DEVELOPMENT OF FRUIT BASED PRODUCTS USING EXTRUSION-DRYING PROCESS FOR NEED BASED APPLICATIONS

By

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DEDICATED TO MY FAMILY AND SUPERVISOR

ABSTRACT

The dietary concerns of consumers are moving rapidly from foods that prevent nutritional deficiency and associated diseases to foods that offer longer-term prevention of chronic diseases. Consuming unhealthy foods is leading to different extremities, lack of nutrition on one hand and aggravation of chronic diseases and obesity on the other. A possible solution to these problems is the creation of healthy and convenient foods. Extrusion processing can serve the food industry with food products which are convenient as well as nutritious by providing a platform for enrichment of food products with fiber, protein, antioxidants and vitamins. This thesis aims at developing nutritionally balanced fruit products using an extrusion process to serve as a potential diet for special need applications such as malnourished children and chronic kidney disease patients.

Extrusion cooking studies were carried out in order to develop two products: fruit licorice and instant porridge using mango and pineapple as base ingredients. D-optimal mixture design was selected for this study to investigate the effect of different functional ingredients on the sensory and nutritional characteristics of the final product. The design generated 16 experimental combinations and an additional control formulation was made for both products. The extrusion screw speed was set to 100 rpm and temperature was set to 120^{O}C, 100^{O}C, 80^{O}C and 60^{O}C for licorice and 140^{O}C, 120^{O}C, 100^{O}C and 80^{O}C for porridge in the four barrel zones, respectively, keeping the highest temperature near the die. The extrudates were finish dried to reduce the moisture content to 8-10% for further analysis. The product characteristics such as bulk density, color, texture etc. were analyzed for both products. Antioxidant level and textural attributes were found to increase with an increase in fruit content in both the products. However, banana flour which was added in instant porridge led to an increase in the hardness and darkness of the porridge. Higher bulk density and rehydration ratios were associated with higher content of pineapple and banana flour. The developed products were also analyzed for protein content to conform to the needs of specific diets, i.e. higher protein level for nutrient supplement (undernourished children) and lower protein level for kidney patients. The products thus developed were compared to some market samples and were found to be similar in texture and flavor, but with better nutritional profiles.

RÉSUMÉ

Les préoccupations diététiques des consommateurs changent rapidement de l'emphase sur les aliments qui préviennent les déficiences nutritionnelles et autres maladies liées à l'alimentation vers des aliments qui préviennent les maladies chroniques à plus long terme. Le fait de consommer des aliments malsains cause deux problèmes très différents, d'un côté le manque d'éléments nutritifs et de l'autre, l'apparition de problèmes d'obésité et de maladies chroniques. Une solution possible à ce dilemme est la création d'aliments sains et pratiques. Le traitement par extrusion peut aider l'industrie alimentaire en créant des produits alimentaires qui sont pratiques et nutritifs en offrant la possibilité d'enrichir les aliments avec des fibres, protéines, antioxydants et vitamines. Cette thèse vise à développer des produits à base de fruits qui sont équilibrés sur le plan nutritif en utilisant le traitement par extrusion dans le but potentiel d'offrir des régimes ayant des demandes spéciales particuliers tels que les enfants souffrant de malnutrition et les patients atteints d'insuffisance rénale chronique.

Des études sur la transformation par extrusion ont été réalisées afin de développer deux produits, la réglisse aux fruits et le gruau instantané, en utilisant la mangue et l'ananas comme ingrédients de base. Le modéle expérimental D-optimal mixture design a été choisi pour cette étude afin d'étudier l'effet des différents ingrédients fonctionnels sur les caractéristiques sensorielles et nutritionnelles du produit final. Le modéle expérimental a généré 16 combinaisons expérimentales, de plus, un mélange additionnel de contrôle a été formulé pour chacun des deux produits. La vitesse d'extrusion était réglée à 100 tr/min et la température était de 120^{O}C, 100^{O}C, 80^{O}C et 60^{O}C pour la réglisse et de 140^{O}C, 120^{O}C, 100^{O}C et 80^{O}C pour le gruau dans chacune des quatre zones respectives en gardant la température la plus haute proche de la fillère. Les extrudats ont été séchés afin de baisser le taux d'humidité à 8-10% pour de plus amples analyses. Les caractéristiques du produit telles que la masse volumique, la couleur, la texture, etc ont été analysées pour chacun des deux produits. Les niveaux d'antioxydants et les attributs texturaux augmentaient si la teneur en fruit augmentait pour les deux produits. Toutefois, la farine de banane a créé qui a été ajoutée dans la bouillie instantanée une texture plus dure et a donné une couleur plus foncée au gruau. Une masse volumique des ratios de réhydratation plus élevés étaient associés à de plus hautes teneurs en ananas et farine de banane. Les produits développés ont également été analysés pour leur contenu en protéine afin de convenir aux besoins d'un régime spécial ex : plus haute teneur en protéines pour un supplément nutritionnel pour enfants malnourris et teneur en protéines plus faible pour patients ayant des problèmes de reins. Les produits développés ont été comparés à des échantillons sur le marché et ont été jugés similaires en texture et saveur tout en ayant de meilleurs profils nutritifs.

CONTRIBUTIONS OF AUTHORS

Several parts of the thesis research have been presented at scientific conferences and manuscripts have been prepared for publication. Hence, the thesis is written in the manuscript style so that the three chapters highlighting the thesis research could be suitably edited for publication. Two authors have been involved in the thesis work and their contributions to the various articles are as follows:

Bavneet Kaur Chahal is the M.Sc. candidate who planned and conducted all the experiments, in consultation with her supervisor, gathered and analyzed the results and drafted the thesis and the manuscripts for publications.

Dr. Hosahalli S. Ramaswamy is the thesis supervisor, under whose guidance the research was carried out, and who guided and supervised the candidate in planning and conducting the research, as well as in correcting, reviewing and editing the thesis and the manuscript drafts for publication.

LIST OF PUBLICATIONS AND PRESENTATIONS

Parts of this thesis have been prepared as manuscripts for publications in refereed scientific journals:

Chahal, B. & Ramaswamy, H.S., 2015. Development of high protein licorice type fruit candy using extrusion processing. (*draft prepared)*

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Parts of this thesis have also been presented at the following scientific conference:

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CHAPTER 1 INTRODUCTION

Consumers nowadays are becoming more and more aware of the concept of convenience and healthy foods. Owing to the changes in the life styles, economic status and health issues, foods are expected to meet many challenges in life. People are moving towards foods that not only prevent nutritional deficiency but also offer long term prevention from chronic diseases. This changing view and perception about food is highly influencing the consumption patterns. Extrusion process offers food scientists a palette of conditions and ingredients from which new foods may be created to meet all new trends of food consumption. Extrusion cooking is a high-temperature, short-time process in which many chemical and nutritional changes occur. This technology has various positive effects over other thermal processes as it maintains the nutritional quality of the food during processing due to minimal temperature effect (Singh et al., 2007). The process has found numerous applications, including increasing number of ready-to-eat cereals; salty and sweet snacks; co-extruded snacks; indirect expanded products; croutons for soups and salads; an expanding array of dry pet foods and fish foods; textured meat-like materials from defatted high-protein flours; nutritious precooked food mixtures for infant feeding; and confectionery products (Harper, 1989). Owing to the various applications of extrusion, the food industry can develop new products with special health enhancing characteristics. High protein licorice type fruit candy and low protein porridge mix are possible meal options with the desirable functional characteristics for malnourished children and chronic kidney disease (CKD) patients respectively. Although less common in extrusion formulations, fruits have the ability to promote good consumer health through their nutritional components such as fiber (both soluble and insoluble fibers), antioxidants and vitamins. Optimized processing conditions can be developed based on these nutritional parameters.

1.1 Malnutrition

Different definitions have been used to define malnutrition. According to Joosten & Hulst (2008) malnutrition can be defined as a state of nutrition in which deficiency or excess of protein, energy, fats, and other nutrients causes measurable adverse effects on tissue, body form and function. Various studies have been done to measure the influence of malnutrition in the prevalence of chronic diseases and deaths and to find solutions to mitigate it. A study done by Sun-Waterhouse

(2011), states that functional foods play a vital role in supplementing the normal diet in order to mitigate nutrient deficiencies i.e. under-nutrition to over-nutrition. Health Canada defines a functional food “as similar in appearance to a conventional food, consumed as a part of the usual diet, with demonstrated physiological benefits and/or reduce the risk of chronic disease beyond the basic nutritional functions” (Health Canada, 2004).

1.1.1 Under-nutrition

Globally approximately 20 million children are severely undernourished, and it has been estimated that half of them will die every year— with more than 1000 in number per hour. The World Health Organization (WHO) estimated that more than two thirds of these deaths are preventable by simple, relatively low-cost interventions, because the leading causes of death are treatable or preventable (Caballero, 2006). According to FAO, approximately one billion people worldwide have inadequate protein intake, thus leading to impaired growth and suboptimal health (Wu et al., 2014). As early as 1960s, malnourishment is recognised as an important concern especially in developing countries where children are more prone to mortality as compared to developed countries (Scrimshaw & Béhar, 1961). According to Shashidhar (2013), malnutrition is directly responsible for 300,000 deaths per year in children younger than 5 years in developing countries and contributes indirectly to more than half of all deaths in children worldwide. It has also been stated that deficient intake of energy, protein and micronutrients is a major health concern all over the world however the condition is severer in developing areas (Rice et al., 2000). Protein deficiencies can also occur in subpopulations in developed countries. Dasgupta et al. (2005) reported low protein intakes lower than the recommended dietary allowance (RDA) of 0.8 g protein/kg body weight/day in 51% of home bound elderly subjects receiving home-delivered meals in the United States. High protein diet and healthy food can help in controlling the prevalence of protein energy malnutrition in children as well as elderly.

1.1.2 Over-nutrition

Over-nutrition results in overweight/obesity which is an important risk factor for death. According to Caballero (2006). Overnutrition ranks fifth among leading mortality risks, and it is responsible for 7% to 8% of deaths globally. Overweight has been a longstanding public health concern for its association with various chronic and non-communicable diseases. This has been an area of concern in developed countries but the focus on developing countries is relatively recent (Caballero, 2006). Higher consumption of unhealthy foods with high levels of fat, sugar and sodium are often responsible for over-nutrition and obesity. Healthy foods with lower amount of sugar, higher dietary fibre, vitamins and proteins can help in controlling this problem and maintaining proper nutritional balance. It has been found that consumption of unhealthy food in early ages of life develops the prevalence of chronic diseases and obesity during elderly age, thus changing dietary habits in early age can help in reducing the occurrence of these diseases (Rooney & Ozanne, 2011).

1.2 Chronic Kidney Disease

According to the National Kidney Disease Education Program (NKDEP) Chronic Kidney Disease (CKD) is a condition in which the kidneys are damaged or cannot function properly. This malfunctioning or damage can cause building up of wastes in the body. In 2005, Chen & Bedhhu estimated that 13% of US adults have CKD and from 1988 to 1994 the prevalence of CKD has increased by 30% in 1999-2004. CKD is a serious disease both in developing and developed countries. The main causes of CKD so far are found to be old age, diabetes, hypertension, obesity and cardiovascular disease in general but exact diagnosis is often difficult. Nutritional status has been found to play a major role in lowering the progression of CKD and improving the outcomes of established CKD conditions (Levey & Coresh, 2012; Chen & Bedhhu, 2015). In the same study by Chen & Bedhhu (2015) it was found that a high protein diet leads to increased renal mass and hyperfiltration which is a recognized risk factor for the progression of kidney damage. Also in studying a modification of diet in renal diseases on animal's results showed a delay in progression of renal disease by restricting the protein intakes. The amount of protein required for kidney patients to maintain nutritional balance mainly depends on the level of kidney damage however for CKD in general the potential benefit has been found at 0.6g/kg body weight/day and 1.2 g/kg body weight/day for patients on dialysis (Chen & Bedhhu, 2015).

1.3 Tropical Fruits

Tropical fruits have a unique taste and aroma along with many nutritional benefits. They play an important role in human nutrition as they are rich in antioxidants, minerals, vitamins, dietary fibre and other micronutrients in small quantity. Mango is the most important tropical fruit with a global production of more than 42 million tons in the year 2013 (FAOSTAT, 2013). They are an excellent source of dietary antioxidants such as Vitamin C, phenolic compounds, carotenoids especially β-carotene, vitamin E and minerals mainly iron. In the literature mango has also been reported to have the ability to inhibit cell proliferation in the leukaemic cell line due to the presence of antioxidant and anti-mutagenic activities.

Pineapple is another tropical fruit which is economically important among tropical fruits. Pineapple is a good source of vitamin C, dietary fibre, iron, calcium, potassium and manganese (Thanaraj & Terry, 2011). The enzyme bromelain has been found to increase the absorption of antibiotics thus indirectly enhancing the antibacterial activities of antibiotics. It has also been reported to help heal physical aches and injuries. Pineapple juice has been found to have a positive effect in growth and strengthening of bones (Hossain et al, 2015).

Banana fruit mainly consists of fibre, starch, sugars (glucose, fructose and sucrose). It is also a rich source of iron vitamins and carotenoids. Banana is found to have chemopreventive activity as its consumption reduces the risk of kidney cancer and other disorders related to kidney damage and urinary tract. Green banana is an excellent source of resistant starch and nonstarch polysaccharides which tend to decrease cholesterol in the human body. (Thanaraj & Terry, 2011).

Slavin (2008) reported that people who consume diets which are deficient in dietary fibre in higher amounts are more prone to chronic diseases. Dietary fibre helps in reducing the risk of Type 2 diabetes which might lead to obesity and CKD. It tends to lower the glycemic index of the food thus preventing prompt release of sugar in the blood stream. Dietary fibre is also found to relieve constipation by increasing the stool bulk and decreasing fecal transit time through the bowel. Owing to its health benefits, different sources of fibre are being explored as ingredients to increase the nutritional value and provide desirable textural properties, such as water-holding capacity in formulated food products. Most of the dietary fibre in tropical fruits is entrapped in the fruit cell walls with complex polysaccharide network consisting of cellulose and non-cellulose polysaccharides, glycoproteins, water, and other smaller molecules, such as phenolic acids. Fruit fibres have balanced soluble and insoluble dietary fibre contents, which may be suitably used in different food products. (Fischer, 2012). Given their importance, tropical fruits have a great potential to improve human health across the world as they are easily available even in developing countries.

1.4 Role of extrusion processing in developing fruit based food

Convenience foods are increasingly becoming popular due to ease of consumption, preparation and storage. Extrusion processing can meet the growing consumer demand for healthy, natural and convenient foods. Its ability to blend, gelatinize starch and cook the raw material make it useful in the development of functional foods. Extrusion process was first introduced by Joseph Bramah for manufacturing lead pipes in 1797. The use of extrusion process in food industries was initiated by General Mills Inc. in 1930s for cereal production. There are two major types of extruders – Single screw extruder and Twin screw extruder. The main difference lies in the screw configuration as a twin screw extruder consists of two screws which are further classified according to the rotation of the screws – intermeshing counter rotating, non-intermeshing counter rotating, intermeshing co-rotating, non-intermeshing co-rotating (Kazemzadeh, 2011).

Based on the type of raw material used and the desired final product, the type of extruder can be selected. The potential of an extruder to convert raw materials into ready to eat or ready to cook foods makes it versatile. Ready to eat (RTE) food sector is the most expanding and continuously growing area due to extrusion processing. RTE snack products are often considered as poor in nutrition and rich in energy as they tend to have a higher glycemic index values. But consumers are becoming more and more health conscious thus incorporating tropical fruits as ingredients in the snack products can enhance the nutritive value of the product. Various factors need to be considered while processing fruits in an extruder since dietary fibre tends to reduce the expansion of the final product. These factors involve residence time, screw speed, temperature and moisture content of the feed. In order to produce fruit products with high nutritional and acceptable sensory qualities it is necessary to understand the physical and chemical changes that occur during extrusion (Brennan et al., 2013).

Therefore the objectives of this research were:

1. To optimize extrusion conditions for the development of a high protein fruit licorice type candy for malnourished children and study its nutritional and physical characteristics.
2. To optimize extrusion conditions for the development of a low protein fruit porridge for chronic kidney disease (CKD) patients and evaluate of its physical and chemical parameters.
3. To carry-out sensory evaluation to compare the developed products to the market product.

CHAPTER 2 REVIEW OF LITERATURE

2.1 Food Extrusion

Extrusion refers to the process by which a liquid or a semiliquid product is forced through a die opening of the desired cross section (Maskan & Altan, 2012). Extrusion is a continuous process to provide shape to the material and to extend the shelf life from a few weeks to several months. It is a process which combines several unit operations such as kneading, mixing, shearing, cooking and shaping. The development history of extrusion is highlighted by Mościcki (2011). Food extruders were first designed to manufacture sausages in 1870s. General Mills, Inc. was the first to use the extruder for the manufacture of ready-to-eat cereals in the late 1930's. Shortly after, single-screw extruders came into common use in the pasta industry for the production of spaghetti and macaroni-type products. Expanded corn collets or curls were first extruded in 1936 but the product was not commercially developed until 1946 by the Adams Corporation. The desire to precook animal feeds to improve digestibility and palatability led to the development of the cooking extruder in the later 1940's and has greatly expanded the application of extruders in the food field. The development of many different technologies seems to have been catalyzed by World War II, as was that of extrusion-cooking technology. In 1946 in US the development of single-screw extruder to cook and expand corn- and rice-snacks occurred. In combination with an attractive flavoring this product type is still popular and the method of producing snacks with single-screw extruder equipment is, in principle, still the same (Mościcki, 2011). A wide variety of extruder designs is offered for this purpose. The past three decades have given rise to the ever – increasing number of applications of the cooking extruder. Dry, expanded, extrusion-cooked pet foods quickly developed in the 1950's largely replacing the baking process. The pre-cooking or gelatinization of starch was also an area of interest. The grain millers began using an increasing number of extruders to pre-cook cereals for their incorporation into nutritious blended foods consisting of a pre-cooked cereal and soy protein in the mid 1960's. Applying basic extrusion technology used in the cooking of cereal grains to defatted oil seeds resulted in the development of a texturized product having meat like structure and a fibrous texture called as Texturized Vegetable Protein (TVP). This work began in the industrial research laboratories of Archer Daniels Midland, Ralston Purina, and Swift in the early 1960's with the introduction of extrusion-textured protein dough creating the conditions for intramolecular cross-linking, necessary for the formation of a fibrous structure (Harper, 1989).

In the mid-1970s the use of twin-screw extruders for the combined process of cooking and forming of food products were introduced, partly as an answer to the restrictions of single-screw extruder equipment. Twin-screw extruders provided a continuous flow and gave better results on scale up from the laboratory extruder for product development. The ability of the extruder to knead and formulate has been further exploited to expand its applicability. Example to this is the variable pitch screw extruder that mixes dough in continuous bread making equipment before it is extruded into pans to be proofed and baked (Moscicki, 2011).

2.1.1 Methods of Operation

Extruders are also classified based on their operational constraints.

Cold Extruders

In cold extruders, the temperature of the food is kept below 100^{O}C i.e. ambient pressure conditions. They are mainly used to mix and shape the foods raw material without causing significant cooking or distortion of the raw material. They are mainly used in confections, pasta, pet food, sausages etc. (Fellows, 2009).

Hot Extruders

In hot extruders, the processing temperature is kept above 100^{O}C. The food is passed into the barrel and temperature and pressure increase in each zone resulting in cooking of the raw material. The food is then forced out through the die, the product expands because of moisture vaporization as it exits through the die into a region of lower pressure. The expanded food gets cooled down rapidly as the steam flashes off (Kumar et al., 2010).

Isothermal Extruders

In isothermal extruders, the temperature is kept constant throughout the barrel. In order to maintain the temperature within the barrel the heat generated is released through the jacket surrounding the barrel length. These extruders are mainly used for shaping as the dough conditions remain relatively constant in this processing conditions (Kumar et al., 2010).

Adiabatic Extruders

In adiabatic extruders, no external heating or cooling is provided to the barrel in any zone. The temperature rise is mainly due to the friction between food particles themselves and with the barrel. Heat losses are found in this type of extruder due to natural convention but still adiabatic conditions are maintained. Snack foods can be made using this kind of extruder (Kumar et al., 2010).

There are various factors that influence the properties of final product which are summarized in Figure. 2.1 below:

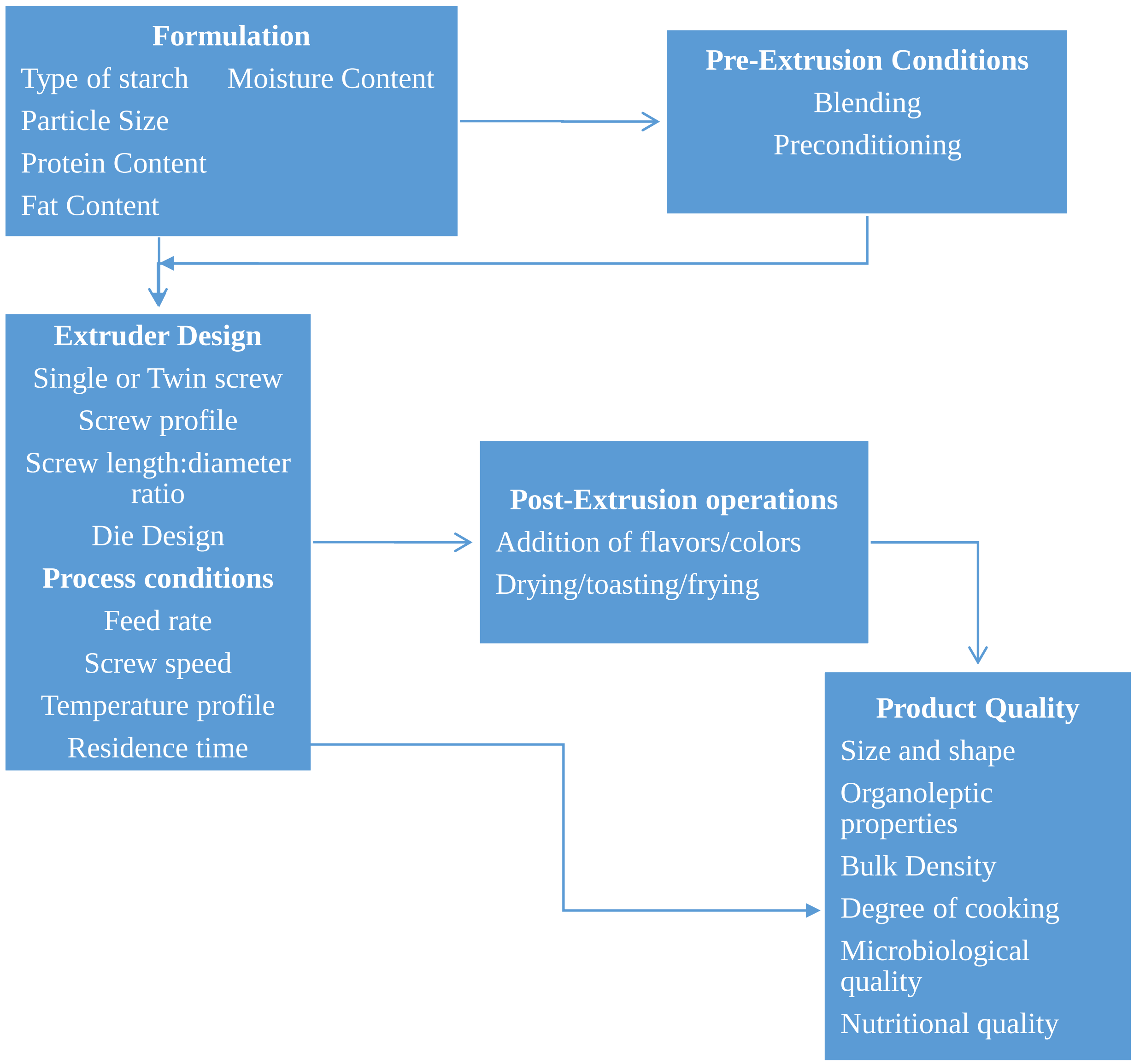


Figure 2.1: Influence of raw material, type of extruder and processing conditions on final product (Adapted from: Fellows, 2009).

