoleptic properties of snack products. In addition it has been shown that the process of extrusion has substantially increased the levels of fibre and antioxidant properties in extruded products. A nutritional evaluation shows that the snack products produced are a good source of dietary fibre, betaglucan, vitamins, minerals and are having fairly high antioxidant property. Keeping in view the increasing concern about the unhealthy snacking and its implications for long- and short-term health, from this study it can be concluded that apple and honey powder can be successfully incorporated for the development of healthy and nutritious snacks.

Numerical optimization was used to generate optimum processing conditions and to predict the corresponding responses as well. Product responses such as SME, bulk density, WAI, WSI, expansion index and breaking strength were major parameters that determined the quality of extruded products. Apple powder incorporation of 10%, moisture content of 15%, screw speed of 450 rpm and temperature of 170°C were predicted the best condition by RSM design, for making extrudate snacks from Corn flour and apple powder blends. All the blended extrudates were subjected to sensory evaluation by a panel 10 semi trained judges. The final product obtained after optimization and sensory evaluation was analysed for moisture, crude protein, crude fiber, dietary fiber, crude fat, ash, total solids, acidity, reducing sugar, non-reducing sugar, total sugar, carbohydrate, calorific value, vitamin, mineral profile, antioxidant activity, water activity, pasting characteristics, β -glucan, colour and breaking strength. The snacks were packed in high density polyethylene (200 gauges) bags and stored for three months under ambient conditions. The product was analysed for following parameters at an interval of 30 days.

To the best blend obtained after optimization and sensory evaluation honey powder was added at the level of 0 to 40%. All other extrusion conditions viz. moisture content, screw speed and barrel temperature were varied as per previous experiment. CCRD design, which generated 30 runs was used for conducting the experiment. The optimum conditions obtained by numerical optimization for development of extrudates were found as honey powder incorporation= 10%, moisture content =15%, screw speed = 450 rpm and barrel temperature=170°C.

The final product obtained after optimization and sensory evaluation was analysed for moisture, crude protein, Crude fiber, dietary fiber, crude fat, ash, total solids, acidity, reducing sugar, non-reducing sugar, total sugar, HMF, carbohydrate, calorific value, vitamin, mineral profile, antioxidant activity, water activity, pasting characteristics, β -glucan, colour and breaking strength. The final product was packed in HDPE stored under ambient conditions for 3 months. The

sample was analysed at an interval of 30 days for various quality attributes viz. moisture, water activity, free fatty acids, breaking strength and TPC.

The following conclusions were drawn from the study:

- Apple powder incorporation showed prominent effect on bulk density, expansion ratio, WAI, WSI and breaking strength in case of corn based extrudates while as honey powder incorporation showed significant effect on bulk density, expansion ratio, WAI, WSI, breaking strength, ΔE and hue angle in case of apple powder incorporated corn-apple blended extrudates.
- Moisture content also showed prominent effect on SME, expansion ratio, breaking strength, L^* , a^* and hue angle in case of corn-apple blended extrudates while as it showed significant effect on SME, WAI, breaking strength, L^* and a^* value in case of honey powder incorporated corn-apple blended extrudates.
- Screw speed showed prominent effect on breaking strength, L^* , b^* , c^* , ΔE and hue angle value in case of corn-apple blended extrudates while as it showed significant effect on WAI, breaking strength, L^* , b^* , c^* and hue angle value in case of honey powder incorporated corn-apple blended extrudates.
- Barrel temperature also showed prominent effect on bulk density, SME, expansion ratio, WAI, WSI, breaking strength, L^* , a^* , b^* , c^* , ΔE and hue angle value in case of corn-apple blended extrudates as well as in honey powder incorporated corn-apple blended extrudates.
- Best product for corn flour and apple powder was obtained at corn to apple ratio 90:10, moisture content 15%, screw speed 450 rpm and temperature 170°C.
- Best product for optimized flour blend (90:10) and honey powder was

obtained at a ratio 90:10, moisture content 15%, screw speed 450 rpm and temperature 170°C.