2.1.2 Processing Steps

Based on the ability of a twin screw extruder to provide better formulation it is most widely used in many food industries. It is more complicated than single screw extruders but it also provides flexibility and better control. Twin-screw extruders have three processing zones, feeding, compressing and a final processing zone or cooking zone (Figure 2.2).

Feeding Zone:

This zone has deep channels, which receive the feed. The preconditioned or dry material entering this zone is conveyed to the kneading zone. This is the zone where water may be injected to help develop dough texture and improve heat transfer in the extruder barrel. The mixed dough is then transferred to the compression zone.

Compression Zone:

The pressure is increased in this zone as screw pitch decreases and the flight angle also decreases to facilitate mixing and a higher degree of barrel fill. This zone applies compression, mild shear and thermal energy to the feedstock, and the extrudates begin to lose some of their granular definition. By the end of this zone, the feed material is a viscoamorphic mass at or above 100ºC (212ºF). Steam and water can be injected in the early part of this zone. Steam injection increases thermal energy and the moisture content of the extrudates. As the extrudate moves through this zone, it begins to form an increasingly cohesive flowing dough mass, which typically reaches its maximum compaction. The material exhibits a rubbery texture similar to very warm dough (Guy, 2001).

Final Processing Zone (Cooking Zone):

The function of this zone is to compress and pump the material in the form of a plasticized mass to the die. Temperature and pressure typically increase very rapidly in this region because of the extruder screw configuration. Shear is highest in this zone, and product temperature reaches its maximum and is held for less than five seconds before the product is forced through the die. The product expands because of moisture vaporization as it exits through the die into a region of lower pressure. The extruded material can then be cut into desired lengths by the cutter attached at the end (Harper, 1989).

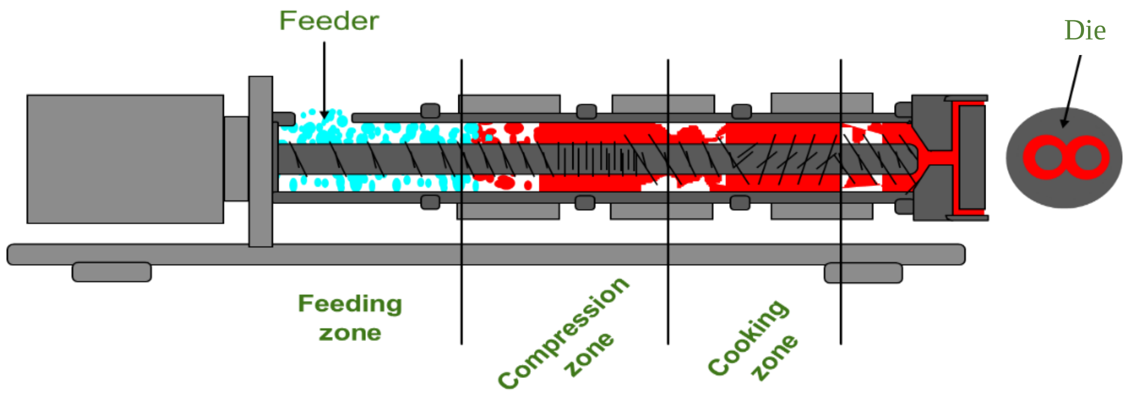


Figure 2.2: Schematic diagram of different zones of extruder.

2.1.3 Nutritional Changes

Owing to the increased applications of extrusion technology, retention of nutrition together with improvements in the protein digestibility are always the potentially important areas for researches. The nutritional changes that occur during extrusion are:

2.1.3.1 Protein

The primary structure of all proteins is comprised of amino acids linked in one or more long chains. The primary function of proteins to structure and function of tissues has been known from ages. Proteins are classified mainly according to their structure and bonds as primary, secondary, tertiary and quaternary structures. Higher order structures are more unstable as compared to the primary structure and thus can be disrupted by mild heat treatment. The disruption of protein is called denaturation. The available nutritional value of proteins is dependent on their digestibility and on the availability of amino acids which also determines the protein quality in adults. Animal protein is more digestible in human body as compared to vegetable protein and the possible reason for this can be the presence of anti-nutritional factors which impair proper digestion. The digestibility of proteins can be enhanced by extrusion cooking as it facilitates denaturation and inactivation of enzymes. The changes in protein during extrusion processing are the most significant factors to determine the nutritional value of the product. The process variables which affect protein digestibility and the corresponding changes are summarized in Table.2.1 (Singh et al., 2007). The extent of protein denaturation is often estimated by water solubility. Protein denaturation is not always favourable as in milk protein blends processed at 125^{O}C with 30% protein only 40% of lysine was retained similarly in cereal blends the lysine loss was high (Maskan & Altan, 2012). Extrusion also enables the reduction of anti-nutritional factors such as trypsin inhibitor, phytates, tannins etc. all of which inhibit protein digestibility. According to Clark and Wiseman (2007) trypsin inhibitor activity (TIA) of soybeans was reduced from 24.8 to 1.9mg/g dry matter in the samples at a temperature of 160^{O}C during extrusion cooking. Similarly Anton et al. (2009) reported a decrease in TIA in small red beans after extrusion processing.

Table 2.1: Effect of processing parameters on protein digestibility (Singh et al., 2007).

Processing Parameter	**Protein digestibility**
Process temperature	Increase with increasing temperature
Feed ratio	Increase with increasing animal protein
Screw Speed	Increase with increasing screw speed
Length to diameter ratio	Insignificant effect

2.1.3.2 Carbohydrates

Carbohydrates are the skeletal components which are capable of existing in more than one form and provide energy to the body. They are comprised of simple molecules like sugars to complex molecules such as starch and fibre. The effect of extrusion is mainly on sugars and starches. Digestibility of starch directly determines the energy derived from food, it greatly influences the body weight and satiety. Starch is indigestible by the human body so in infant food, gelatinized starch is required for easy digestion however, for diabetic and obese people resistant starch is beneficial. Extrusion has been evaluated as a means of producing gelatinized and resistant starch. Gelatinization occurs at lower temperature in extrusion as compared to other food processing methods as the temperature, pressure and shear is increased in the extruder, the rate of gelatinization also increases (Maskan & Altan, 2012). Presence of other food components such as salts, lipids and sucrose also affects the rate of gelatinization by depressing the enthalpy of gelatinization and increasing the temperature required for its initiation. Slower screw speed, that is about 30 rpm, produces higher levels of resistant starch in extruded maize, mango and banana starches however extrusion temperature had no effect on its creation. Other factors which influence the formation of resistant starch are type of extruder used, acid reaction and amylose content (Singh et al., 2007).

Sugars are the simple carbohydrate molecules and are a quick source of energy. They undergo numerous chemical changes during extrusion processing which makes it essential to control the level of sugars in product to maintain its sensory and nutritional quality. According to researchers, extrusion causes loss of sugar content in the final product which may be due to conversion of sucrose into glucose and fructose and loss of these reducing sugars in maillard reactions with protein (Singh et al., 2007). Loss of 2-20% of sucrose has been reported in biscuit production using extrusion process at temperature 170-210^{O}C and 13% feed moisture (Camire et al., 1990). Oligosaccharides are also found to decrease due to the effect of temperature thus enhancing the nutritional quality of the final product. The nutritional quality is increased as the oligosaccharides induce flatulence in legumes thus impairing their nutritional utilisation (Singh et al., 2007).

2.1.3.3 Dietary Fibre

According to The American Association of Cereal Chemists (2001) dietary fibre (DF) is defined as the edible part of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine. Dietary fibre includes polysaccharides, oligosaccharides, lignin and associated plant substances. Dietary fibre promotes beneficial physiological effects including laxation and/or blood cholesterol attenuation and/or blood glucose attenuation. Addition of dietary fibre reduces expansion, increases bulk density and a less crispy texture in extruded product however soluble dietary fibre tends to increase expansion volume and has less effect on the bulk density of final product as compared to the insoluble dietary fibre. The selection of the analytical method for quantifying the DF influences its interpretation as there are variety of analytical methods available. Also DF molecules interact with other food components and may convert starch to resistant starch which further reduces the possibility of interpreting DF changes in post extrusion. Many factors influence the solubility of fibre such as treatment of food material with alkaline or acidic medium prior to extrusion steps. Thus extrusion has both positive and negative effects on DF depending on the type of food material used for final product however, at mild extrusion conditions there were no significant changes in the DF content (Maskan & Altan, 2012; Rungsardthong, 2014; Singh et al., 2007).

2.1.3.4 Lipids

Lipids are the group of heterogeneous non-polar material which provide 9kcal/g of energy. They consist of phospholipids, triglycerides, glycerides, sterols and waxes, among these triglycerides are the most common in food materials. Overconsumption of dietary lipids leads to serious health problems such as heart disease, cancer and obesity (Camire, 2001). Common raw materials for extrusion such as wheat and corn contain low oils (2%) whereas oats contain up to 10% of oil. More than 10% oil in food material impairs the ability of the extruder because of high levels of lipids which reduce the torque resulting in poor expansion of the extrudates. During extrusion, lipids are released from the cell walls due to high temperature and pressure and might leak from the die, but this occurs only in high fat materials. Free fatty acids are produced in foods from hydrolysis of triglycerides due to lipase enzymes and high temperatures however during extrusion hydrolysis enzymes are denatured thus preventing their production. Due to short residence time and denaturation extrusion prevents lipid oxidation by deactivating enzymes even after the presence of larger surface area created by the air cells. Thus for extrusion cooking low fat materials are always selected which enables minimization of lipid oxidation and thus increase nutritional and sensory quality of the final product (Guy, 2001; Maskan, & Altan, 2012).

2.1.3.5 Vitamins

Vitamins are crucial for good health as they are the enzyme cofactors that cannot be produced in the human body. Because of their importance in daily intakes it is essential to know the effect of extrusion processing on the vitamin content of foods. Vitamins are classified as water soluble and fat soluble, they also differ in their chemical structure and composition and thus the effect of extrusion also varies. The extent of vitamin degradation varies according to time of retention, exposure to light & oxygen, moisture, temperature and pH. Vitamin D and Vitamin K being lipid soluble are fairly stable, but Vitamin A, C and E are sensitive to heat and oxidation. According to Guzman-Tello & Cheftel (1990) the major contributing factor β-carotene was reduced by 50% in wheat flour at 200^{O}C extruder barrel temperature. Similarly Vitamin C was found to decrease when extruded at high temperature and low moisture of 10%. Vitamin A levels were also found to decrease as post-extrusion storage temperature increased. In conclusion, extrusion processing retains vitamin under mild temperature conditions and low screw speed.

2.2 Tropical Fruits

Fruits are an important part of the human diet as they provide an abundant amount of vitamins, minerals and energy. Higher fruit consumption has been associated with lower cardiovascular and other chronic diseases. A diet rich in fruits can also help in lowering amount of saturated and total fat content and thus can help in lowering the blood pressure. Fruits being rich in flavonoids such as anthocyanin, flavone, flavonol, isoflavonoids and tannins have been found to lower the risk of cancer and inhibit the production of histamine-induced inflammation. Fruits have been used as medicinal remedies as they tends to strengthen the immune system. Regular consumption of fruits also tend to increase the antioxidant activity in blood and blood tissues and thus protects against oxidative damage to cells and tissues. In 2004, World Health Organization (WHO) recommended an intake of fruits and vegetables more than 400g per person per day. Being rich in vitamin C, carotene and fiber fruits have been reported to reduce the risk of colon cancer Fiber rich diets facilitate fecal bulk, lower colonic pH and lower serum cholesterol. Researches have also found anti-aging properties in some fruits such as strawberries. Increasing the fruit consumption in human diet has various health promoting properties and the health benefits of the main fruits used in this research are discussed below (Yahia, 2009).

2.2.1 Mango

Mango (*Mangifera indica* L.) is a member of the family Anaradiaceae. They have long been cultivated in India but it was in the 16th century when the cultivation of mangoes spread around the world. Botanically, mangoes grow into large trees with a height of 35-40meters, they are fleshy drupe large fruits with their pericarp divided into three parts mainly: the epicap, edible fleshy middle layer and the inner hard shell. Major producers of mango are India, Pakistan, Indonesia, Mexico, Brazil and the Philippines (Mukherjee & Litz, 2009). The mango pulp production in the world accounts to more than one million five hundred tonnes. Asia contributes the largest proportion of the total production i.e. 83% (Figure 2.3), India being the highest producer in this (Figure 2.4).

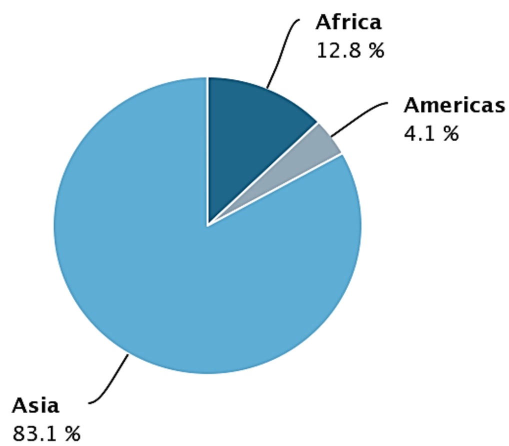


Figure 2.3: Production share of mango pulp by region (FAO, 2013)

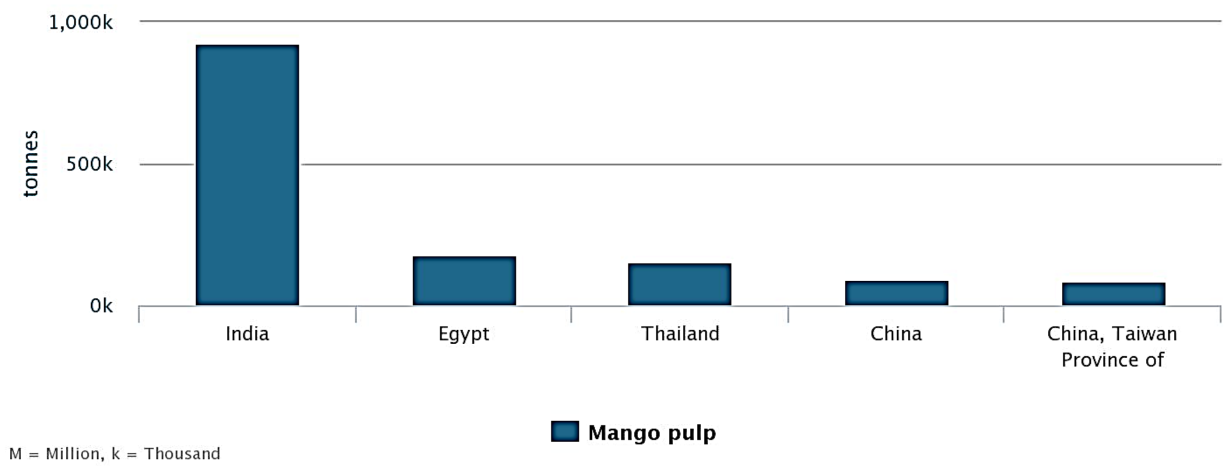


Figure 2.4 Top five producing countries (FAO, 2013)

Mangoes are generally harvested at a mature stage based on their physiology and optimum ripening quality. Fruits are hand-picked or plucked with a harvester. After harvest, the fruits are usually heaped under a tree on the ground which might cause bruises and injuries that develop into black spots making the fruits unattractive. Moreover, injuries to the peel or to the stalk end serve as invasion spots for microorganism and lead to rotting of the fruits. The post-harvest losses in mangoes have been estimated in the range of 25-40 per cent from harvesting to consumption stage. The losses can be minimized by the use of proper methods of harvesting, handling, transportation and storage (Johnson et al., 1997).

The mango is an important tropical fruit for human nutrition which is widely accepted by consumers throughout the world for its succulence, sweet taste and exotic flavor, being called the ‘king of fruits’. The chemical composition of mango pulp varies with the location of cultivation, variety, and stage of maturity. Ripening of mango involves various stages and there is an increase from 1 to 14% in the starch content during its development, and towards the end of maturity, with an increase in reducing and non-reducing sugars. This whole process involves a series of physiological, biochemical, and organoleptic changes that lead to the development of a soft, edible, ripe fruit with desirable quality characteristics (Tharanathan, 2006).

Mango is considered as a good source of dietary antioxidants, such as ascorbic acid, carotenoids and phenolic compounds. β-carotene being the most abundant carotenoid in various mango varieties provides highest amount of vitamin A. The nutritional value of mango as a source of vitamin C and pro-vitamin A is also of great value. Vitamin C helps in prevention of scurvy and also helps in various biological functions such as in collagen formation, inorganic iron absorption, inhibition of nitrosamine formation, and immune system enhancement. Ascorbic acid acts as an antioxidant and therefore offers some protection against oxidative stress-related diseases and acts as an anti-aging, anti-inflammatory compound. Vitamin A plays an active role in various biological functions such as maintenance of vision, reproduction and immune function along with degeneration of reactive oxygen species (Ribeiro et al., 2007). Phenolic composition of mango pulp consists of mangiferin, gallic acids (*m*-digallic and *m*-trigallic acids), gallotannins, quercetin, isoquercetin, ellagic acid, and β-glucogallin are among the polyphenolic compounds already identified in the mango pulp (Masibo & He, 2008).

Antioxidant properties of polyphenols have been widely studied and latest researches have suggested that they not only reduce oxidative stress, but also include protection against related pathologies, such as cancer, diabetes, and cardiovascular and neurodegenerative diseases. Dietary fiber is another component of mango which makes it useful since dietary fiber (DF) plays an important role in decreasing the risks of many disorders such as constipation, diabetes, cardiovascular diseases (CVD), diverticulosis and obesity.

2.2.2 Pineapple:

Pineapple (*Ananas comosus* L.) is a member of the family Bromeliaceae. It is one of the major commercial fruits and is thus named as queen of fruits. It is the third most important tropical fruit after banana and citrus due to its excellent flavor and taste. Botanically, the pineapple plant is 1-2 meters high and 1-2 meter wide (Hossain et al., 2015). Major producers of pineapple are

Costa Rica, Brazil, Philippines, Indonesia and Thailand. The pineapple production in the world accounts to more than 24 million tonnes. Asia contributes the largest proportion of total production i.e. 45% (Figure. 2.5), while Costa Rica is the highest producer (Figure. 2.6).

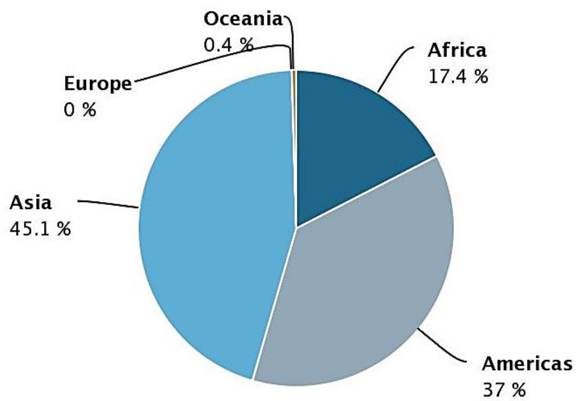


Figure 2.5 Production share of pineapple by region (FAO, 2013)

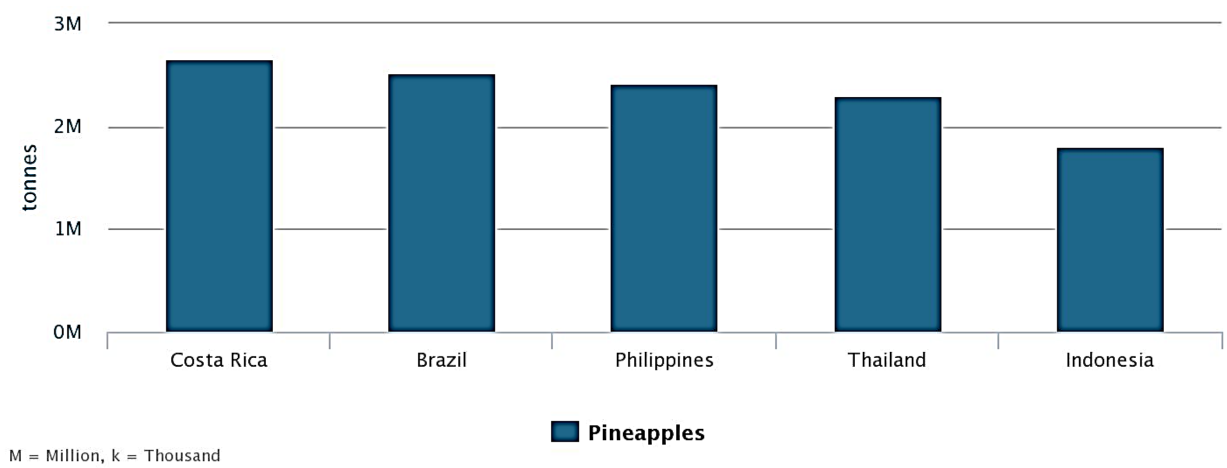


Figure 2.6 Top five producing countries (FAO, 2013)

Pineapple is a vibrant tropical fruit having exceptional taste and juiciness, and immense health benefits. Pineapple contains considerable amount of calcium, potassium, vitamin C, carbohydrates, crude fibre, water and different minerals that are good for the digestive system. Consumption of pineapple helps in maintaining ideal weight and balanced nutrition (Hossain, 2015). Pineapple is composed of 81.2-86.2% moisture, 13-19% total solids which mainly comprise sucrose, glucose and fructose and fibre makes up for 2-3% of the fruit. It is rich in bromelain enzyme and vitamin C. Abundance of vitamin C makes it extremely useful as a half cup of juice tend to can provide 50% of the recommended dietary amount of vitamin C for an adult's body. Minerals present in pineapple are: manganese and traces of copper. Manganese helps in bone formation and trace amount of copper helps in absorption of iron and regulation of blood pressure and heart rate. It also acts as a natural anti-inflammatory source and aids in digestion. Bromelain helps in treating physical injuries and aches. Drinking pineapple juice helps in improving immune system, bone health and reduce swelling. Pineapple enzymes have been successfully used in treating arthritis, gout tissue repair, general surgery, diabetic ulcers and injuries. Pineapple contains various vitamins, carbohydrates, minerals, fiber and enzymes useful for the human diet thus its consumption is increasing rapidly while adding it to a daily diet can help in increasing the consumption rate further and promote health benefits (Hossain et al, 2015).

It can be concluded that consumption of fruits according to the recommended dietary pyramid can help in promoting health. Although consumers are aware of the dietary benefits of fruits, there are various barriers that inhibit the consumption of fruits by people: high perishability of fruits, high cost of fresh fruits, time issues and taste preferences. High perishability reduces the availability of fruits in grocery stores and also it effects the price of produce and thus low income people tend to reduce their consumption of fruits. Owing to the busy life of people these days, the meals are eaten out of home more often, they prefer convenient packaging. Consumption of fruits involves long and cumbersome steps which is hard to fit in the modern busy life. Some people identify taste as the barrier to consume healthy fruits based on parental behaviour, living environment and age. Thus to encourage incorporation of fruits in daily diet, the food industry plays an important role. Strategies can be developed to produce fruit based food products at affordable costs (Yeh et al, 2010).

2.3 Whey protein isolate

Whey is the major by-product in the cheese production industries accounting for 80-90% of the volume of transformed milk. Whey is characterized based on the pH value and milk source, mainly being classified as sweet whey and acid whey. Nearly half of the solids, like lactose, minerals, protein and fat that are found in whole milk are present in whey. The composition differs in every whey protein because of variations in milk source, production method, type of cheese and manufacturer's specifications. The main constituents of whey protein are α-lactalbumin and β-lactoglobulin. Whey protein is considered as natural with great biological value and versatile functional properties (Tariq et al, 2013). Industries have spent a great time and effort to manufacture highly functional Whey Protein Concentrate (WPC) and Whey Protein Isolate (WPI).

WPC has various applications in both food and animal feed but it has been found to alter the flavor/texture, surfactant, visual, textural and rheological properties of the food because of its high lipid content. WPI protein content is higher as well as more functional as compared to WPC. WPI contains more than 90% protein on a dry basis and contains less fat, lactose and mineral content. Due to the emergence of new technologies it has become possible to separate fat, lactose and peptides thus reducing the allergic potential of WPI (Bulut Solak & Akın, 2012). Whey protein isolate is becoming popular these days owing to its nutritional and functional properties, along with being a protein source it is a good source of thiamin, riboflavin, pantothenic acid, vitamin B6 and B12. β-lactoglobulin which is the major constituent in whey protein isolate is a retinol binding protein thus helping in the absorption of vitamin A. It is also being used as a probable allergy lowering component in infant formulas in a hydrolyzed version. It is an outstanding source of essential branched chain amino acids which tend to avert muscle breakdown and store glycogen during workout or exercise. The second important component α-lactalbumin is a prominent source of tryptophan. It is also found in human milk and bovine serum, as it helps to bind calcium and make it vital for liberation of calcium to the infants and fetus (Tariq et al., 2013). Walzem et al. (2012) reported α-lactalbumin to have stress reducing, anti-carcinogenic, antimicrobial and antiviral activities. The high content of cysteine in α-lactalbumin is also valuable in boosting the immune system and promoting wound healing.

2.4 Almond Flour

Almond, *Prunus dulcis* is a species of *Prunus* belonging to the subfamily *Prunoidae* of the family *Rosaceae*. Within *Prunus*, it is classified with the walnut in the subgenus Amygdalus, distinguished from the other subgenera by the corrugated seed shell (Ahmad, 2010). According to FAO statistics (2013), United States of America is the largest producer of almonds in the production year 2012-2013, accounting for 62.2% of the total world production. Figure 2.7 shows the production chart of the top 5 producing countries. Almonds are readily accepted worldwide and are consumed raw, fried, roasted and are also used in a variety of food products.

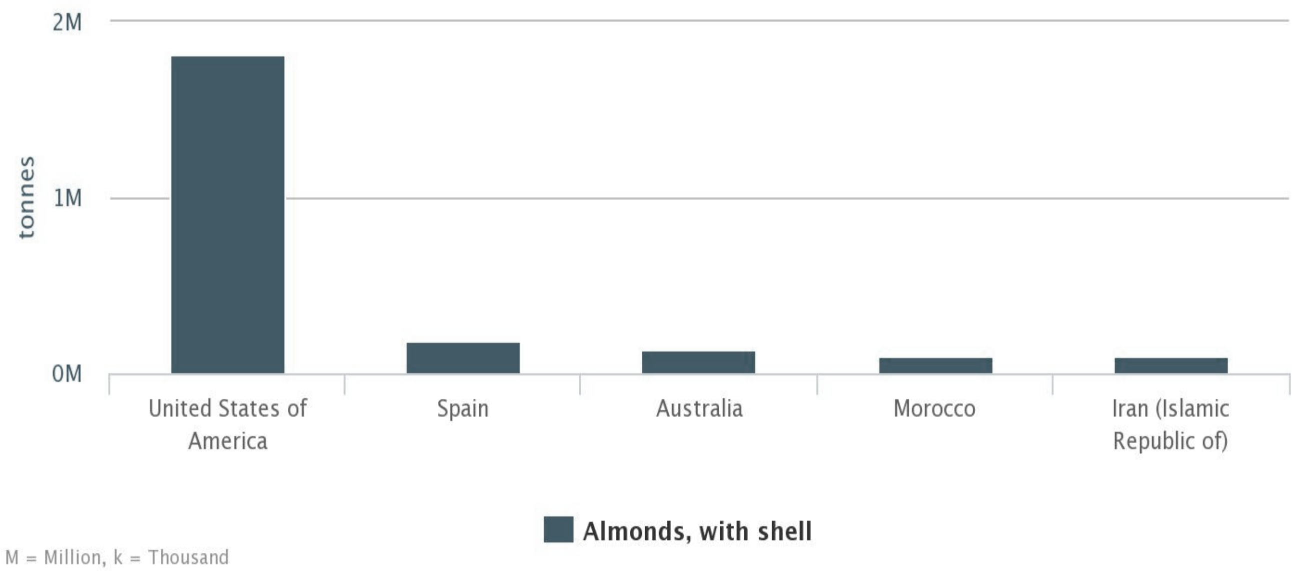


Figure 2.7: Production of top 5 almond producing countries (in million tonnes) (FAO, 2013)

The nutrient composition of almonds is genotype-dependent, and can be influenced by the environmental factors such as region, cultivation methods, climatic conditions that vary between harvest years, and kernel maturity, or interactions of these factors. Almonds have various nutritional benefits being rich in polyphenols and flavonoids, dietary fiber, vitamins and sterols. Most of the flavonoids are concentrated in the skin and they represent 0.2-0.8% of the dry weight of almond skins (Bolling et al., 2010). Consumption of almonds has been proven clinically to benefit metabolic factors that are implicated in the progression of diabetes type 2 – glycemia and insulinemia (Shelke & Miller, 2012). Almonds are found to lower the risk of cardiovascular disease by lowering the total cholesterol levels. Inflammation plays a critical role in the progression of cardiovascular disease and almond tends to provide anti-inflammatory actions by reducing oxidative stress. Almonds are the richest source of vitamin E and contain a variety of phenolic constituents, localised principally in their skin, including flavonols (isorhamnetin, kaempferol, quercetin), flavanols (catechin, epicatechin), flavanones (naringenin), anthocyanins (cyanidin, delphinidin), procyanidins (B2, B3) and phenolic acids (caffeic acid, ferulic acid, *p*-coumaric acid, protocatechuic acid, vanillic acid) thus incorporating almonds in the diet can have anticipated antioxidant activity in the body (Chen et al., 2006).

2.5 Banana flour and its properties

Banana belongs to the genus Musa of the family Musaceae. Banana is a starchy fruit that contains a high proportion of indigestible compounds, such as resistant starch and non-starch polysaccharides. The fruit is either consumed ripe, due to its high sugar content, or unripe, in several indigenous dishes requiring high starch content. It is an important fruit crop grown in the tropical and sub-tropical regions of the world. Figure. 2.8 shows the production of the top 5 producing countries. In 2012-2013 according to FAO production statistics (2013) the overall production rate in the world was more than 106 million tonnes. Like most of the tropical fruits, banana also requires special climatic conditions found in tropics.

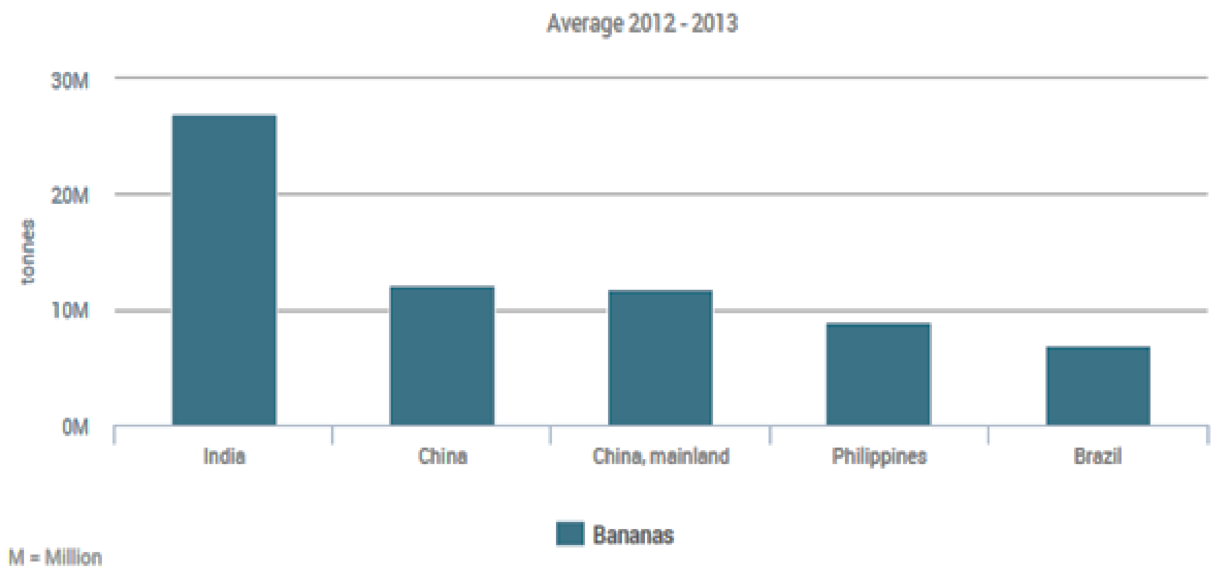


Figure 2.8: Production of top 5 producers in million tonnes (FAO, 2013)

The composition of bananas changes dramatically during ripening. The stages of ripening have been classified into eight stages based on peel color. The most important change that occurs during ripening is in starch which is the principal component of green bananas. The average starch content drops from 70 to 80% in the pre-climacteric (prior to starch breakdown) period to less than 1% at the end of the climacteric period. The sugars which mainly comprise of sucrose accumulate to more than 10% of the fresh weight of the fruit. Total soluble sugar content can reach 16% of the fruit fresh weight or above (about 80% water content), indicating a high rate of conversion. Amylases participate in the starch hydrolysis, but they are probably not linked to sucrose synthesis. Starch - sucrose transformation during ripening of bananas involves several enzymes and more than one pathway. In spite of the importance of this transformation in terms of fruit physiology, little is known about the mechanisms involved. In 1983, Terra et al, followed the sugar and starch concentrations and the enzyme activity during the ripening stages of banana. It was found that with an increase in sugar content, the starch content was decreasing however the UDP-glucose pyrophosphorylase activity remained constant. They observed an increase in sucrose synthase and invertase which indicated that starch to sucrose transmission might be carried out via glucose 1-phosphate and UDP-glucose. Another research in 1988 by Garcia and Lajolo found the activity of three α- and four β-amylases and α-1,4- and α-1,6-glucosidase during ripening stages of the fruit. They observed a significant increase in their activity till much of the starch had disappeared. β-amylase activity increased only before the onset of respiration and there was a decrease in its activity with a decrease in starch content. Various other pathways have been suggested in the literature for the disappearance of the starch reserve during ripening because of various enzymes acting together (Zhang et al., 2005). Because of its higher enzymatic activity, processing of banana is necessary in order to reduce its waste.

Green bananas are an excellent source of starch as well as bioactive compounds. They also contains a high amount of minerals and vitamins such as vitamin A, B1, B2 and C and potassium. The starch content of green banana is comparable to corn grain endosperm and pulp of white potato, apart from starch it is also a rich source of dietary fiber. Because of higher perishability of banana after ripening, it is converted to various products to reduce production losses. Most common products are banana chips, banana flour, banana powder, banana fruit bar, banana puree, banana juice, banana biscuit, banana jam and jelly, banana fiber, banana wine (Wang et al, 2012).

Banana flour is prepared from green banana with a high starch and dietary fiber content. In literature it has been prepared using different methods such as drum drying, alkaline treatment and freeze drying. Banana flour is an excellent source of resistant starch type-II and it contains upto 61.3-76.5 g/100g of starch on a dry basis (Wang, 2012). Banana flour has potential for both its functional and nutritional properties. It also shows antioxidant properties as it is a rich source of catechin, epicatechin and gallocatechin (Choo & Aziz, 2010). Several studies have suggested that consumption of a diet rich in antioxidants and resistant starch exerts beneficial effects on human body. Antioxidants present in banana flour have a degenerative effect against cancer, rheumatoid arthritis and cardiovascular disease (Loypimai, & Moongngarm, 2015). Resistant starch tends to have beneficial effects on diabetes which is a precursor of CKD. Resistant starch refers to the portion of starch which resists digestion and tends to pass through the gastrointestinal tract undigested. It increases the fecal bulk, lowers colonic pH, lowers serum cholesterol, controls glycemic and insulinemic responses in diabetic patients, improves blood lipid profile and increases satiety and micronutrient absorption. It also acts as a prebiotic by selectively stimulating the growth of selective bacteria for the host in the gastrointestinal tract (Fuentes-Zaragoza et al, 2010). Owing to all its health benefits, it has been widely used as a functional food ingredient.

2.6 Proteins in food

Proteins are the most abundant molecules in cells which make upto 50% or more of their weight on a dry basis. Proteins are made up of amino acids and there are about 20 different amino acids found in nature. Every protein has a unique structure based on the structure and composition of amino acids present. Proteins play an important role in determining the texture of food and they are important nutritionally as well as functionally. Proteins are sub-categorized as primary, secondary, tertiary and quaternary proteins based on their structure. Functional uses of proteins involve functions such as: solubility, thickening or binding, gellyfying agent, structure forming and emulsification. Nutritionally protein plays a vital role in supporting the wellbeing of the human body. The quality of protein depends on its digestible and researchers have found that animal protein is more digestibility as compared to plant protein due to the presence of protein inhibitors in plants. The daily requirement of protein is based on age, sex and health conditions. On average the protein requirement as per WHO/FAO/UNU joint report of 2007 is 0.83g/kg body weight of a healthy person. Nutritional assessment of diets and populations is concerned with the dietary adequacy and the effect of low or inadequate nutrient intakes. For a proportion of the population in developing countries many nutrients are consumed in lower amounts compared to the dietary recommendations however in developed countries people tend to consume not only abundant nutrients in their usual diet but also consume supplements. This is especially true for protein in both the parts of world. There are several issues arising from the potential for protein intakes to be over or below to the recommended intake (WHO, 2007).

2.6.1 Protein deficiency in children

Protein deficiency is a major problem faced by developing countries these days. Malnutrition with its 2 constituents of protein-energy malnutrition and micronutrient deficiencies continues to be the major cause of mortality. Malnutrition adversely affects the immune system, leading to the onset of infectious disease in this cycle thus worsening the medical situation (Batool et al. 2015). Approximately 20 million children in the world are severely undernourished, and it has been estimated that half of them will die every year— with more than 1000 in number per hour. The World Health Organization (WHO) estimated that more than two thirds of these deaths are preventable by simple relatively low-cost interventions, because the leading causes of death are treatable or preventable. According to FAO, approximately one billion people worldwide have inadequate protein intake, thus leading to impaired growth and suboptimal health. Malnutrition has been reported to be directly responsible for 300,000 deaths per year in children younger than 5 years in developing countries and contributes indirectly to more than half of all deaths in children worldwide (Shashidhar , 2013). This has been primarily caused by deficiency in the intake of energy, protein and micronutrients (Rice et al., 2000). There are various factors (Figure 2.9) that affect malnutrition in developing countries such as poverty, insufficient protein sources, low income and high cost of processed food. Introducing high protein diet in early ages can be a step towards decreasing the prevalence of malnutrition in developing countries.

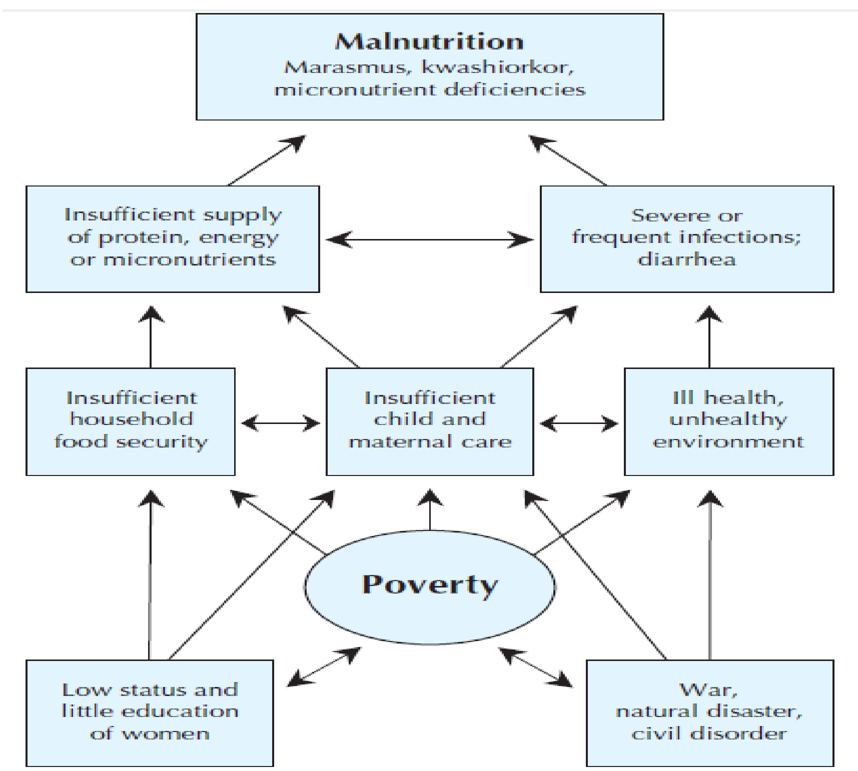


Figure 2.9: Various causes of Malnutrition (Müller & Krawinkel, 2005).

2.6.2 Kidney disease and low protein diet

Owing to the changes in eating habits and dietary components, the prevalence of Chronic Kidney Disease (CKD) is increasingly high. These days high protein diet intake is usually associated with muscles, vitality, strength, power, energy and liveliness. Vast majority of people consume food these days full of carbohydrates and proteins whereas the optimal diet ratio involves low levels of carbohydrates and fats with macronutrient compositions of proteins. This scenario is based on the explosive interest in the area of protein rich diets proposed for weight loss. Recently there has been an intense debate on the role of high protein diet in CKD patients (Pecoits-Filho, 2007).

In the United States, the protein intake range is set from 10% to 35% of energy (E %) by the department of Agriculture. World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO), United Nations University (UNU) 2007 have defined the daily protein requirement based on nitrogen-balance studies to be 0.66 g/kg body weight, and the subsequent Recommended Dietary Allowance to be 0.83 g good-quality protein/kg body weight per day for healthy adults of both sexes and at all ages. This corresponds to around 8 E% to 10 E% protein in a diet that covers energy needs. The upper intake level is defined as the maximum level of long-term (months or years) daily nutrient intake that is unlikely to pose a risk of adverse effects in humans. As such there are no specifications for the upper limit by FAO, WHO or UNU but it has been found that ingestion of protein more than 2 to 3 g/kg body weight might cause adverse effects to the human health. This value is contrary to the high protein intakes recommended for weight loss these days. The research to support the relation of protein with weight loss are very scarce and some studies also suggest a negative effect of the high protein diet on renal health of the human body. It has been found that a high protein diet intake promotes renal damage by chronically increasing the glomerular pressure and hyperfiltration Figure 2.10 shows the suspected links to CKD. The renal failure also leads to uremic toxicity which is the condition of organ dysfunction and is attributed to the retention of a myriad of compounds that under normal condition are excreted by the healthy kidneys (Marckmann et al., 2015).

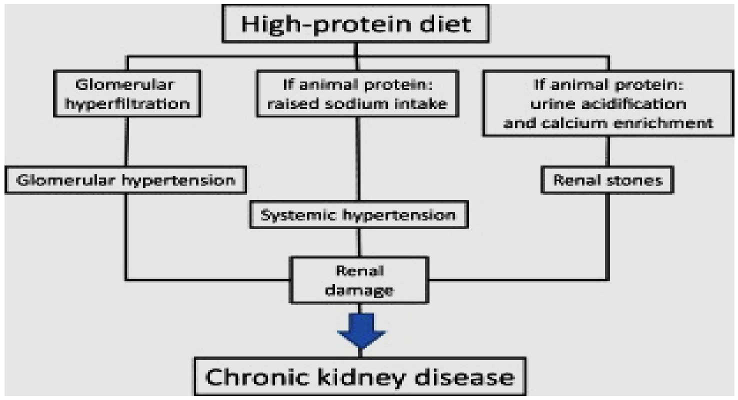


Figure: 2.10: Suspected links from high protein diet to CKD (Marckmann et al., 2015)

The aims of balanced low protein diet are: 1) to maintain good nutrition, 2) to reduce uremic toxicity, 3) to retard the rate of progression of renal failure (Hirschberg & Kopple, 1988).

2.7 Drying

Drying is a process of removal of water from a material to obtain a dried product. It is the most important and oldest unit operation in the food industry. It has been used for various materials for thousands of years such as wood, coal, paper, biomass and wastes. The main aim of drying in food the industry is preservation and increasing shelf life. It helps in reducing the mass and volume of the product thus facilitating transportation, storage and packaging. The microbiological steadiness of the product is increased as the water content is reduced below the favourable requirements of microbes. Various food products are produced using a drying process some of them are pastes, dried fruit powders, slurries, continuous sheets, candies and milk powder. Various methods have been used for drying such as drum drying, spray drying, vacuum drying, solar drying, freeze drying and many more. Each method has its own specifications and is suitable for selected products and ingredients (Michailidis & Krokida, 2015).

Drying kinetics is a convenient way to explain the moisture loss from the product during drying. Several equations have been developed so far for modeling drying kinetics, simplest of them is the exponential model or Lewis equation, which includes a constant, known as the drying constant. This is a phenomenological coefficient of heat and mass transfer. Drying kinetics replace complex mathematical models for the description of a simultaneous heat and mass transport phenomena in the internal layers of the drying material and at the interface with the surrounding space. It is a function of the material characteristics (physical properties, dimensions) and the drying environment properties, including temperature, humidity and velocity of air, chamber pressure, microwave power, ultrasound intensity and other factors depending on the drying method(s) used. The drying constant is determined experimentally in a pilot plant dryer based on drying experiments of the examined material under varying drying parameters (Michailidis & Krokida, 2015)

Water activity is an important measure of the success of a drying process as the main aim of drying is to preserve the food product and the water activity is an indicator of the rate of spoilage. Water activity is defined as the vapor pressure of water above a sample divided by the vapor pressure of pure water at the same temperature. The water activity of water is exactly one. It is a dimensionless quantity and is used to represent the energy status of the water in a system. The shelf life of a product is higher with an optimum water activity. It is an important factor to control determine the storage properties of the food. The following Figure 2.11 (Ramaswamy and Marcotte, 2006) shows the relationship between water activity and the microbial growth.

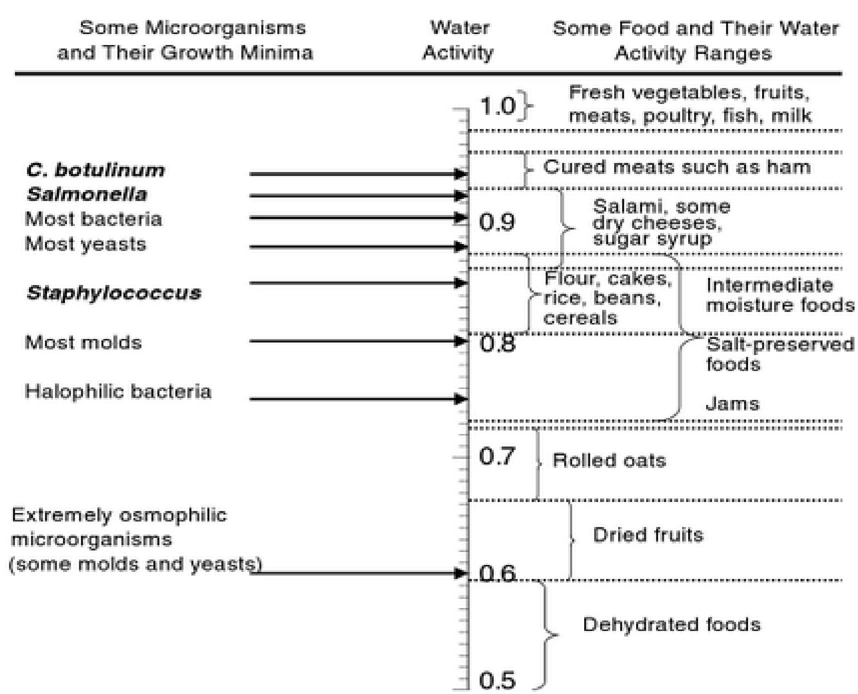


Figure 2.11 Water activity vs. growth of microorganisms (Ramaswamy and Marcotte, 2006).

2.7.1 Tray Dryer

Tray drier are convective dryers where drying medium of mostly hot air (obtained by electric heating or through combustion of gases coming from furnace). They can be used for any food material which can be placed on the trays in batch or continuous flow process. The drying ability of the tray drier depends on a number of parameters such as air temperature, humidity, air flow rate as well as flow direction (cross flow, through flow, fluidized bed etc.) and extent of recirculation in addition to the loading characteristics such as product size, bed depth, number of trays, tray loading pattern. In order to operate the drier at maximum efficiency each factor needs to be maintained at their best level that promote rapid moisture removal. Dried fruit products have been widely prepared in pilot cabinet driers (Ramaswamy et al., 1989). This drier is based on the cross-flow type of air. There are many types of air-flow which can be used to operate tray dryers. The pros and cons of different dryers are given in Table 2.2. A thermostatically controlled air heater was used to maintain the temperature of the drier. This method increases the quality of dried products and decreases the drying time. The following Figure 2.12 shows the schematic of a typical tray drier.