- Storage study suggested that the product can be stored in HDPE bags for three months at ambient conditions.

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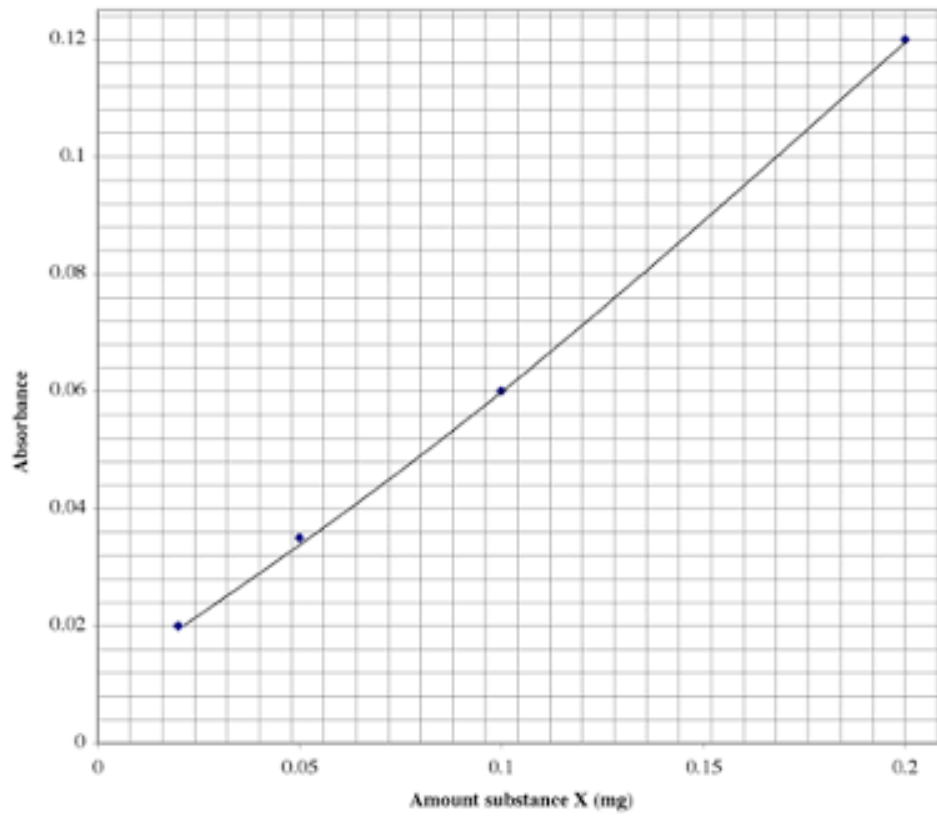
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Standard curve – Total Sugars



Appendix-II

Sensory Evaluation Proforma

Name of Panellist _____ **Date** _____

Kindly evaluate the brown rice based cracker sample for appearance, colour, hardness, taste and over all acceptance.

Numerical Scale	Numerical Scale Description
5.	Excellent
4.	Very good
3.	Good
2.	Fair
1.	Poor

Sample code	Appearance	Colour	Texture	Flavour	Mouthfeel	Overall acceptability

Signature of the Panellist

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Faculty of Horticulture, Division of Food Science and Technology

CERTIFICATE

Certified that all the corrections/amendments as suggested by External Examiner Dr. M.A. Mir, Former Professor & Head, Division of Food Science & Technology, SKUAST-Kashmir during Viva-Voce examination held on November 17, 2017 have been incorporated in the manuscript entitled **“Utilization of honey-apple blends for the development of corn based breakfast snacks using extrusion technology”** submitted by **Ms. Jasia Nissar (Regd. No. 2012-419-D)**.

(Dr. H. R. Naik)
Chairman
Advisory Committee