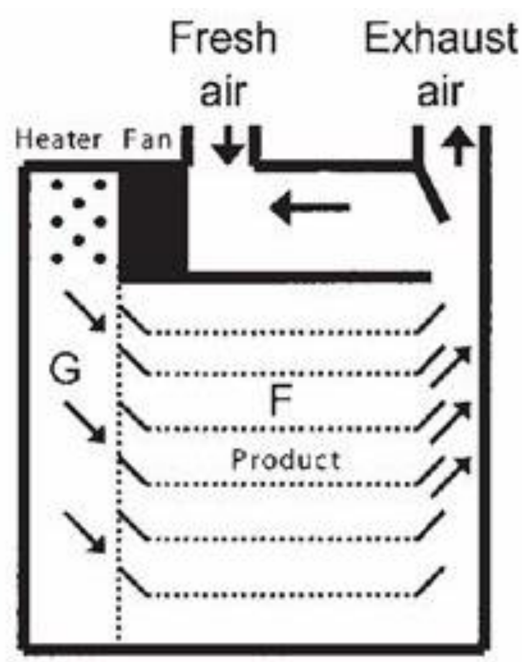


Figure 2.12: Schematic diagram of tray dryer.

Table 2.2 Types of air flow and their pros and cons.

Types of air flow	Pros	Cons
Counter or current type Food → Air Flow ←	Favourable for low moisture foods as air temperature is high and keeping products for longer duration might cause nutritional losses. Very economical operating costs	Higher risk of nutritional and physical damage to the product. Causes higher shrinkage to the product
Parallel or counter type Food → Air Flow →	Rapid process. Less heat damage. Less shrinkage.	Difficult to maintain low moisture as air is moist as it passes over the food in same direction.
Centre Exhaust Type Food → Air Flow → ↑ ←	Low bulk density and less shrinkage of food	Expensive setup.
Cross Flow type Food → Air Flow ↓ ↑	Uniform drying rate.	Difficult to maintain and complexed use.

2.7.2 Freeze Drying

Freeze drying is a process which operates below the triple point of water and therefore allows the removal of water by sublimation, where water transforms directly from its solid form (ice crystals) to a gas, bypassing the liquid state. This process therefore allows for low drying temperatures and high product quality. As a result, freeze dried products are often regarded as a superior in terms of quality as compared to other drying techniques and as a result freeze drying is often used as a reference for other drying procedures. However, this technique is very expensive, where at an industrial scale the cost of freeze drying has been estimated to be 5-10 times more than that of hot air drying, thus limiting its use at the commercial level. Along with installation costs, the maintenance is also expensive for freeze drying mainly attributing to the energy consumption, which is very high due to the high level usage of vacuum that must be maintained throughout the process in order to allow sublimation. Freeze drying is the most versatile drying method concerning the final product quality but its application is limited due to high operating costs (Wray & Ramaswamy, 2014; Nijhuis et al., 1998)). In this study it has been used to convert mango puree to fruit powder, Figure. 2.13 shows the schematic diagram of the freeze dryer used for the study.

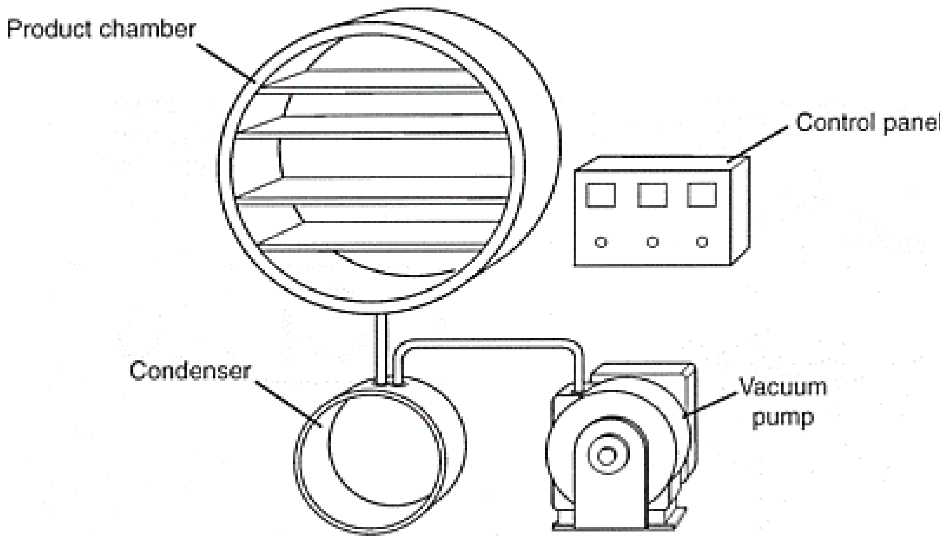


Figure 2.13: Schematic diagram of a freeze dryer (Cook, 2002)

PREFACE TO CHAPTER 3

Malnutrition is an important challenge as it leads to chronic diseases. The rate of incidence of malnutrition is alarmingly owing to the improper dietary patterns especially in young children. Many studies have been carried out to develop high protein diets for children but most of them aim at cereals and legumes which are not well accepted by children. Licorice type candy is becoming popular these days because of its taste, texture and convenience. In this study, the licorice type fruit candy was developed using fruits and an additional protein source. Processing conditions were optimized in order to develop a candy with high nutritional quality and acceptable sensory quality.

All experimental work and data analysis in the study were carried out by the candidate under the supervision of Dr. H.S. Ramaswamy.

CHAPTER 3 DEVELOPMENT OF A HIGH PROTEIN LICORICE FRUIT CANDY USING MANGO, PINEAPPLE, ALMOND FLOUR AND WHEY PROTEIN ISOLATE

3.1 Abstract

Extrusion cooking studies were carried out in order to develop a licorice fruit candy using mango and pineapple as the base ingredients and almond flour & whey protein isolate as the protein supplement. D-optimal mixture design was used for this study to investigate the effect of various concentrations of mango and pineapple on the quality characteristics of the final product. The design generated 16 combinations and an additional control formulation was made without any external source of protein. The extrusion screw speed was set to 100rpm for all the trials to provide similar retention time and the temperature pattern was set to 120^{O}C, 100^{O}C, 80^{O}C and 60^{O}C in the four barrel zones respectively, keeping the highest temperature near the die. The extrudates were tray dried subsequently to reduce the final moisture content to 8-10% prior to further analysis. The extrudate characteristics such as color, texture, antioxidants properties etc. were evaluated in the final product. The formulated product was compared with commercially available licorice candies for texture, sensory, color and water activity. The antioxidant level and textural properties were found to increase with an increase in mango and pineapple content. At higher moisture content the toughness was found to decrease. The water activity in the final product was kept below 0.75 to maintain good shelf stability. A naturally colored candy with an antioxidant level between 68.34% to 79.79% activity and protein content varying between 18.5-19.4 g/100g was formulated. Sensory evaluation score for the overall acceptability based on taste, texture and aroma was found to vary between 7.1-7.7 out of 9 (78.8-85.5%).

3.2 Introduction

The term “Licorice candy” is used for the soft chewy texture of the candy containing a flavor, which is not essentially licorice but can be any other flavor. Currently, licorice is the most widely consumed candy because of its convenience, taste and hassle free packing available these days. According to a publication by Johnson, (2012), the overall licorice sales have increased by 6.95% in the year 2013, topping $500 million annually, as reported by the Chicago-based research group Symphony IRI. Licorice type candies are available in many flavors such as strawberry, licorice, cherry and many more. The preferences vary from region to region and country to country.

Historically, licorice was believed to have medicinal properties and was used as a balm for coughs and stomach ulcers. In Chinese medicine it was used as a tonic for various disorders related to heart, spleen, stomach and skin. But these beliefs have resulted in the liberal consumption of licorice candy which has led to various abnormalities. According to U.S. Food and Drug Administration (2011) consumption of higher amount of licorice candy per day can lead to abnormal heart rhythms, as well as high blood pressure, edema (swelling), lethargy, and congestive heart failure due to the presence of licorice flavor (Omar et al., 2012). As a consequence to this, artificially flavored candies are being preferred by consumers because of better taste, similar mouth feel and attractive appearance.

The conventional method of licorice production involves open kettle cooking method. A slurry containing 40% moisture content is made in a kettle using water, syrup, wheat flour, molasses, sugar and flavors. The slurry is then dumped in a cylindrical steam jacketed kettle with a strong built-in agitator which stirs the slurry as it heats up. The slurry gets thickened and swells but with further cooking the volume is decreased and shine develops in the cooked slurry. This slurry is then held overnight under room temperature. The acids like citric or malic or lactic are added after the end of the cooking because they can weaken the wheat starch if added sooner. The candy is subjected to molding and cooling to reduce stickiness. The molded candies are then dried for final packaging. This whole process involves more than 24 hours. This process also involves undesirable effects such as caramelization if the temperature of the kettle is not regulated and rapid heating causes brittleness in the texture (Rest & Smylie, 1974).

These licorice candies in general contain 0-2.56g of protein, 0g of fiber, 30-40 g of sugar per 100 g of edible portion according to Health Canada Nutritional Database. The basic ingredients used for licorice candy are corn syrup, wheat flour, molasses, anise oil, sugar, cornstarch, palm oil, mono and diglycerides, citric acid, artificial flavor and artificial color, which are not all very healthy for daily consumption. Consumption of high amount of sugars can lead to obesity/overweight and this portion also effects the daily food consumption. Most of the sugars that are added to these candies are cane sugar, honey, molasses, beet sugar or corn syrup which are not as healthy as naturally occurring sugars present in fruits and milk. Thus these sugars provide empty calories and almost no nutritional value other than energy (Shumow, 2014). The use of tropical fruits can help in developing a nutritional candy containing natural sugars. Tropical fruits were selected for the study owing to the role they play in the human diet, because of their high and diverse concentrations of vitamins, minerals, carotenoids and other bioactive compounds. Mango is a good source of carotenoids, vitamin A and vitamin C while pineapples are rich in vitamin C and bromelain enzyme. They also contain high level of fiber and cellulose which are believed to promote intestinal motility. Vitamin C or the antioxidant effect of pineapple is also related to its capacity to remove reactive oxygen species (ROS), regenerate Vitamin E and reduce the risk factors of cancer and cardiovascular disease. (Ribeiro & Schieber, 2010).

Apart from obesity, undernourishment is another challenge being faced in the world. Incorporation of a protein source in the candy can help in reducing the evidence of undernourishment. Protein requirements for children as recommended by the Center for Disease Control and Prevention (CDC) in 2012 are as follows:

Table: 3.1 Recommended Dietary Allowances (RDA) for different age groups (CDC, 2012)

Recommended Dietary Allowance for Protein	
	Grams of protein needed each day
Children ages 1 – 3	13
Children ages 4 – 8	19
Children ages 9 – 13	34
Girls ages 14 – 18	46
Boys ages 14 – 18	52

The addition of a protein source to these fruit candies can help in reducing the evidence of protein deficiency. These candies can be introduced in mid-day school meals in developing countries to supplement the meals that contain lentils and cooked grains which are not always liked by children. Introducing processed healthy and nutritious candy in their diet can help in increasing their overall consumption rate (Singh et al. 2014). Consumers these days are becoming aware of the concept of convenience and healthy foods. Owing to the changes in life styles, economic status and related health issues foods are expected to meet these challenges in life. People are moving towards the food that not only prevent nutritional deficiency but also offer long term prevention from chronic diseases.

Food extrusion is a process which combines several unit operations such as kneading, mixing, shearing, cooking and shaping. Food extruders were first designed to manufacture sausages in the 1870s. General Mills, Inc. was the first to use an extruder for the manufacture of ready-to-eat cereals in the late 1930's (Harper, 1989). Extrusion cooking is a versatile, low cost, and very efficient technology in food processing, and has been used in the production of breakfast cereals, baby foods, snack foods, pasta products, pet foods, instant powders, confections, bakery products, modified starches, etc. (Ficarella et al 2006; Jin et al 1995; Singh and Singh 2004). The process consists of three zones: a feeding zone where dry or the preconditioned mix is fed to the extruder at a certain rate. This zone transfers the mix to the kneading or compression zone where the material is compressed and kept under heat. This is the zone where the mix starts losing its granular characteristic. The flowing mass is then transferred to the last zone where it gets cooked due to high temperature and is transferred to the die. As the mass comes out of the die due to a drop in pressure it gets expanded (Harper, 1989). But this procedure makes it difficult to use fruits as they tend to become more viscous as the temperature and pressure increase. Research on whole fruit utilization using extrusion technology has been limited.

Some studies have focused on extrusion of dried fruits (figs, cranberries, prunes, raisins), fruit juice concentrates (orange, pineapple, grape, cranberry), and spray dried fruit powders (blueberry, cranberry, concord grape, raspberry) blended with cereal flours (Camire et al., 2007). McHugh and Huxsoll (1999) examined the effects of feed moisture level, temperature and sugar concentration on the physical and textural properties of drum dried peach puree processed in a twin screw extruder. Recently, Sarkar et al (2011) used whole cactus pear fruit in addition to rice flour to make extruded snacks, and this study demonstrated the potential of utilization of cactus pear fruit for production of expanded food products.

Thus the objective of this study was to identify the optimal extrusion conditions and formulation of extruded licorice type fruit candy product with enhanced nutritional and sensory qualities. The subsequent objective was to evaluate the physico-chemical properties of the licorice type fruit candy made from mango and pineapple with incorporation of other nutritional components such as almond flour and whey protein isolate.

3.3 Materials and Methods

3.3.1 Mango puree of Deep brand distributed by Chetak New York, USA containing 94% Kesar mango pulp and 5% sugar, and Great Value crushed pineapple containing pineapple, pineapple juice and citric acid were purchased from a local market. Almond flour, potato starch & 90% whey protein isolate were purchased from Bulk Barn store. Twizzlers Pull ‘N’ Peel and Twizzlers Twist (Hershey's Brand, Hershey, PA, USA) were also bought from local Marche in Montreal, Canada.

3.3.2 Since the required amount of moisture in the feed was higher than what would be present in the feed mix, one of the two containing high amount of moisture needed to be dehydrated. Mango puree was chosen as the component because this had lower amount of moisture than pine apple and drying it was sufficient to bring down the feed moisture to the required range. Freeze drying technique was adopted for this purpose to impart minimal influence of the drying on dried mango product. The freeze dried mango product was then ground to form a powder with a final moisture content of 6.5-7.0% whereas the crushed pineapple was processed to form a puree with moisture content between 60-80%. Almond flour was added to improve the textural attributes by enhancing the fiber and improve texture, and potato starch to impart bulkiness and better mouthfeel to the final product. Combinations were formulated by varying the quantities of mango freeze dried powder, pineapple puree and almond flour using D-optimal mixture design with selected constraints (Table 3.2) based on preliminary trials. However, the amounts of whey protein, and potato starch were kept constant in all trials. The calculated components of different formulations were weighed on the weighing scale up to 2 decimal point and were then mixed using a Hobart mixer (Hobart Food Equipment Group Canada, North York, Ontario, Canada).

Table 3.2: Design Constraints: Percentage of components in the final mix (wet bases)

Low (%)	Constraint	High (%)
14.1	A: Freeze dried Mango	17.6
27.1	B: Crushed Pineapple	35.3
21.2	C: Almond Flour	25.9
	A+B+C (mixture constraint)	70.5

3.3.2.1 Extrusion: Extrusion trials were performed using the pilot-scale co-rotating intermeshing twin screw extruder (DS32-II, Jinan Saixin Food Machinery, Shandong, P. R. China), consisting of four independent zones of controlled temperature in the 20:1 length to diameter ratio barrel with a screw diameter of 30mm. The die of length 27mm was used for this process with a diameter hole of 5mm. The extruder was fed automatically through a conical hopper at a feed rate of 15kg/h on a wet basis, keeping the flights of the screw filled and avoiding accumulation of the material in the hopper. In order to find optimal processing conditions, the trials were performed at different feed moisture which was varied by varying the amount of fruits, extrusion temperature and screw speed. Table 3.3 shows the observations of the preliminary trials.

Table 3.3: Preliminary test runs with different extrusion processing conditions.

Trial No.	Temperature (^{O}C)	Screw Speed (rpm)	Feed Moisture (%)	Observations
1	180,160,140,120	75	45	Caramelization occurred
2	180,160,140,120	100	45	Caramelization occurred
3	170,150,130,110	75	45	Viscous and caramelized
4	170,150,130,110	90	40	Boiling and spluttering
5	160,140,120,100	75	40	Viscous and unappealing
6	160,140,120,100	100	40	Could not retain its shape for cutting after extrusion
7	150,130,110,90	75	35	Pulpy and brownish orange color
8	150,130,110,90	100	35	Pulpy
9	140,120,100,80	75	35	Pulpy
10	140,120,100,80	90	35	Sticky and no shape formation
11	130,110,90,70	75	35	Sticky and no shape formation
12	130,110,90,70	90	32	Sticky and no shape formation
13	120,100,80,60	75	32	Higher stickiness and improper shape
14	120,100,80,60	100	32	Proper stickiness and shape

Following this, all operating conditions were kept at selected practical levels to favor texture and color of the final product. The screw speed was set to 100rpm and temperature was set to 120^{O}C, 100^{O}C, 80^{O}C and 60^{O}C for the four zones respectively, keeping the highest temperature near the die with final moisture content between 21-31%.

3.3.2.2 Formulation of Blends: Based on the practical range of extrusion conditions found, a D-optimal design was used for experimental modeling by varying the percentage of freeze dried mango, crushed pineapple and almond flour using Design expert software (Stat-Ease Inc., Minneapolis, USA). However, the amount of fruit components was kept higher as addition of fruit components helped to enrich the antioxidant properties of the product and higher the incorporation, higher is the antioxidant activity. The levels of whey protein isolate and potato starch were however kept constant. Higher amount of whey protein isolate was found to impart a bitter flavor to the final product and higher amount of potato starch impart a starchy mouth feel to the final product. In total 16 formulations (Table 3.4) were generated by the software. The ingredients were mixed according to the percentage calculated by software for each run. Each sample with different proportion of additives was extruded at the preselected formulation conditions. Following extrusion the extrudates were cut into small strands with length of about 6 cm.

Table 3.4: D-optimal mixture design variable component formulations.

Run[1]	Freeze dried Mango (%)	Pineapple (%)	Almond Flour (%)
1	17.6	28.7	24.2
2	15.9	30.1	24.6
3	14.1	31	25.5
4	14.1	33.6	22.9
5	15.4	31.8	23.3
6	16.3	28.4	25.9
7	14.1	35.3	21.2
8	15.4	31.8	23.3
9	16.9	32.5	21.2
10	14.1	31	25.5
11	15.5	33.9	21.2
12	14.1	35.3	21.2
13	15.4	31.8	23.3
14	16.9	32.5	21.2
15	17.6	27.1	25.9
16	17.6	30.4	22.5

[1] All runs contained 17.7% Whey Protein Isolate and 11.8% Potato Starch

3.4 Drying: Following extrusion the strands were collected in a tray and dried to lower the moisture content to 8.6-10.0% and water activity below 0.77. The temperature in the cabinet tray dryer (Figure. 3.1) was kept at 55^{o}C with the airflow at 0.1m/s. The weight of strands in the dryer was measured by a lab scale balance at regular intervals till 3 h, which were used to determine the kinetics of water loss during the drying. Extruded products were subjected to drying for 270 min and moisture loss was recorded after every 30 min by measuring the loss of weight of the dried product. Moisture content in the final product was expressed on a wet weight basis. Water activity was determined at room temperature using the water activity analyzer water activity analyzer (ROTRONIC HygroLab 3, Rotronic Instrument Corp., New York, NY, USA) lab scale instrument. The dried products were then stored in a plastic container to prevent moisture gain before further analysis.

Figure. 3.1: Lab scale cabinet tray dryer.

3.5 Properties of the extruded products: Various physical and chemical parameters were selected to analyze and describe the properties of the extrudates. These are:

3.5.1 Texture

The firmness of the fruit licorice samples was evaluated by a compression test using TA-42 chisel blade on TA.XT2 plus texture analyzer (TA-XT plus Texture Analyser, Texture Technologies Corp, USA). The TA-42 blade was used which was 3 mm thick, 70 mm wide with a 45° chisel end. The blade probe mimics the front teeth penetration through the licorice product to determine its firmness and toughness. The test settings were kept same for all trials: pre-test speed of 2.0

mm/sec; test speed of 1.0 mm/sec; distance of 90% strain; and a post-test speed of 3.0 mm/sec with a sample weight of 5 g. The firmness and toughness were also compared to the market product twizzler pull and peel and twizzler twist of Hersheys.

3.5.2 Color

The color properties were assessed using a Minolta colorimeter CM-500d to determine L* value (lightness or brightness), a* value (redness or greenness) and b* value (yellowness or blueness) of the final samples. The procedure involved initial warming up of the colorimeter for 20 min followed by calibration using a white standard tile: L=95.87, a*=0.86 and b*=2.47. Measurements were then taken for the samples and the average of L*, a* and b* values were obtained. ΔE value was also calculated for the product in comparison to the market product using the formula:

$$\Delta E = [(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)]^{1/2}$$

3.5.3 Antioxidant Activity

The antioxidant activity (AA%) of each sample was expressed as a percentage using the DPPH free radical scavenging activity method (Singh & Ramaswamy, 2014) with some modifications. A measured 5 g of sample was soaked in 15 mL of water and 30 mL of ethanol for 2 h. The soaked sample was then ground using a pestle and mortar, and filtered through Whatman No. 1 filter paper. A 0.5ml of extracted sample was allowed to react with stable DPPH radical in an ethanol solution. The reaction mixture consisted of adding 2 ml of sample, and 2 mL of 0.1 mM DPPH radical solution dissolved in 95% ethanol. When DPPH reacts with an antioxidant compound, which can donate hydrogen, it is reduced. The changes in the violet color of DPPH solution were read [Absorbance (A)] at 517 nm after 30 min incubation in a dark at room temperature using a UV spectrophotometer. The 95% ethanol was used as a blank. The scavenging activity percentage (AA%) was determined using the following formula [with A_O and As representing absorbance values for blank (95% ethanol) and sample, respectively]:

$$AA\% = \frac{(A_O - As)*100}{A_O}$$

3.5.4 Protein

The protein content of the product was not measured but estimated based on the protein content of individual components in the feed mix and the dry basis moisture content in the feed mix and the final product. Because the process involved mild temperature conditions, it was assumed that only minor modification in the structure would result and the actual protein content will remain unchanged within the components (Singh et al, 2007). The licorice samples were evaluated for protein content from the samples themselves as a measured amount of an external source of protein (Whey Protein Isolate) was added to the mix. The calculation used is shown below:

$$\text{Protein content} = \frac{100\text{*Protein content (g/100g of the feed mix)}}{\text{Content of final product left after drying (dry basis)}}$$

3.5.5 Sensory Analysis

The primary consideration for selecting and eating a food commodity is the product's palatability or eating quality. A laboratory based sensory analysis was used to measure eating quality attributes of the product: aroma, taste, aftertaste and textural properties. It was performed using an Hedonic sensory evaluation scale for appearance, aroma, taste, texture, aftertaste and overall acceptability. Attributes were scored on a nine-point scale varying from 9 = like extremely to 1 = dislike extremely.

3.5.6 Statistical Analysis

The statistical analysis was executed using Design Expert software. For the analysis two-way ANOVA at 95% level of confidence and 5% level of significance were used. The effect of freeze dried mango powder, crushed pineapple and almond flour on the texture, color, antioxidant activity, protein content and sensory analysis was evaluated using ANOVA. The numerical optimization was done to maximize the overall quality of the final product.

3.6 Results and discussion

3.6.1 Drying

Extruded products were subjected to drying for 270 min and moisture loss was recorded after every 30 min Figure 3.2 shows the moisture loss trend during the drying and Figure 3.3 shows the moisture content prior to extrusion, following extrusion and the final moisture content after the drying of samples. The moisture content of different runs after extrusion and after drying are tabulated in detail in Table 3.5. The moisture content was influenced by the amount of different ingredients used in the formulation and since the time was kept constant the final moisture content varied according to the initial moisture content. Since fiber has a tendency to absorb more moisture content, formulations with higher amount of almond flour tended to take less time to dry in comparison to other formulations. In the moisture loss trend it was found that most of the formulations followed the same path with slight variations. Most of the moisture was lost in first 90 min and after 210 min the moisture loss was minimal as the moisture was being driven out from the interior of candy.

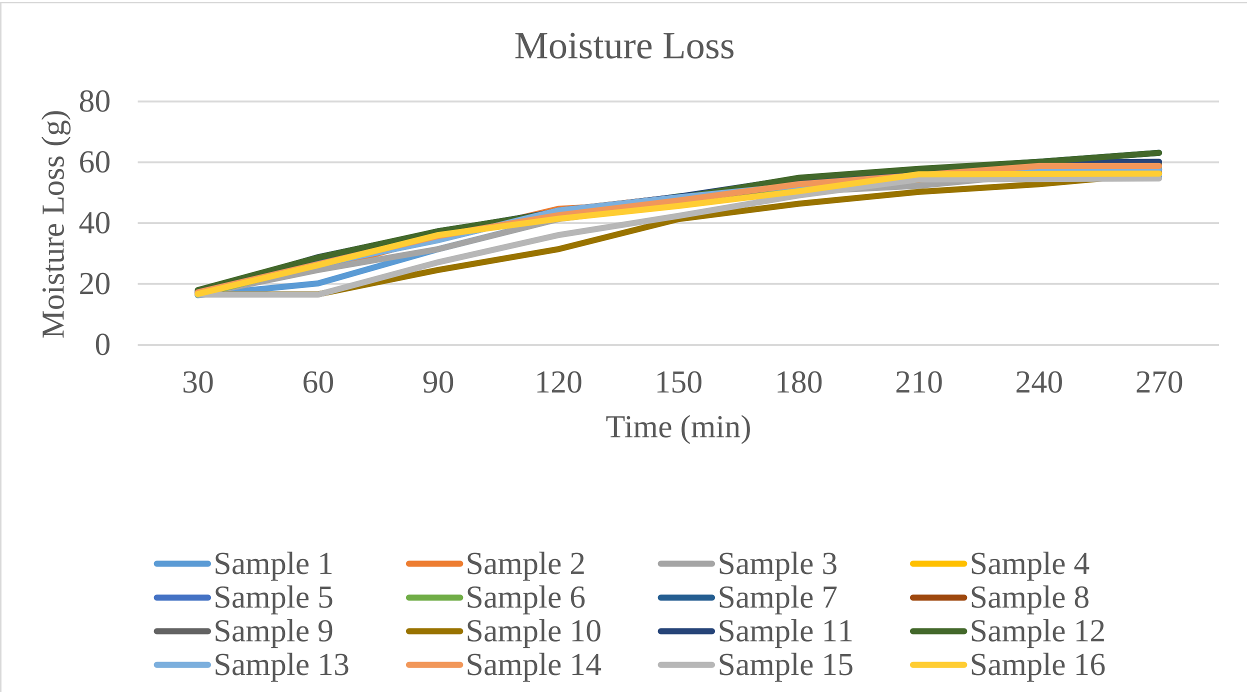


Figure 3.2: Drying Trend of runs according to time.

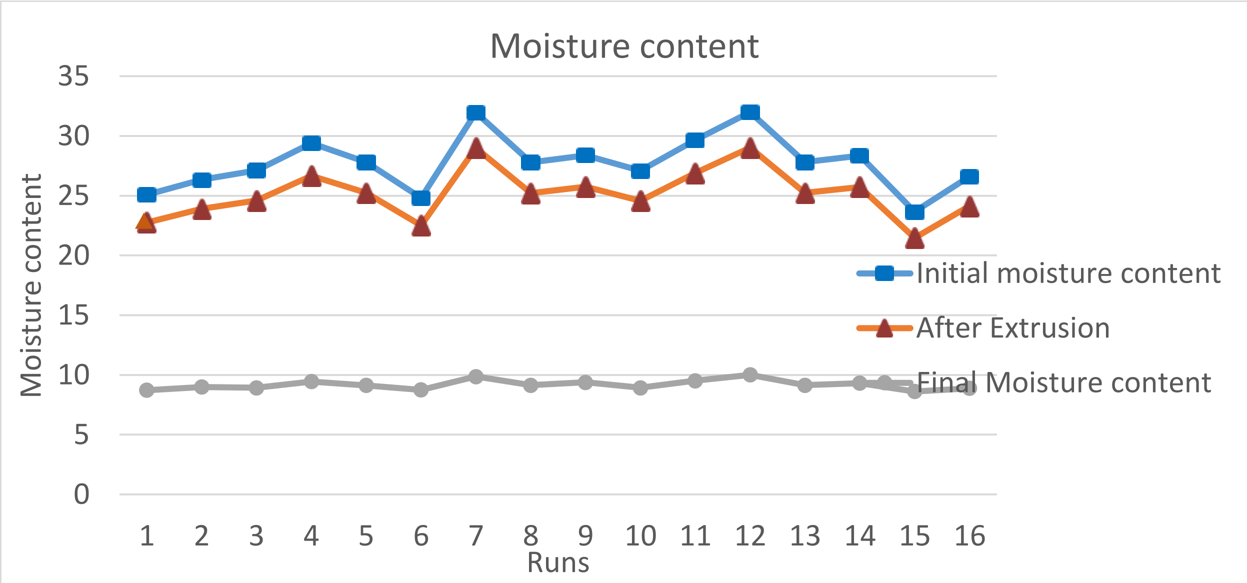


Figure 3.3: Final Moisture Content.

Table 3.5 Moisture content of developed candy at following different process conditions.

RUN	AFTER EXTRUSION (%MC)	FINAL (%MC)	WATER ACTIVITY (Aw)
1	22.76	8.73	0.748
2	23.90	9.00	0.751
3	24.59	8.93	0.749
4	26.67	9.45	0.754
5	25.23	9.13	0.751
6	22.52	8.75	0.747
7	29.00	9.87	0.767
8	25.21	9.15	0.749
9	25.75	9.38	0.759
10	24.58	8.93	0.751
11	26.90	9.52	0.761
12	29.03	10.02	0.769
13	25.23	9.15	0.753
14	25.73	9.32	0.755
15	21.47	8.62	0.734
16	24.14	8.89	0.749

The water activity was in the range 0.734-0.769 which showed that the developed candy would be fairly shelf-stable. The extrudates following various extrusion processing conditions were assessed for quality in order to evaluate the effect of variation of process variables in the formulation. The final product after drying is shown in Figure 3.4:

Figure 3.4: Final product after extrusion and tray drying.

3.6.2 Properties of extruded licorice fruit candy product

3.6.2.1 Texture

Texture plays an important role in the overall acceptability and identification of the food product. Licorice candy attracts consumers because of their firm while chewy and flexible texture. This texture is highly influenced by the ingredients and the processing conditions. This study analyzed the effect of mango powder, pineapple and almond flour on the firmness and toughness of the developed licorice type candy.

Firmness: Based on lack of fit (Table 3.6) the quadratic, special cubic and cubic models were found to be not significant (P>0.05) and they were adequate for describing the effect of process variables. ANOVA test (Table 3.7) was done using the quadratic model to test the significance of the variables.

Table 3.6: Lack of fit tests for firmness

Source	Sum of Squares	DF	Mean Square	F Value	p-value Prob > F
Linear	1.676E+005	8	20955.49	5.02	0.0460
Quadratic	75517.37	5	15103.47	3.62	0.0921
Special Cubic	65845.84	4	16461.46	3.95	0.0823
Cubic	20991.09	1	20991.09	5.03	0.0749
Special Quartic	40284.93	2	20142.46	4.83	0.0680

Table 3.7 ANOVA for firmness of developed candy

Source	Sum of Squares	DF	Mean Square	F Value	p-value Prob > F	
Model	5.237E+005	5	1.047E+005	10.87	0.0009	significant
Linear Mixture	4.316E+005	2	2.158E+005	22.39	0.0002	
AB	90611.96	1	90611.96	9.40	0.0119	
AC	52871.98	1	52871.98	5.49	0.0412	
BC	5202.06	1	5202.06	0.54	0.4794	
Residual	96376.88	10	9637.69			
Lack of Fit	75517.37	5	15103.47	3.62	0.0921	*not significant*
R-Squared	0.8446					
Adj R-squared	0.7669					
Pred R-Square	0.6052					

The model F-value of 10.87 implies the model is significant. There is only 0.09% chance that an F-value this large could occur due to noise. Values of Prob>F less than 0.0500 indicate that model terms are significant. In this case A, B, C, AB, AC are significant model terms. Values greater than 0.05 (or 0.10, as chosen) indicate the model terms are not significant. The lack of fit F-value of 3.62 implies there is a 9.21% chance that a lack of fit F-value this large could occur due to noise. The pred R-squared of 0.6052 is in reasonable agreement with the Adj R-squared of 0.7669 thus this model can be used to navigate the design space. The fit of the model was expressed by the R-squared, which was found to be 0.8446 indicating that 84.46% of the variability of the response could be explained by the model. The quadratic model was prepared after considering all the parameters which is as follows:

$$\textbf{Firmness} = +295.46634*A + 10.71336*B + 11.51938*C - 0.77932*AB - 0.77232*AC + 0.10814*BC$$

The measured firmness was found to increase with an increase in mango content however there was a decrease in firmness with increase in pineapple content as shown in the contour graph (Figure 3.5). Figure. 3.6 shows the comparison of the developed licorice type candy with the selected market licorice products. The decrease in firmness can be related to the fiber content of pineapple as it tends to bind the moisture content in fiber. Huang & Hsieh (2005) found pectin to be the most important factor in determining the texture of pear fruit leather, as pectin tends to form cross links which are hard to deform, similarly fiber in pineapple binds to decrease the firmness in the developed candy.

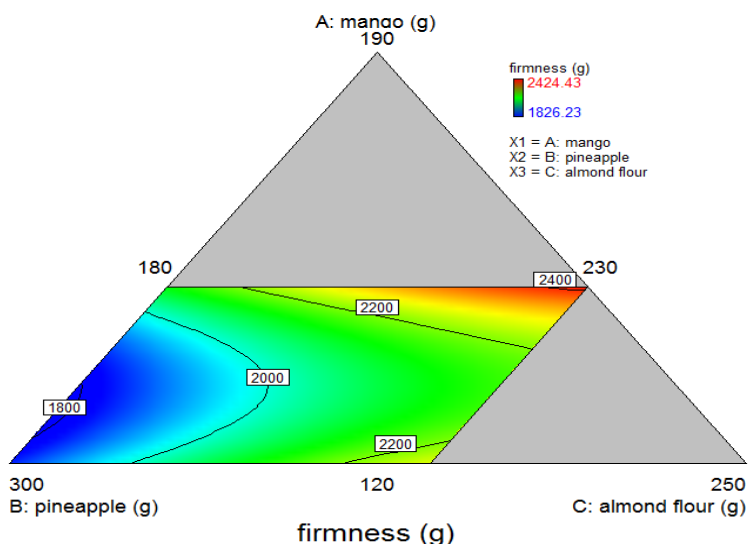


Figure. 3.5 Contour graph for firmness value of different formulations.

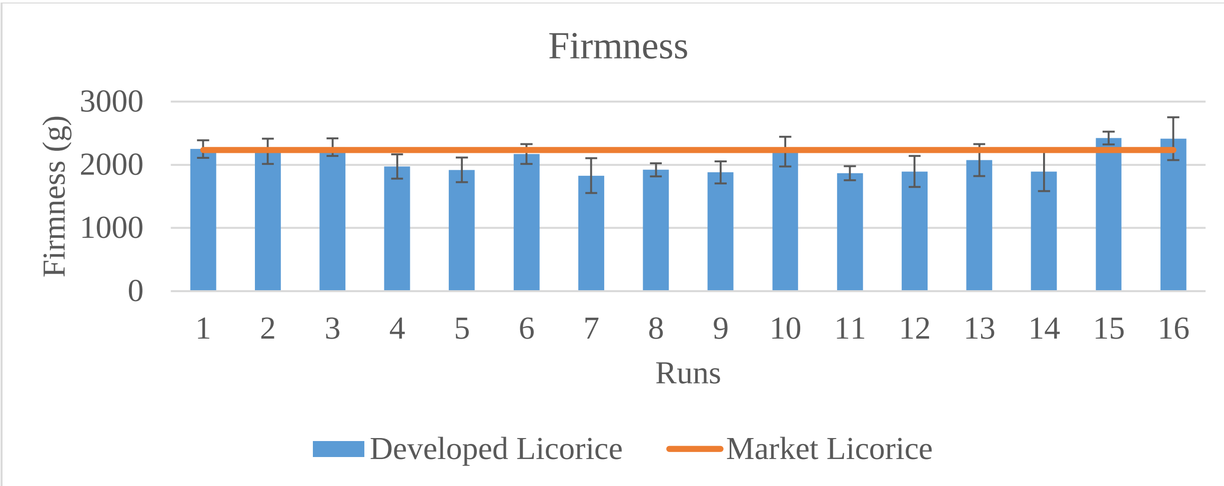


Figure 3.6: Comparison of firmness between selected market and developed product.

Toughness: The toughness was also measured for the developed candies to mimic the penetration of front teeth through the candy. The lack of fit for quadratic, special cubic and linear models was found to be highly non-significant with P>0.8 (Table 3.8) and hence all models were adequate for describing the effect of variables. ANOVA test (Table 3.9) was done using the linear model based on the highest R-squared value.

Table 3.8: Lack of Fit Test for toughness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	8.207E+005	8	1.026E+005	0.40	0.8774
Quadratic	4.239E+005	5	84779.53	0.33	0.8728
Special Cubic	4.045E+005	4	1.011E+005	0.40	0.8030
Cubic	1.074E+005	1	1.074E+005	0.42	0.5438
Special Quartic	1.681E+005	2	84071.89	0.33	0.7324

Table 3.9 ANOVA for toughness of developed candy.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.069E+007	2	5.343E+006	33.26	< 0.0001	significant
Linear Mixture	1.069E+007	2	5.343E+006	33.26	< 0.0001	
Residual	2.088E+006	13	1.606E+005			
Lack of Fit	8.207E+005	8	1.026E+005	0.40	0.8774	*not significant*
R-squared	0.8365					
Adj R-squared	0.8114					
Pred R-squared	0.7446					

The model F-value of 33.26 implied the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of Prob > F less than 0.0500 indicate model terms are significant. In this case B and C are most significant. The lack of fit F-value of 0.40 implies the lack of fit was not significant relative to pure error. The pre R-squared of 0.7446 is in reasonable agreement with the Adj R-squared of 0.8114 which implies that this model is fit for the design space. The model was generated based on this equation:

Toughness = +40.82546*A – 5.60051*B +34.42793*C

Toughness was found to be higher at higher amount of pineapple and almond flour. This can be attributed to the lower expansion of the product. The texture of different samples was measured at different water activity levels as the water activity increased, the toughness was found to decrease however at water activity between 0.73-0.77 it was found to be comparable with the selected market product (Figure. 3.9). Huang & Hsieh (2005) also found that with an increase in water activity or moisture content the toughness tend to decrease and cohesiveness increase in pear fruit leather. Figure 3.7 shows the graph for toughness and Figure 3.8 shows the relation of toughness with water activity.

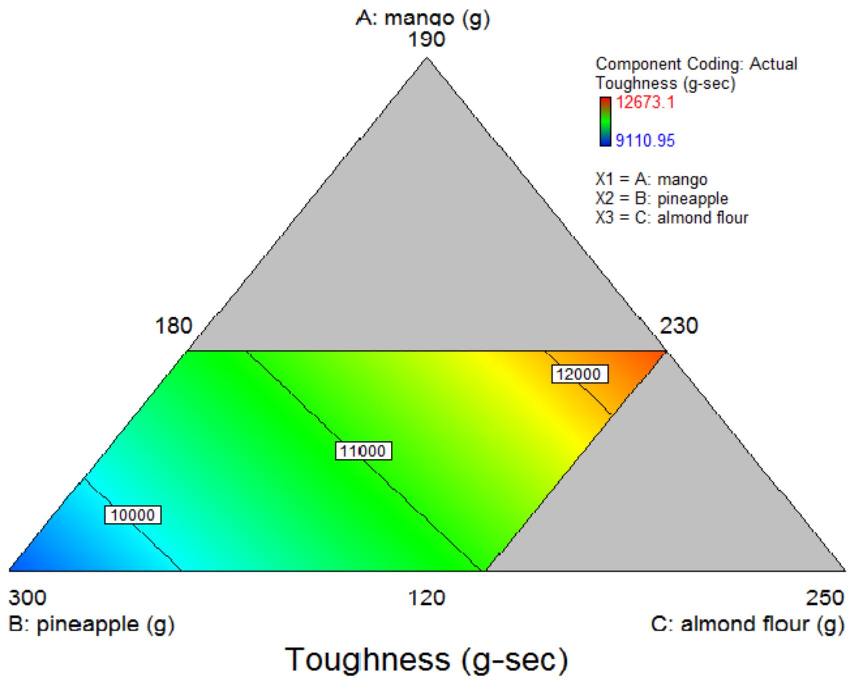


Figure 3.7: Toughness of different formulations.

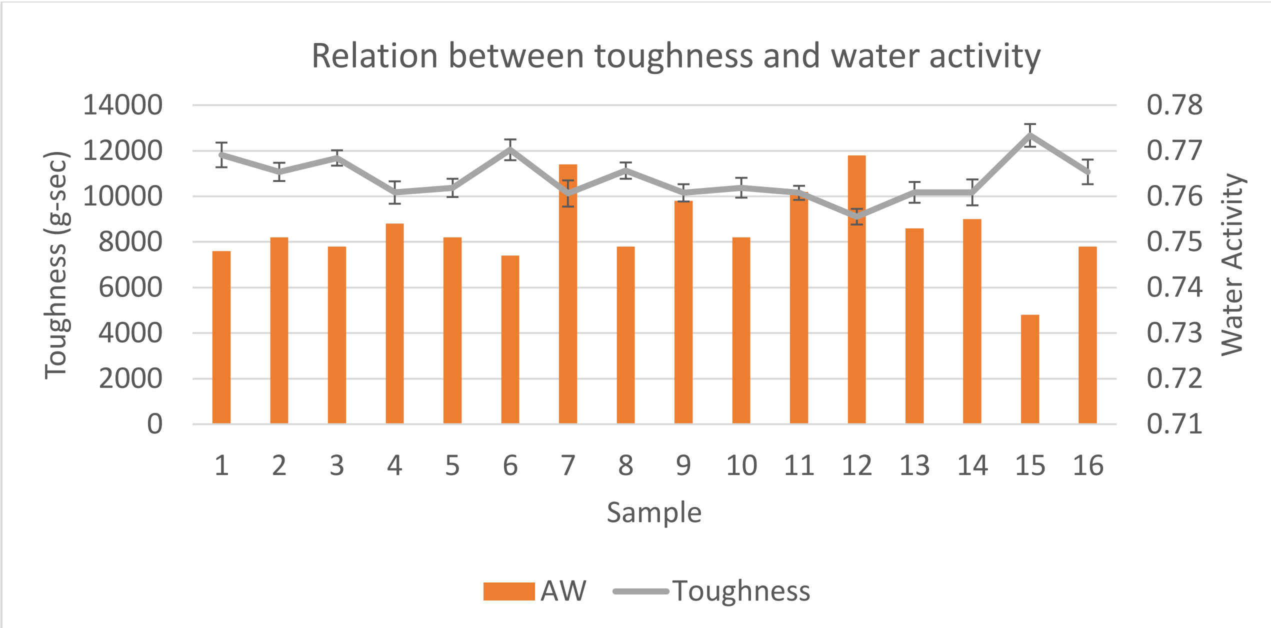


Figure 3.8: Relation of toughness and water activity.

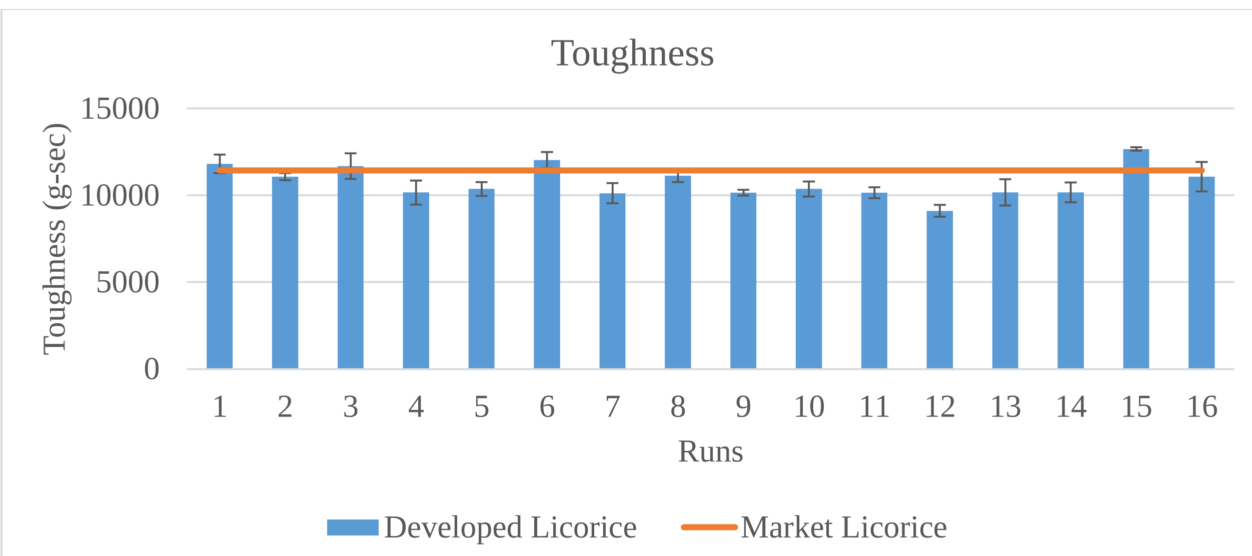


Figure 3.9: Comparison between toughness for market and developed product.

3.6.2.2 Color

Color of a food product plays a key role in food choice by influencing taste thresholds, sweetness perception, food preference, pleasantness, and acceptability (Clydesdale, 1993). The effect of variables in the color formulation was analyzed using L*, a*, b* and ΔE values.

L* value

L* value is the measure of lightness and darkness of the product. Special quartic model was selected for its statistical analysis based on the lack of fit test (Table 3.10). The model F-value of 5914.69 implied that the model is significant (Table 3.11). There was only 0.01% chance that an F-value this larger could occur due to noise.

Table 3.10 Lack of fit Test for L* value

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	1.36	8	0.17	12.59	0.0063
Quadratic	0.60	5	0.12	8.83	0.0160
Special Cubic	0.52	4	0.13	9.67	0.0142
Cubic	0.014	1	0.014	1.01	0.3602
Special Quartic	3.327E-003	2	1.664E-003	0.12	0.8870

The lack of fit F-value of 0.12 implies the lack of fit is not significant relative to the pure error. There is 88.7% chance that a lack of fit this large could occur due to noise. The pred R-squared of 0.9993 is in reasonable agreement with the adj R-squared of 0.9997. The ANOVA for special quartic model is given in Table 3.11 below.

Table 3.11 ANOVA for L*value

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	480.04	8	60.01	5914.69	< 0.0001
Linear Mixture	478.68	2	239.34	23591.73	< 0.0001
AB	3.400E-006	1	3.400E-006	3.352E-004	0.9859
AC	0.058	1	0.058	5.75	0.0476
BC	0.23	1	0.23	22.80	0.0020
A^2BC	0.12	1	0.12	12.03	0.0104
AB^2C	0.20	1	0.20	19.45	0.0031
ABC^2	0.17	1	0.17	16.91	0.0045
R-Squared	0.9999				
Adj R-Squared	0.9997				
Pred R-squared	0.9993				

The special quartic model was prepared using the formula

$$\textbf{L* value} = +70.79*A + 70.74*B + 92.14*C + 0.068*AB + 11.62*AC + 7.08*BC - 86.61*A^2BC - 51.84*AB^2C + 85.20*ABC^2$$

Almond flour made the product lighter and thus high L* value was observed. However, pineapple and mango powder were found to impart darker color due to higher amount of fiber and the red color of the mango powder. The importance of independent variables on the L* value was in the order of almond flour < pineapple crush < mango powder. The interactions of the process were observed with the contour graph (Figure 3.10) between the process variables. The range varied from 70.7-85.8. The results were similar to the study done by Gujral & Khanna (2002) where they found that with an increase in soy protein, an increase in lightness of mango leather was observed as almond flour also decreases the color of final product.

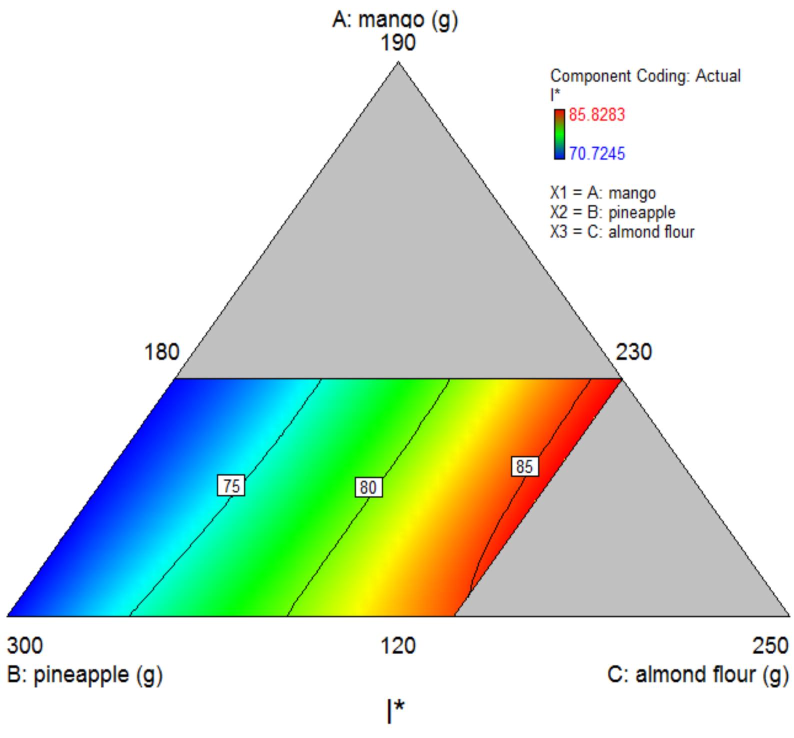


Figure. 3.10 Contour graph of effect of variables on L* value of final product.

a* value

The a* value indicates the redness and greenness of the product. Positive value indicates red and a negative value indicates green. The quadratic, special cubic and cubic models were found to be significant based on lack of fit model (Table 3.12). C was the most significant value among the variables based on the model terms. The quadratic model was used for ANOVA analysis (Table 3.13).

Table 3.12: Lack of fit test for a* value.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	10.95	8	1.37	26.27	0.0011
Quadratic	0.84	5	0.17	3.21	0.1129
Special Cubic	0.76	4	0.19	3.64	0.0943
Cubic	0.11	1	0.11	2.03	0.2140
Special Quartic	0.21	2	0.10	1.98	0.2321

Table 3.13 ANOVA table for a* value.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	149.37	5	29.87	272.08	< 0.0001
Linear Mixture	139.26	2	69.63	634.15	< 0.0001
AB	8.40	1	8.40	76.53	< 0.0001
AC	7.33	1	7.33	66.75	< 0.0001
BC	0.60	1	0.60	5.42	0.0421
R-Squared value	0.9927				
Adj R-Squared value	0.9891				
Pred R-Squared value	0.9803				

The model F-value of 272.08 implies the model is significant. There is only 0.01% chance that the F-value this large could occur due to noise. Values of Prob>F less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, BC are significant model terms. The lack of fit value of 3.21 implies the lack of fit is not significant relative to the pure error. There is a 11.29% chance that a lack of fit F-value this large could occur due to noise. Non-significant lack of fit is good. Also the pred R-squared value of 0.9803 is in reasonable agreement with the Adj R-squared of 0.9891 i.e. the difference is less than 0.2, thus this model can be used to navigate the design space. The quadratic model was prepared after considering all the parameters which is as follows:

a* value: +3.08*A + 0.24*B + 0.53*B - 7.51*AB – 9.09*AC – 1.16*BC

The addition of freeze dried mango powder resulted in an increase in the red color of the final product. Other process variables had a very little effect on the a* value of final product. The importance of independent variables on the a* value was in the order mango powder < pineapple crush < almond flour (Figure 3.11). a* value was found to vary between 7.43-15.44 with the increase in mango content.

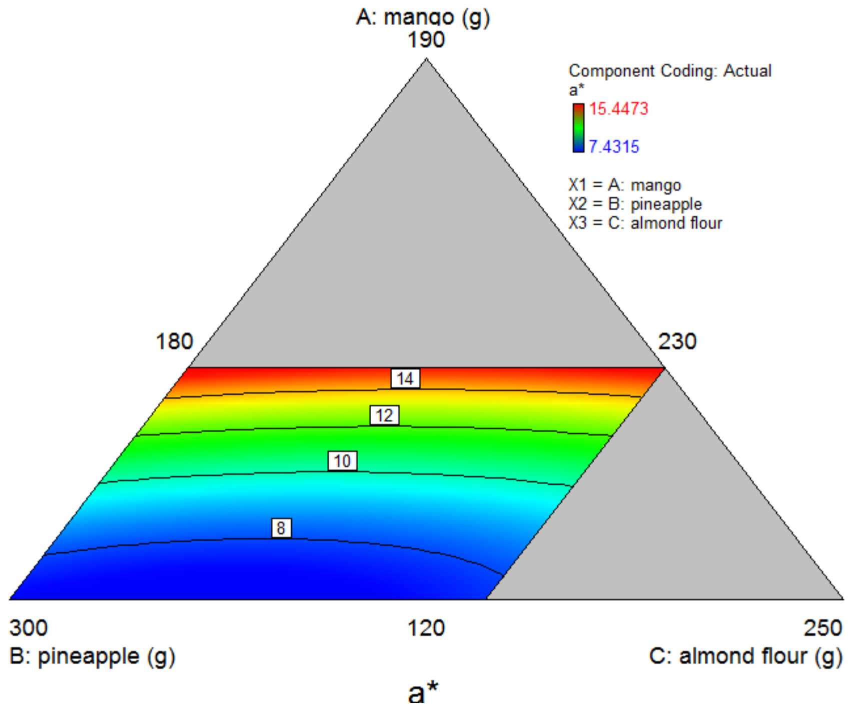


Figure 3.11: Contour graph of effect of variables on a* value of final product.

b* value

b* value is the measure of yellowness and blueness of the product. Positive value indicates yellow and negative indicates blue color. Quadratic model was selected for its statistical analysis based on the lack of fit test (Table 3.14).

Table 3.14: Lack of fit test.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	6.46	8	0.81	31.44	0.0007
Quadratic	0.43	5	0.086	3.36	0.1048
Special Cubic	0.39	4	0.097	3.79	0.0881
Cubic	0.19	1	0.19	7.42	0.0416
Special Quartic	0.21	2	0.10	4.04	0.0905

B was the most significant value among the variables based on model terms. The model F-value of 882.60 implied that the model is significant in the ANOVA table (Table 3.15). There was only 0.01% chance that an F-value this large could occur due to noise. Values of prob>F less than 0.0500 indicate model terms are significant. The lack of fit F-value of 3.36 implied the lack of fit is not significant relative to the pure error. There is a 10.48% chance that a lack of fit F-value this large could occur due to noise. The Contour graph of effect of variables on b* value of final product is shown in Figure 3.12.

Table 3.15: ANOVA table for effect of variables on b* value of final product.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	247.03	5	49.41	882.60	< 0.0001
Linear Mixture	241.00	2	120.50	2152.68	< 0.0001
AB	5.71	1	5.71	102.01	< 0.0001
AC	3.29	1	3.29	58.83	< 0.0001
BC	8.095E-004	1	8.095E-004	0.014	0.9067
R-Squared	0.9977				
Adj R-Squared	0.9966				
Pred R-Squared	0.9944				

The pre R-squared of 0.9944 is in reasonable agreement with the Adj R-squared of 0.9966 i.e. the difference is less than 0.2. The R-squared value of 0.9977 indicated that 99.77% of the variability can be explained using the model. The quadratic model was used using the following formula:

b* value = +2.05010*A + 0.35709*B + 0.33568*C – 6.18659E-003*AB – 6.09508E-003*AC + 4.26565E-005*BC

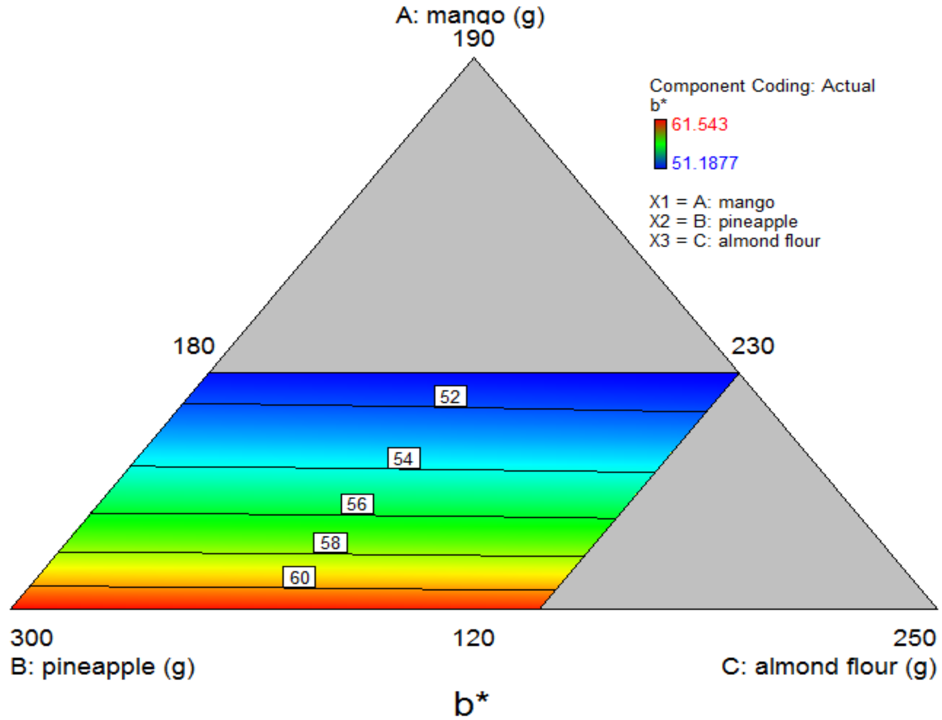


Figure 3.12: Contour graph of effect of variables on b* value of final product.

ΔE value

In order to measure the change in color in comparison to the market product, ΔE value was measured for the product. Special quartic and quadratic models were found to be significant based on lack of fit test (Table 3.16). The quadratic model was used for ANOVA test. B and C were found to be significant values based on the test (Table 3.17). The model F-value of 36.34 implied that the selected model was significant. There was only a 0.01% chance that an F-value this large could occur due to noise. The pred R-squared of 0.8738 is in reasonable agreement with the Adj R-squared of 0.9218 i.e. the difference is less than 0.2.

Table 3.16 Lack of fit test for ΔE value.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	1.08	8	0.14	643.35	< 0.0001
Quadratic	0.20	5	0.039	186.40	< 0.0001
Special Cubic	0.19	4	0.048	230.94	< 0.0001
Cubic	0.017	1	0.017	81.99	0.0003
Special Quartic	9.603E-003	2	4.801E-003	22.86	0.0030

Table 3.17 ANOVA test

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	3.58	5	0.72	36.34	< 0.0001
Linear Mixture	2.69	2	1.35	68.36	< 0.0001
AB	0.67	1	0.67	34.01	0.0002
AC	0.11	1	0.11	5.74	0.0376
BC	0.12	1	0.12	5.92	0.0353
R-Squared	0.9478				
Adj R-Squared	0.9218				
Pred R-Squared	0.8738				

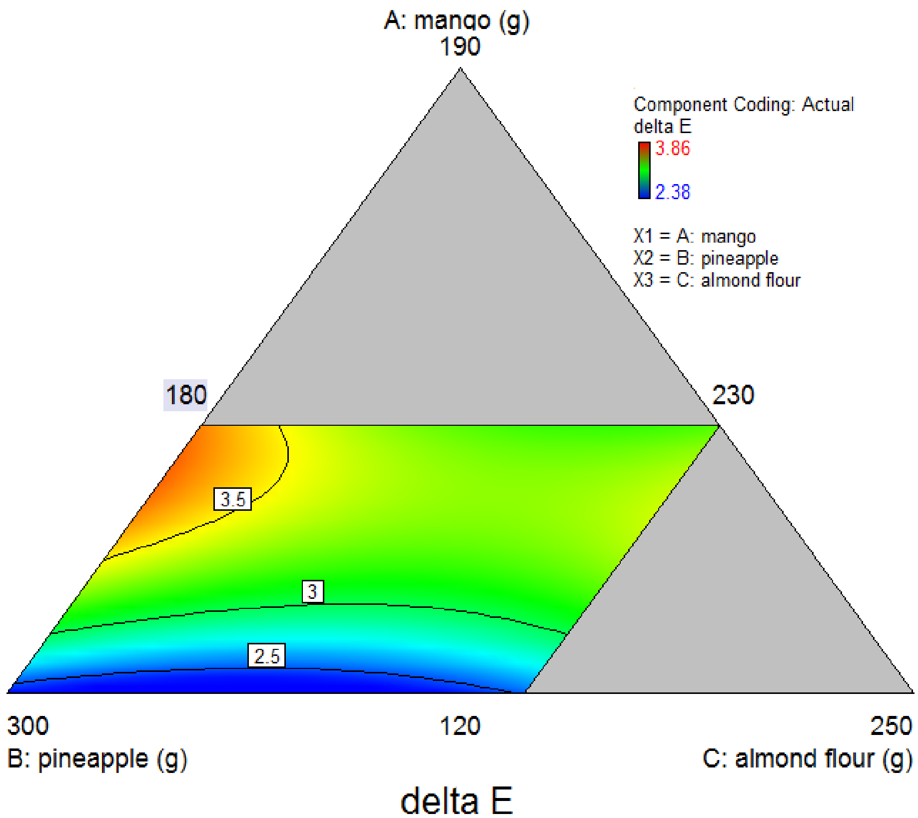


Figure 3.13 Contour graph of contour graph of ΔE value of different formulations.

Figure 3.13 shows the contour graph of ΔE value of different formulations. For all samples the difference was in the range 2.3-3.9 which is visible to a trainer's eye but is not significant.

3.6.2.3 Antioxidants

Antioxidants varied from 68.34% to 79.79% for different samples. From the statistics it was found that the variables had significant effect on the antioxidant activity of the final product. The reduction in antioxidant level from the original antioxidant level of the fruits was due to suppression of antioxidant activity of anthocyanins during extrusion processing. However, in the market product (twizzlers pull & peel and twizzlers twist of Hershey's company) no antioxidant activity was detected with this method which can be due to the absence of fruits or any other antioxidant ingredient.

From the lack of fit tests the model with insignificant lack of fit was selected (Table 3.18). Cubic model was found to have an insignificant lack of fit as the value of p-value is higher than F-value. The model F-value of 608.16 implies the model is significant. There is only 0.01% chance than an F-value this large could occur due to noise. Values of Prob>F less than 0.05 indicate model terms are significant. In this study values of mango (A) and pineapple (B) were found to be significant however there were some effects of interaction of all the components according to the analysis of variance as shown in Table 3.19. As the value of A and B increased in the formulation the antioxidant activity was also found to increase, it was found to reach a maximum of 79.79% in the final product.

Table 3.18 Lack of fit tests for antioxidant activity.

Source	Sum of Squares	DF	Mean Square	F-Value	p-value (Prob > F)
Linear	33.57	8	4.2	87.44	6.03284E-05
Quadratic	4.31	5	0.86	17.94	0.00329
Special Cubic	3.41	4	0.85	17.76	0.00370
Cubic	0	1	0	0.00066	0.98036
Special Quartic	2.86	2	1.43	29.76	0.00167
Pure Error	0.24	5	0.05		

Table 3.19 ANOVA for D-optimal cubic model for antioxidant activity

Source	Sum of Squares	DF	Mean Square	F-Value	p-value (Prob > F)
Model	218.94	9	24.33	608.16	3.51019E-08
Linear Mixture	185.36	2	92.68	2317.05	2.16207E-09
AB	1.12	1	1.12	27.97	0.00185
AC	0.99	1	0.99	24.64	0.00254
BC	1.73	1	1.73	43.27	0.00059
ABC	1.03	1	1.03	25.74	0.00228
AB(A-B)	1.14	1	1.14	28.5	0.00176
AC(A-C)	1.05	1	1.05	26.23	0.00218
BC(B-C)	1.49	1	1.49	37.25	0.00088
R-squared	0.9989				
Adj R-Squared	0.9973				
Pred R-Squared	0.9967				

The fit of the model was expressed by the R-squared, which was found to be 0.9989 indicating that 99.89 % of the variability of the response could be explained by the model. The quadratic model was prepared after considering all the parameters which is as follows:

Antioxidants= +5.85.9137*A + 79.5892*B - 30.4729*C - 916.985*AB - 788.293*AC + 198.0258*BC + 753.9255*ABC - 464.588*AB (A-B) - 793.993*AC (A-C) - 122.452*BC (B-C)

The Pred R-Squared of 0.9967 is in reasonable agreement with the Adj R-Squared of 0.9973 i.e. the difference is less than 0.2. Thus this model can be used to navigate the design space. The final percentage of antioxidant activity was found to be highly effected by mango and pineapple content as shown in the contour graph in Figure 3.14 of different samples. This reduction in antioxidant level in comparison to the original fruit antioxidant activity was found to be similar to earlier studies such as by Camire, et al. (2007) who used fruit powder in cereal flour blends to produce extruded cereal snacks and observed a reduction in the anthocyanin content after extrusion due to heat processing. Potter et al, (2013) also stated a lack of increase in antioxidant level in fruit samples after extrusion as compared to control sample. The possible reason was determined to be the inhibition from the Maillard reaction during extrusion process because of the use of fruit powders. Potter et al., (2013) also stated a variation in antioxidant level with variation in fruit type due to its different composition.

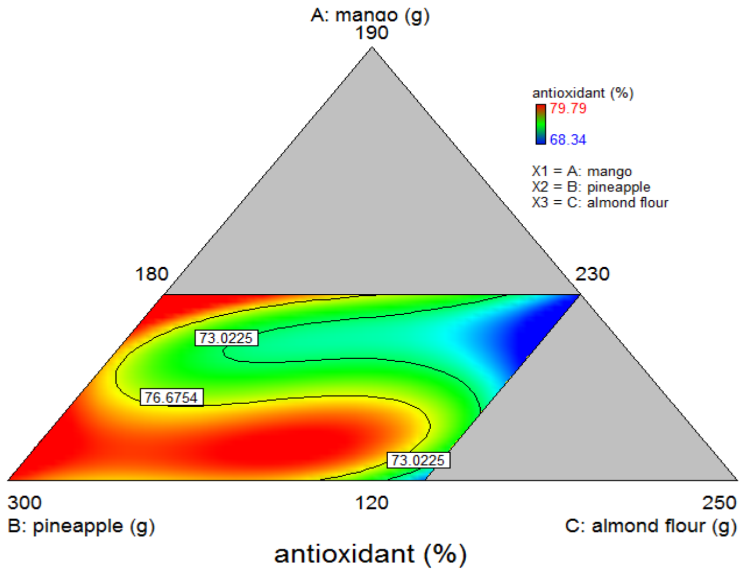


Figure 3.14: Contour plot for Antioxidant values.

3.6.2.4 Protein

In the developed fruit licorice the protein content was assumed to remain same only its digestibility would be increased as a result of heat treatment making it more available to human body. The whey protein content was kept constant in all the formulations to keep the final protein content above 15g/100g of the product which is enough to meet the recommended dietary allowances of protein for growing children. The final content varied between 18.5-19.4 g/100g of the product. The variation was due to the variation in the amount of almond flour used. The comparison between protein value of developed product and market product is given in the Figure 3.15.

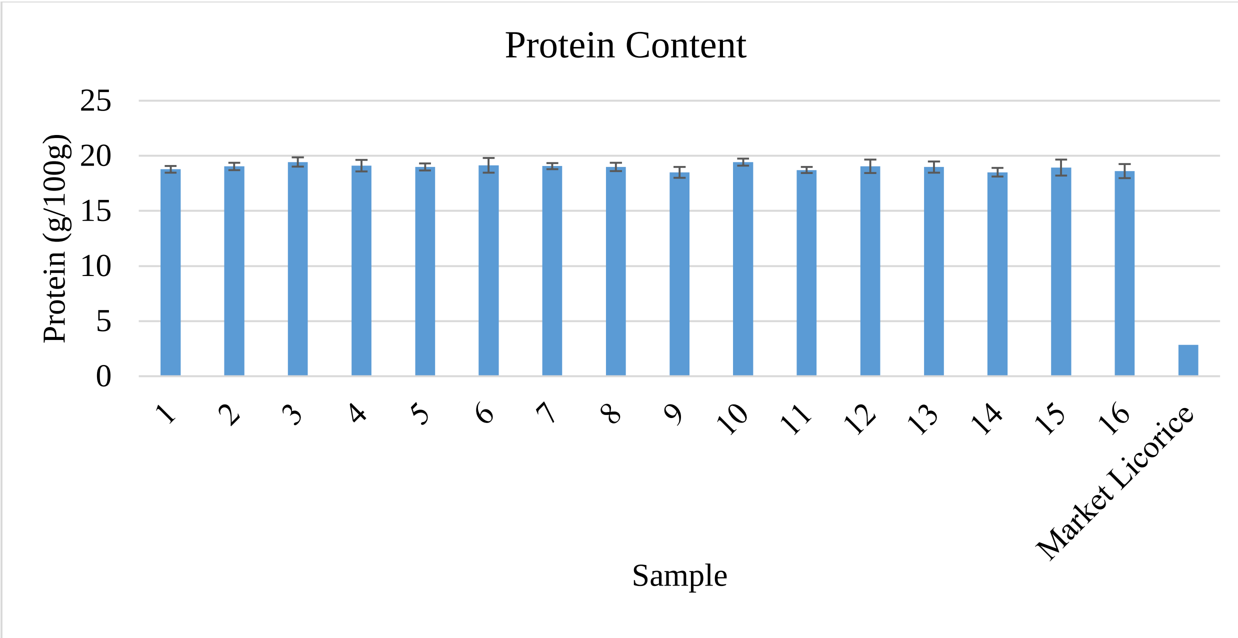


Figure 3.15: Comparison between protein content for market and developed product.

3.6.2.5 Sensory Analysis

The sensory analysis of the product was done for assessing acceptability based on color, texture and flavor of the product. The sensory results are tabulated in Table 3.20. The acceptability score was recorded separately for all the components (Figure 3.16), the mean score was found to be in the range of 5.6-7.17. The most acceptable formulations had 15.4-16.9% mango powder; 31.8-32.5% pineapple crush and 21.2-23.3% almond flour. Thus the formulations with higher number of fruit content had higher acceptability. The linear, quadratic and cubic models were found to be significant based on lack of fit test (Table 3.21). Cubic model was used for ANOVA test (Table 3.22). The model F-value of 673.91 implied that the model is significant. There is only 0.01% chance that an F-value this large could occur due to noise. The lack of fit value 3.17 implied the insignificance of lack of fit relative to the pure error. There is only 29.53% chance that a lack of fit value this large could occur due to noise. The Cubic model was prepared based on the following equation:

Sensory score = -54.58*A + 0.32*B + 9.53*C + 0.15*AB + 0.14*AC – 0.03*BC – 2.39*ABC + 1.36673E-004*AB(A-B) + 2.31831E-004*AC(A-C) + 2.66422E-005*BC(B-C)

Table 3.21: Lack of fit test for sensory evaluation

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	0.13	8	0.017	25.74	0.0012
Quadratic	0.017	5	3.358E-003	5.14	0.0483
Special Cubic	0.015	4	3.639E-003	5.57	0.0438
Cubic	8.918E-004	1	8.918E-004	1.37	0.2953
Special Quartic	7.670E-003	2	3.835E-003	5.87	0.0488

Table 3.22: ANOVA test for sensory evaluation

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	4.20	9	0.47	673.91	< 0.0001
Linear Mixture	4.07	2	2.04	2936.22	< 0.0001
AB	0.011	1	0.011	16.37	0.0068
AC	0.011	1	0.011	15.45	0.0077
BC	9.907E-003	1	9.907E-003	14.29	0.0092
ABC	0.012	1	0.012	17.61	0.0057
AB(A-B)	0.012	1	0.012	16.75	0.0064
AC(A-C)	0.011	1	0.011	15.18	0.0080
BC(B-C)	8.298E-003	1	8.298E-003	11.97	0.0135
R-Squared	0.9990				
Adj R-Squared	0.9975				
Pred R-Squared	0.7886				

Increasing levels of almond flour lowered the sensory acceptability with respect to color, flavor and texture as it contains higher amount of fibers. Increasing levels of freeze dried mango powder improved the color, flavor and aroma scores of the fruit licorice. Texture values were found to be more significantly affected by interactions of mango powder and pineapple crush. The mean score for fruit licorice is shown in Figure 3.17.

Table 3.20: Effect of process variables on final product sensory quality.

Run	Antioxidant (%)	Protein (g/100g)	Firmness (g)	Toughness (g-s)	L*	a*	b*	ΔE	Color Score	Texture Score	Flavor Score	Sensory Score
1	75.56±0.64	18.78±0.30	2249.16±0.80	11813.57±4.23	80.63±0.32	15.45±0.66	51.19±0.80	3.21±0.59	7.5±0.53	5.2±0.30	5.8±0.57	6.17±0.47
2	75.45±0.99	19.04±0.34	2212.11±0.32	11073.21±4.12	81.50±1.43	10.07±0.75	54.36±0.62	3.31±0.93	6.5±0.85	5±0.55	6±0.50	5.83±0.63
3	72.87±0.19	19.44±0.42	2277.73±2.03	11078.38±6.34	83.50±2.32	7.56±0.32	61.14±1.03	2.38±1.22	5.5±0.94	4.8±1.19	6.5±1.12	5.6±1.08
4	77.52±0.86	19.10±0.53	1971.95±4.02	10171.33±5.63	76.24±1.65	7.56±1.54	61.14±0.42	2.38±1.2	5.5±0.26	5.8±0.57	7.3±0.42	6.2±0.42
5	77.49±1.12	18.99±0.32	1917.96±5.32	10373.47±1.99	77.42±1.54	8.54±1.03	56.53±2.12	3.08±1.56	6±0.60	5.5±0.52	6.8±0.94	6.1±0.69
6	68.34±0.32	19.13±0.66	2169.89±3.452	12040.37±5.23	85.83±1.98	11.57±0.42	53.42±1.65	3.47±1.35	7.2±0.51	4.5±0.96	5.5±0.05	5.73±0.51
7	79.39±1.30	19.07±0.28	1826.23±4.21	10127.49±3.42	70.73±4.31	7.43±1.23	61.43±1.99	2.4±2.51	5.5±0.41	7±1.00	7.6±0.31	6.7±0.57
8	77.57±0.89	18.98±0.38	1920.7±1.87	11127.50±6.12	77.40±3.42	8.07±0.55	56.28±0.70	3.06±1.56	6.2±0.72	5.5±0.72	6.8±0.18	6.17±0.54

9	79.32±1.14	18.50±0.49	1880.29±1.99	10156.04±4.05	70.73±5.32	13.35±0.68	52.35±0.54	3.86±2.18	7.3±0.48	7±0.24	7.2±1.02	7.17±0.58
10	72.98±1.53	19.43±0.32	2206.61±5.23	10373.47±3.42	83.83±1.53	7.43±2.03	61.50±0.69	2.4±1.41	5.5±1.03	4.8±0.56	6.5±0.48	5.6±0.69
11	79.59±0.64	18.71±0.28	1867.41±6.43	10156.04±3.75	70.75±0.70	8.83±0.66	56.25±0.86	3.04±0.74	6.2±0.74	7±0.84	7.50±0.2	6.9±0.59
12	79.79±0.47	19.04±0.61	1893.81±6.33	9110.95±1.96	70.75±0.93	7.49±0.99	61.50±0.17	2.41±0.69	5.5±0.04	7±0.32	7.6±1.01	6.7±0.46
13	77.91±0.70	18.98±0.51	2074.05±5.23	10178.40±3.97	77.54±0.92	8.72±0.41	56.56±0.63	3.04±0.65	6.2±0.19	5.5±0.41	6.8±0.26	6.17±0.29
14	79.65±0.59	18.51±0.39	1893.2±4.99	10171.33±3.74	70.81±0.83	13.13±0.49	52.49±0.83	3.86±0.72	7.3±0.67	7±0.22	7.2±0.51	7.17±0.47
15	68.42±0.36	18.94±0.73	2424.43±6.32	12673.08±6.52	85.83±1.12	15.44±0.92	51.25±0.93	3.21±0.99	7.5±0.81	4.5±0.81	5.3±0.41	5.77±0.68
16	79.41±1.21	18.61±0.64	2411.94±6.92	11684.00±5.93	74.23±0.65	15.44±1.12	51.19±1.54	3.21±1.1	7.5±0.24	6.2±0.11	6.2±0.48	6.63±0.28

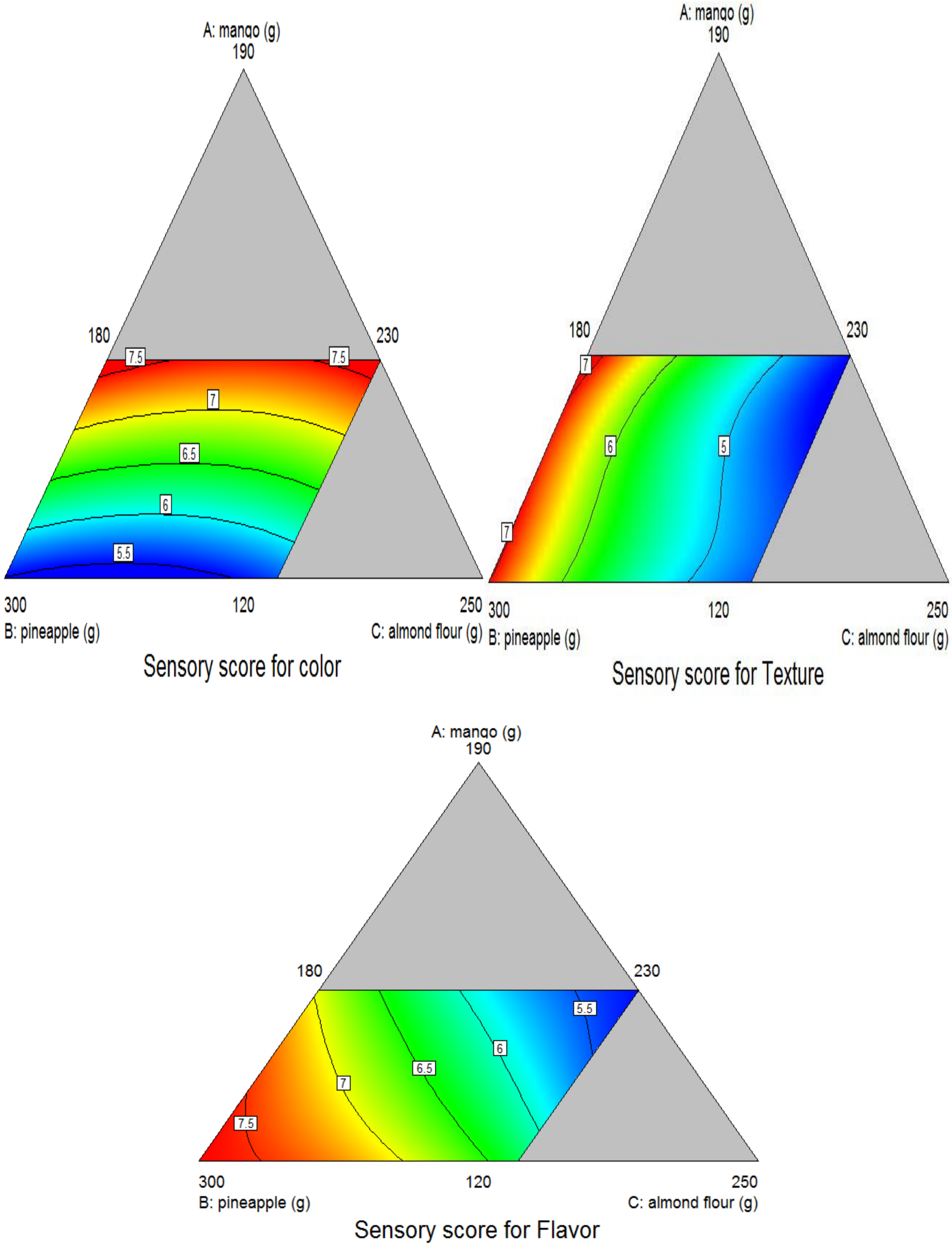


Figure 3.16: Sensory score based on color, texture and flavor of the final product.

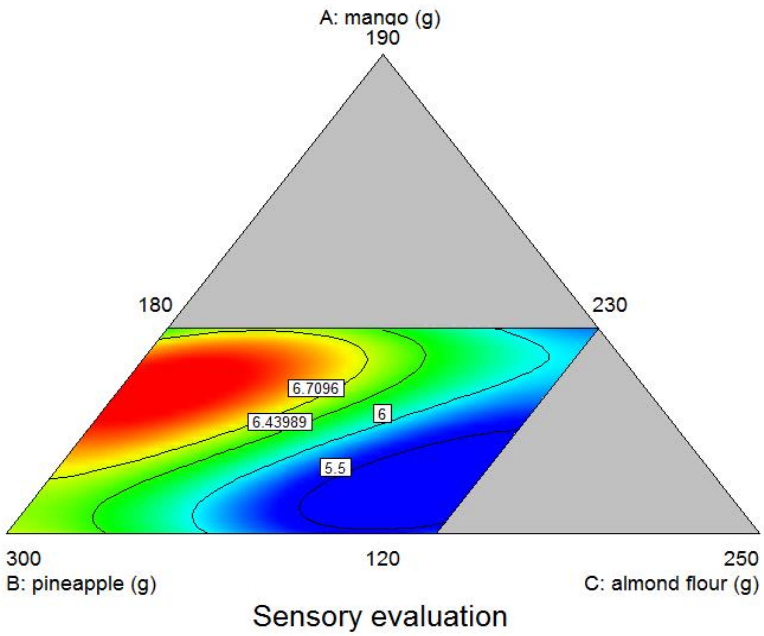


Figure 3.17: Overall sensory score for developed fruit licorice type candy

3.6.2.6 Optimization approach

Statistical analysis was done to optimize the process. The optimization was done using Design Expert 9.0.4 software to optimise the quality of final product. The optimum conditions maximized the antioxidant value, textural properties and protein level in the final product by keeping the process variables in the same range. The constraints (Table 3.23) were set to maximize the acceptability in terms of sensory value along with higher nutritional profile. These constraints with optimum process conditions generated 3 optimum solutions (Table 3.24).

Table 3.23: Optimization Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:mango	maximize	14.1	17.6	1	1	3
B:pineapple	maximize	27.1	35.3	1	1	3
C:almond flour	is in range	21.2	25.9	1	1	3
antioxidant	maximize	68.34	79.79	1	1	3
protein	maximize	25.69	27.22	1	1	3
firmness	is in range	1826.23	2424.43	1	1	3
Toughness	is in range	9110.95	12673.1	1	1	3
Sensory evaluation	maximize	6	7.17	1	1	3

Table 3.24: Optimized solutions

0.	Mango (%)	Pineapple (%)	almond flour (%)	Antioxidant (%)	Protein (g/100 g)	Firmness (g)	Toughness (g/s)	Sensory Evaluation	Desirability
1	17.60	30.40	22.50	76.82	19.10	2180.56	11148.74	6.90	0.592
2	18.40	31.50	20.60	79.25	18.51	2247.42	11278.36	6.63	0.580
3	16.20	32.30	22.00	74.31	19.00	1927.75	10524.39	7.17	0.556

The optimized results showed sensory score between 6.6-7.2. The general recommendation is to maximize antioxidant value by maximizing fruit content. Higher levels of toughness were found to reduce the acceptability of the final product. The protein content was found to be 18.51-19.10 g/100g of the product. All optimization solutions depict that sample will be well accepted based on sensory score. The optimization results helped in fulfilling the objective of the study by increasing the quality of fruit licorice in order to serve as a potential healthy candy for malnourished children.

3.7 Conclusion

After complete evaluation of all the attributes for physical and chemical parameters like texture, color, antioxidant value and protein content, it was found that there was a strong relationship between the antioxidant values and the levels of mango and pineapple. Almond flour and WPI had negative effect on color of the extruded licorice as they lowered the L* and a* values. The optimum range for maximum acceptability of extruded licorice was found to be 17.6% mango, 30.4% pineapple, 22.5% almond flour, 17.6% WPI and 11.8% potato starch. Successful utilisation of tropical fruits with added functionality in candy production will definitely open up new dimensions to the food industry especially in developing countries as it can be introduced in school meal as a nutritional supplement.

PREFACE TO CHAPTER 4

In Chapter 3, a licorice type candy was developed using fruits in extrusion processing. It was found that fruits can be used solely in extrusion processing for product development. Based on the process parameters and model a second product is developed to serve as a potential diet choice for Chronic Kidney Disease (CKD) patients. CKD is another major challenge faced by the world these days and there are very little processed products available in the market. This product can be of a great industrial interest. In the literature, various porridge products have been developed in combination with cereals and with higher protein content which are not suitable for CKD patients, using different processing techniques. The instant porridge was prepared with different formulations containing variable amount of freeze dried mango, pineapple and banana flour to increase the nutritive value of the product. The addition of banana flour also helped in increasing the resistant starch content which helped in better extrusion processing.

The preliminary runs were performed to estimate the range of components and the potential of extrusion processing in using banana flour. The extrudates developed were evaluated for their physical and chemical properties and sensory evaluation was done. The developed product was convenient low in protein and easy to cook.

A part of this thesis was presented at Research Feeding Industry (RFI) 2014 at Montreal. One manuscript is under preparation for publication from this chapter.

All experimental work and data analysis in the study were carried out by the candidate under the supervision and guidance of Dr. H. S. Ramaswamy.

CHAPTER 4 DEVELOPMENT OF AN INSTANT FRUIT PORRIDGE MIX USING MANGO, PINEAPPLE AND UNRIPE BANANA FLOUR

4.1 Abstract

A relationship has been established between dietary habits and disease risk in humans which states that a healthy diet can improve the state of well-being of a person. Keeping this statement in mind, unripe banana flour and tropical fruits, which are an excellent source of vitamins, minerals and antioxidants, were used to develop a porridge using extrusion-drying processing. For this study a D-optimal mixture design was used to formulate different ingredient level selections by varying the amount of mango, pineapple and unripe banana flour. The design generated 16 combinations which were processed under same extrusion conditions to measure the effect of different formulations on the final product. The screw speed was kept constant at 90rpm in order to provide equal residence time and temperature was set to 140^{O}, 120^{O}, 100^{O} and 80^{O}C in the respective barrel zones of the extruder. The extruded product was tray dried further to reduce the moisture content to 7-8% and analyzed for different quality characteristics: physical properties bulk density, expansion ratio, water activity, rehydration ratio, color and texture. The ingredient composition variations had a significant effect on the final product with higher amount of banana flour increasing hardness, darkness, bulk density and rehydration ratio of the product. However there was a resulting decrease in the expansion ratio. The final product was developed with better texture, rehydration properties and low protein content (1.1-1.4 g/100g) than market samples keeping in view of the low protein requirement of chronic kidney disease patients.

4.2 Introduction

Porridge is conventionally considered as an important processed food from grains. It is a traditional food in most of Northern Europe but its growing popularity and nutritional benefits has made it an acceptable food worldwide. It was primarily a savory dish, with a variety of meats, root crops, vegetables, and herbs added for flavor. In many modern cultures, porridge is consumed as breakfast and is made by boiling oats, sorghum, rice, wheat, barely, corn or sometimes another cereal in water, milk, or both. Being a cereal food product porridge is rich in fibre and provides satiety after consumption (Gandhi & Singh, 2014). Porridge consumption has been widely expanding owing to its ability to mitigate obesity, cardiovascular diseases and control cholesterol due to its nutritional properties (Geliebter et al., 2014; Shakoor et al., 2014).

Historically porridge processing involved roasting of cereals followed by grinding and packaging. The packaged porridge mix is then cooked before consumption in order to gelatinize the starch. With progression in food processing techniques, instant porridges were introduced in the market. The acceptability and nutritious values are frequently being enhanced by food processors by adding ingredients to the traditional cereal porridge. Instant porridge became more popular owing to their less burdensome cooking process as they involve only addition of hot water or milk. According to the Health Canada Nutritional Database, oats porridge consists of 11.7g/100g of protein while another oat porridge with wheat and flax seed incorporation contains 15.2g/100g of protein. The status and explanatory role of nutrition is getting more certain in consumers these days especially in developed countries. Product development research has focused on developing high protein porridge. Pelembe et al. (2002) developed protein rich porridge using sorghum-cowpea combination, Plahar et al. (2003) also developed a high protein weaning food for infants using peanuts, soybean and maize. People tend to eat high protein diet to develop muscles, maintain strength and to reduce appetite. But the supporting evidences for these statements are uncertain and the diet-induced physiological consequences might lead to an increase in the prevalence of chronic kidney disease (CKD) in the general population without preexisting kidney disease (Marckmann et al., 2015). Thus the production of a fruit porridge without incorporation of cereals can be a possible diet choice for CKD patients. The amount of protein required for kidney patients to maintain nutritional balance mainly depend on the level of kidney damage however for CKD in general the potential benefit of protein reduction has been found at 0.6g/kg body weight/day and 1.2 g/kg body weight/day for patients on dialysis (Chen & Bedhhu, 2015).

Unripe or green banana flour is rich in resistant starch, antioxidants, and other bioactive compounds. The starch content ranges between 17.5% and 42.82% depending upon the variety of banana used. Consumption of banana flour has been related to various health benefits as it is an excellent source of resistant starch as well as bioactive compounds. It also contains a high amount of minerals and vitamins such as vitamin A, B1, B2 and C and potassium. The starch content of green banana is comparable to corn grain endosperm and pulp of white potato, apart from starch it is also a rich source of dietary fiber (Wang et al, 2012).

Banana flour has potential for both its functional and nutritional properties. It also shows antioxidant properties as it is a rich source of catechin, epicatechin and gallocatechin (Choo & Aziz, 2010). Several studies have suggested that consumption of a diet rich in antioxidants and resistant starch exerts beneficial effects on human body. Antioxidants present in banana flour have a degenerative effect against cancer, rheumatoid arthritis and cardiovascular disease (Loypimai, & Moongngarm, 2015). Resistant starches tend to have beneficial effects on diabetes which is a precursor of CKD. Resistant starch refers to the portion of starch which resist digestion and tend to pass through the gastrointestinal tract undigested. It increases the fecal bulk, lowers colonic pH, lowers serum cholesterol, it controls glycemic and insulinemic responses in diabetic patients, improves blood lipid profile, increase satiety and micronutrient absorption. It also acts as a prebiotic by selectively stimulating the growth of selective bacteria for the host in gastrointestinal tract (Fuentes-Zaragoza et al, 2010), which can help prevent certain cancers.

Extrusion cooking has been used in a large number of food applications as it has some unique positive features compared with other heat processes and it tends to maintain the nutritional profile of the ingredients due to minimal heat effect. During the extrusion process, the material is treated not only by heating, but also by intense mechanical shearing, compression and torque, which are able to break the covalent bonds in biopolymers (Singh et al., 2007). Thus, the functional properties of the food ingredients are rapidly modified due to the combined influence of temperature, pressure, shear and time (Carvalho & Mitchell, 2000). Food extruders also permit to inactivate the undesirable enzymes that may affect the quality and can eliminate several anti-nutritional factors, such as trypsin inhibitors, haemagglutinins, tannins and phytates (Bhandari et al.,2001; Singh et al., 2007). The relationship between process parameters and the physical properties of the extrudates, which incorporate banana flour, mango powder and pineapple crush, has not been studied in detail. This kind of study is the essential for product development and process control considering the popularity of new application development of health benefiting ingredients. Many studies have focused on development of porridge using extrusion processing. In literature, most of the porridge were developed using sorghum-cowpea combination, kidney beans, soy-maize-sorghum-wheat combination or maize-finger millet blend. Recently in 2014, Gandhi & Singh (2014) developed a porridge using guava blends and wheat. Loypimai & Moongngarm (2015) utilized pre-gelatinized unripe banana flour to develop a porridge without the use of extrusion processing.

Thus the objective of this study was to identify the optimal formulation and extrusion conditions required to develop a fruit porridge with lower protein content without sacrificing the sensory quality. The subsequent objective was to evaluate the physico-chemical properties of a fruit porridge made from mango, pineapple and unripe banana flour.

4.3 Materials and Methods

4.3.1 Mango puree from Deep brand distributed by Chetak New York, USA containing 94% Kesar mango pulp, 5% sugar, and Great Value crushed pineapple containing pineapple, pineapple juice and citric acid were purchased from a local market. Banana flour was imported from Wedo Gluten Free, USA. Instant Oats porridge (Jordan Brand, The Jordans & Ryvita Company, a division of ABF Grain Products Limited, UK) and ground wheat porridge (Deep brand, Punjab, India) were bought from local Marche in Montreal, Canada for comparison.

4.3.2 Since the required amount of moisture in the feed was higher than what should be present in the feed mix, one of the two containing high amount of moisture needed to be dehydrated. Mango puree was chosen as the component because this had lower amount of moisture than pineapple and drying it was sufficient to bring down the feed moisture to the required range. Freeze drying technique was adopted for this purpose to impart minimal influence of the drying on dried mango product. The freeze dried mango product was then ground to form a powder with a final moisture content of 6.5-7.0% whereas the crushed pineapple was processed to form a puree with a moisture content between 60-80%. Unripe banana flour was added to the product to provide texture and replace traditional flours. Combinations were formulated by varying the quantities of freeze dried mango powder, pineapple puree and unripe banana flour using D-optimal mixture design with constraints (Table 4.1) selected after preliminary trials. The mixture resulted in 16 formulations. The calculated components of different formulations were weighed on the weighing scale upto 2 decimal point and were then mixed using a Hobart mixer (Hobart Food Equipment Group Canada, North York, Ontario, Canada).

Table 4.1: Design Constraints

Low (%)	Constraint	High (%)
18.33	A:mango	25.00
41.67	B:pineapple	50.00
25.00	C:Banana Flour	33.33
	A+B+C	100

4.3.2.1 Extrusion: Extrusion trials were made using a pilot-scale co-rotating intermeshing twin screw extruder (DS32-II, Jinan Saixin Food Machinery, Shandong, P. R. China), consisting of four independent barrel zones of controlled temperature in the 20:1 length to diameter ratio barrel with a screw diameter of 30mm. The die of length 27mm was used for this process with a diameter hole of 5mm. The extruder was fed automatically through a conical hopper at a feed rate of 15kg/h on wet basis, keeping the flights of the screw filled and avoiding accumulation of the material in the hopper (Yu, 2011). In order to find the optimal processing conditions, the trials were performed at different feed moisture which was varied by varying the amount of ingredients in composition, extrusion temperature and screw speed. Table 4.2 shows the observations of the preliminary trails.

Table 4.2: Quality observations of different trials at variable processing conditions.

Trial No.	Temperature (^{O}C)	Screw speed (rpm)	Feed moisture (%)	Quality observations
1	180,160,140,120	75	45	Highly viscous banana flour came out
2	180,160,140,120	100	45	Caramelization occurred
3	170,150,130,110	75	40	Dry pallets with hard texture
4	170,150,130,110	90	35	Black, hard balls were formed
5	160,140,120,100	75	35	Black viscous solid was formed
6	160,140,120,100	100	35	Could not retain its shape for cutting after extrusion
7	150,130,110,90	75	30	No puffiness, dripping viscous liquid
8	150,130,110,90	100	30	Higher stickiness and lumps were formed
9	140,120,100,80	75	25	Sticky, less puffed
10	140,120,100,80	90	28	Puffed extrudates were formed

Based on the above, all the operating conditions were set to favor desirable texture and color development in the final product. The screw speed was set to 90 rpm and temperature was set to 140^{O}, 120^{O}, 100^{O} and $80^{O}C$ for the four zones respectively, keeping the highest temperature near the die with final moisture content between 25-28%.

4.3.2.2 Formulation of blends: Based on the practical extrusion conditions found, a D-optimal mixture design was used for experimental modeling by varying the percentage of freeze dried mango powder, crushed pineapple and unripe banana flour using Design expert software (Stat-Ease Inc., Minneapolis, USA). In total 16 formulations (Table 4.3) were generated by the software. The ingredients were mixed according to the percentage calculated by the software for each run. Each sample with different proportion of additives was extruded at optimal formulation conditions found earlier after various trials. Following extrusion, the extruded product were cut into small strands with length of about 8 cm and dried in a tray drier.

Table 4.3: D-optimal mixture design variable component formulations.

Run	Freeze dried Mango (%)	Pineapple (%)	Banana flour (%)
1	21.48	45.19	33.33
2	22.30	47.61	30.09
3	24.68	45.93	29.38
4	21.33	50.00	28.67
5	22.3	47.61	30.09
6	18.33	49.01	32.66
7	25.00	47.84	27.16
8	24.68	45.93	29.38
9	23.19	50.00	26.81
10	18.33	49.01	32.66
11	21.48	45.19	33.33
12	25.00	41.67	33.33
13	25.00	50.00	25.00
14	21.33	50.00	28.67
15	20.40	47.34	32.26
16	23.96	44.14	31.90

4.4 Drying

Following extrusion, the extruded strands of the product were collected in the tray and dried to lower the moisture content to 7.50-9.53% or water activity below 0.56. The temperature in the cabinet tray dryer was kept at 55ºC with the airflow at 0.1m/s. The weight of strands in the dryer was measured by a lab scale at regular intervals till 2 h, which were used to determine the amount of water loss during the drying. Extruded products were subjected to drying for 120 min and moisture loss was recorded after every 15 min by measuring the loss of weight of the dried product. Moisture content in the final product was expressed on a wet weight basis. Water activity was determined at room temperature using the water activity analyzer (ROTRONIC HygroLab 3, Rotronic Instrument Corp., New York, NY, USA)lab scale instrument. The time was kept same for all the samples in order to measure the effect of variable combinations on drying rate. These were crushed to prepare coarse particles for preparing the instant porridge mix. The final products were stored in a plastic container to prevent moisture gain before further analysis.

4.5 Properties of extruded products: Various physical and chemical parameters were selected to analyze and describe the properties of the extruded porridge mix. These are:

4.5.1 Expansion Ratio

It describes the degree of puffing undergone by the material as it exits the extruder. It was measured by taking the diameter of 10 extrudates with the help of a Vernier calliper averaged and divided by the diameter of the die of the extruder. Several researchers have demonstrated that the expansion ratio of extruded cereals depends on the degree of starch gelatinization.

4.5.2 Bulk Density

Bulk density is a very important parameter in the production of expanded and formed food products. It has been linked to the expansion ratio in describing the puffing in extrudates. However, the expansion ratio considers the expansion ratio only in the direction perpendicular to the extrudate flow, while bulk density considers expansion in all directions. It was calculated as per mass per unit volume using the following formula:

$$\text{Density (g/cm}^3\text{)} = \text{mass}/\pi r^2 l$$

4.5.3 Protein

The protein content of the product was not measured but estimated based on the protein content of individual components in the feed mix and the dry basis moisture content in the feed mix and the final product. Because the process involved mild temperature conditions, it was assumed that only minor modification in the structure would result and the actual protein content will remain unchanged within the components (Singh et al, 2007). The protein content was computed from the protein content of the ingredients as indicated in the labels and Health Canada Nutrition database. No external source of protein was added to the formulations thus the main source of protein was banana flour which consisted of 3.3g of protein per 100g as fruits contained 0g of protein.

4.5.4 Antioxidant Value

The antioxidant activity (AA%) of each sample was expressed as a percentage using the DPPH free radical scavenging activity method (Singh & Ramaswamy, 2014) with some modifications. A measured 5 g sample was soaked in 15 mL of water and 30 mL of ethanol for 2 h. The soaked sample was then ground using a pestle and mortar, and filtered through Whatman No. 1 filter paper. A 0.5ml of extracted sample was allowed to react with stable DPPH radical in an ethanol solution. The reaction mixture consisted of adding 2 ml of sample, and 2 mL of 0.1 mM DPPH radical solution dissolved in 95% ethanol. When DPPH reacts with an antioxidant compound, which can donate hydrogen, it is reduced. The changes in the violet color of DPPH solution were read [Absorbance (A)] at 517 nm after 30 min incubation in a dark at room temperature using a UV spectrophotometer. The 95% ethanol was used as a blank. The scavenging activity percentage (AA%) was determined using formula (with A_O and As representing absorbance values for blank and sample, respectively):

$$AA\% = \frac{(A_O - As)*100}{A_O}$$

4.5.5 Texture

Texture analysis was performed using a texture analyzer (TA-XT plus Texture Analyser, Texture Technologies Corp, USA) following the method reported by Prasert and Suwannaporn (2009) with some modifications. Ten grams of instant porridge was rehydrated with 50 mL of hot boiled water for 3 min. The rehydrated sample was molded into a cube using a cubical mold (20 mm inside diameter and 20 mm height). It was compressed to 50 % with a cylindrical probe (35 mm diameter) at a speed of 2.0 mm/s. Hardness was measured from the force derived on the porridge cube.

4.5.6 Rehydration Ratio

Rehydration ratio was measured using the method described by Loypimai & Moongngarm (2013) with some modifications. Ten grams of instant porridge powder was added with 10 mL of distilled hot water and then heated by microwave for 5 min. the mix was then weighed. The rehydration ratio was calculated as follows:

Rehydration ratio = weight of dry porridge (g)/ weight of porridge after adding hot water (g)

4.5.7 Color

The color properties were assessed using a Tri-stimulus Minolta Colorimeter to determine L* value (lightness or brightness), a* value (redness or greenness) and b* value (yellowness or blueness) of the final samples. The colorimeter was warmed up for 20 min and calibrated using a white standard tile: L=95.87, a = 0.86 and b=2.47. Measurements were made on samples and the average of L*, a* and b* values are obtained. However, in porridge the whiteness index was more important rather than the L* a* b* values alone because banana flour tend to impart darker color to the final product on heating, darker porridge is not so pleasant to the eye. Therefore, the whiteness index was measured using the formula as described by Loypimai & Moongngarm (2013):

$$\textbf{Whiteness index} = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{0.5}$$

4.5.8 Sensory quality

The organoleptic evaluation of this product, reconstituted with hot milk was conducted with a taste panel. A 9-point Hedonic rating scale was used for analysis. Based on the color, texture and taste.

4.5.9 Statistical optimization

The statistical analysis were made using the Design Expert software. For the analysis, two-way ANOVA at 95% level of confidence and 5% level of significance were used. The effect of freeze dried mango powder, crushed pineapple and banana flour on the texture, color, antioxidant activity, protein content and sensory analysis was evaluated using ANOVA. The numerical optimization was done to maximize the nutritional quality of the final product with higher sensory acceptability.

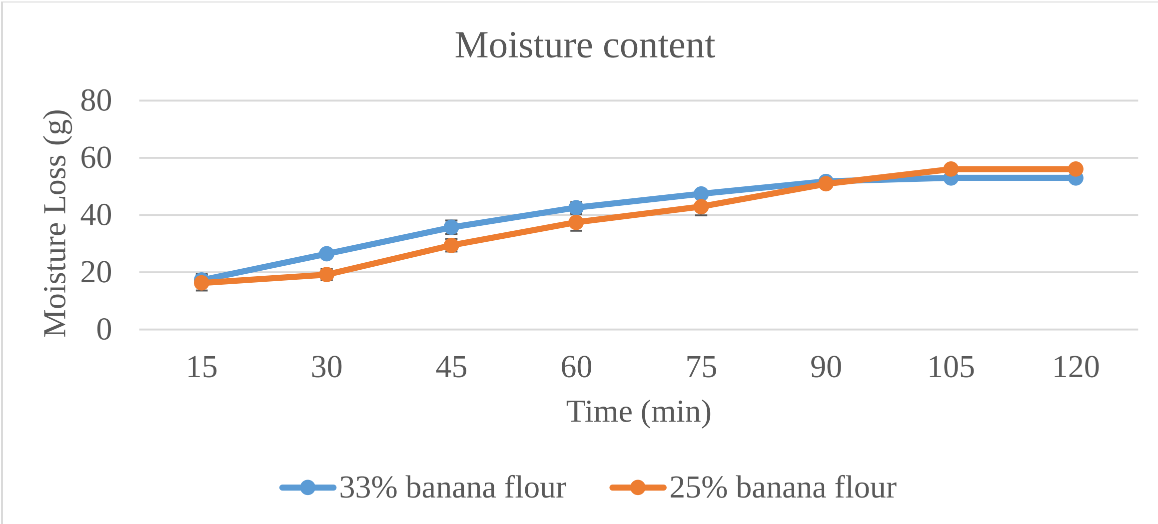
4.6 Results and discussion

4.6.1 Drying

The extruded products were subjected to drying for 2 h and the moisture loss was recorded after every 15 min. Table 4.4 shows the moisture content of the product before extrusion, after extrusion and after drying. The highest amount of moisture was lost in the first 60 min after which the rate decreased as the moisture was being removed from interior of the product. The trend of moisture loss is shown in Figure 4.1. The samples with higher amount of banana and pineapple content were found to take less time as compared to other samples, which can be attributed to the high fiber content of the product. Ovando-Martinez et al., (2009) also reported a decrease in the moisture content of spaghetti when banana flour level increased in the spaghetti. This pattern is related to the decrease in network produced by the gluten and consequently increase in separation of water during drying. Low-moisture content is important in the shelf-life of food products. The dried extrudates were then subjected to grinding in order to make porridge (Figure 4.2).

Table 4.4: Moisture content at different stages.

Run	Initial Moisture content	After Extrusion	After drying	Water Activity
1	26.10±1.01	20.36±0.80	7.50±0.64	0.401
2	29.59±0.93	23.08±0.31	8.59±0.99	0.452
3	27.43±0.53	21.40±2.03	8.85±0.19	0.469
4	32.42±1.12	25.29±1.02	8.89±0.86	0.484
5	29.59±1.43	23.08±0.32	8.59±0.12	0.452
6	31.71±0.52	24.73±0.66	8.00±0.32	0.419
7	30.86±0.09	24.07±1.87	8.96±0.30	0.505
8	27.43±0.33	21.40±0.63	8.78±0.89	0.459
9	33.75±0.52	26.33±0.54	9.00±0.49	0.558
10	31.71±0.05	24.73±0.32	8.00±0.14	0.419
11	26.10±1.02	20.36±1.05	7.50±0.53	0.401
12	25.64±1.23	20.00±1.12	7.50±0.70	0.401
13	35.63±0.45	27.79±0.89	9.53±0.36	0.594
14	32.42±0.40	25.29±1.49	8.89±0.47	0.484
15	28.00±1.01	21.84±0.39	8.30±0.10	0.436
16	26.62±0.03	20.76±0.80	8.45±0.29	0.448



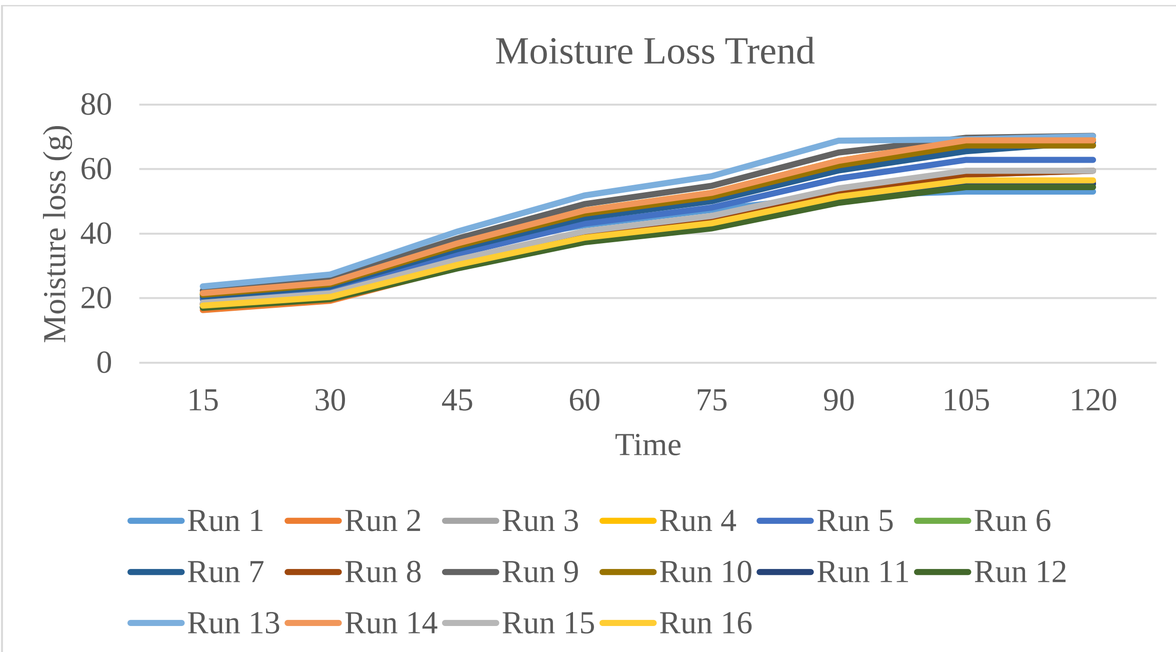


Figure 4.1 Trend of moisture loss.

Figure 4.2 Dried and reconstituted ready to eat instant porridge.

4.6.2 Expansion Ratio (ER)

Expansion ratio measures the ability of a product to expand. Based on lack of the fit test (Table 4.5) quadratic and cubic functions were found to be significant. Quadratic model was used for ANOVA test (Table 4.6) to measure the effect of variables. The F-value of 42.84 implied that the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of prob>F less than 0.0500 indicate model terms are significant. In this case BC i.e. Pineapple and Banana flour are most significant. The lack of fit of 7.25 implies there is only 2.43% chance that a lack of fit F-value this large could occur due to the noise. The Pred R-squared of 0.8254 is in reasonable agreement with the Adj R-Squared of 0.9331 i.e. difference is less than 0.2. The quadratic model was built using the following equation:

$$\textbf{Expansion ratio} = +0.051223*A - 0.024197*B - 0.075493*C - 1.15611E\text{-}004*AB + 1.24580E\text{-}004*AC + 3.39950E\text{-}004*BC$$

Table 4.5 Lack of fit test for ER

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	0.11	8	0.014	12.23	0.0068
Quadratic	0.041	5	8.261E-003	7.25	0.0243
Special Cubic	0.041	4	0.010	9.05	0.0164
Cubic	4.046E-003	1	4.046E-003	3.55	0.1183
Special Quartic	0.035	2	0.018	15.40	0.0073

Table 4.6 ANOVA test for ER

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	1.01	5	0.20	42.84	< 0.0001
Linear Mixture	0.94	2	0.47	99.63	< 0.0001
AB	3.718E-003	1	3.718E-003	0.79	0.3947
AC	5.228E-003	1	5.228E-003	1.11	0.3164
BC	0.058	1	0.058	12.42	0.0055
Residual	0.047	10	4.701E-003		
Lack of Fit	0.041	5	8.261E-003	7.25	0.0243
R-Squared	0.9554				
Adj R-Squared	0.9331				
Pred R-Squared	0.8254				

Fiber content was the most significant factor affecting the ER. The effect of interactions between fruits has been observed to be complex. ER was found to be minimum when the amount of banana flour and pineapple mix were maximum. The ER value varied from 1.98 to 2.97 for different formulations. The data with respect to different formulations has been given in Table 4.7 and Figure 4.3. Gandhi et al, (2013) found that with an increasing level of guava pulp in wheat porridge the expansion ratio of extrudates decreased. This may be attributed to the dilution effect of fruit pulp on the starch content. Also this effect may be attributed to the high fibre content, which competes for the free water found in the matrix, lowering its expansion capabilities. Lowered expansion ratio in biscuits on addition of orange pulp was also reported by Larrea et al (2005).

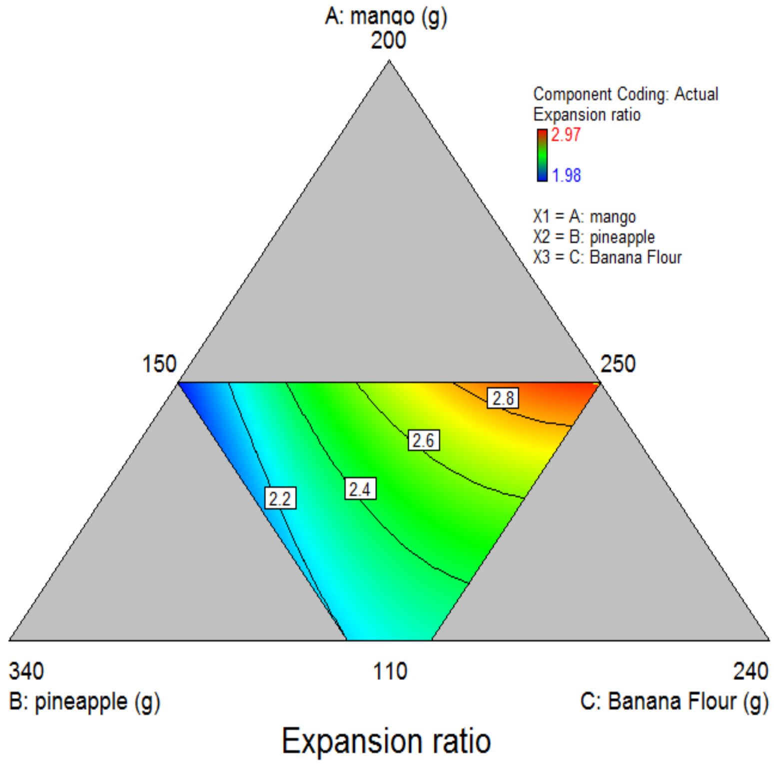


Figure 4.3: Contour graph for effect of variables on Expansion ratio.

4.6.3 Bulk Density (BD)

Significant models were determined through the ANOVA test for BD, and found to be special quartic and quadratic models based on the lack of fit test (Table 4.7). Quadratic model was used for ANOVA test (Table 4.8). The model F-value of 136.09 implied that model is significant and there is only a 0.01% chance that an F-value this large could occur due to noise. Values of Prob>F less than 0.0500 indicate model terms are significant. The Pred R-squared value of 0.9512 is in reasonable agreement with the Adj R-Squared of 0.9783 thus this model can be used to navigate the design space.

Table 4.7: Lack of fit test for BD

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	1.234E-003	8	1.543E-004	15.43	0.0040
Quadratic	7.204E-004	5	1.441E-004	14.41	0.0054
Special Cubic	5.938E-004	4	1.485E-004	14.85	0.0056
Cubic	1.078E-004	1	1.078E-004	10.78	0.0219
Special Quartic	3.503E-004	2	1.751E-004	17.51	0.0055

Table 4.8: ANOVA test for BD

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	0.052	5	0.010	136.09	< 0.0001
Linear Mixture	0.052	2	0.026	336.90	< 0.0001
AB	3.925E-006	1	3.925E-006	0.051	0.8260
AC	3.992E-004	1	3.992E-004	5.18	0.0461
BC	2.764E-005	1	2.764E-005	0.36	0.5625
Residual	7.704E-004	10	7.704E-005		
Lack of Fit	7.204E-004	5	1.441E-004	14.41	0.0054
R-Squared	0.9855				
Adj R-Squared	0.9783				
Pred R-sqaured	0.9512				

The quadratic model was built using the following equation:

Bulk Density = -0.14*A + 0.36*B + 0.23*C – 0.030*AB + 0.28*AC + 0.060*BC

Data with respect to moisture content and mango & pineapple content were presented in Table 4.7 and Figure 4.4. The range of bulk density varied between 0.13 to 0.31g/cm^3 which was increasing with an increase in moisture content and fibre (Figure 4.5). The main source of fibre and moisture was pineapple crush, thus higher bulk density was found in the run with higher content of pineapple and banana flour. Similarly, Gandhi et al, (2013) reported an increase in density with increase in fruit pulp content. Highest bulk density was associated with a low expansion ratio as can be expected. At low feed moisture content, as the product temperature increases, the product mix gets cooked and plasticized and thus flashing moisture and high pressure of the die increase the expansion ratio and decrease the bulk density. From this it can be realized that with an increase in fruit content the bulk density increase as the cell walls of the fibre particles tend to rupture even before the gas bubble can expand to their full potential. Sugar content present in the fruits can also be a reason as sugar tends to bind with the water and thus decrease the gelatinization of the starch. Nyombaire et al. (2011) also found an increase in bulk density with an increase in moisture as water tends to lower down the friction and increase the vaporization which facilitated the higher bulk density by causing expansion.

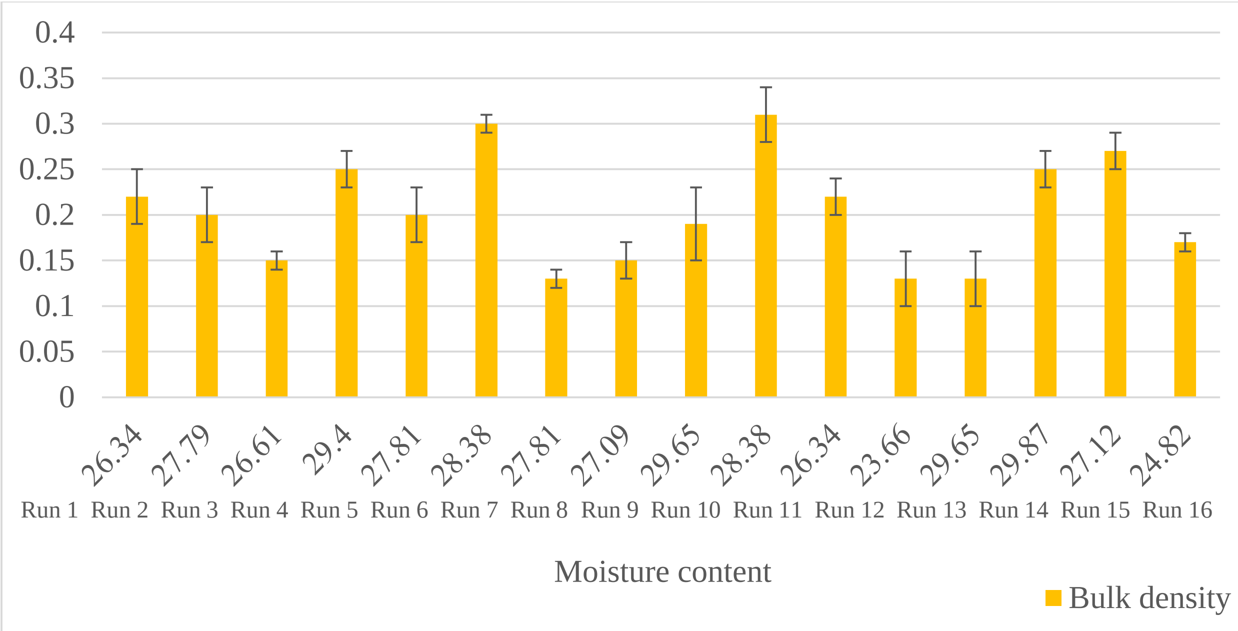


Figure 4.4 Relation between BD and moisture content of runs.

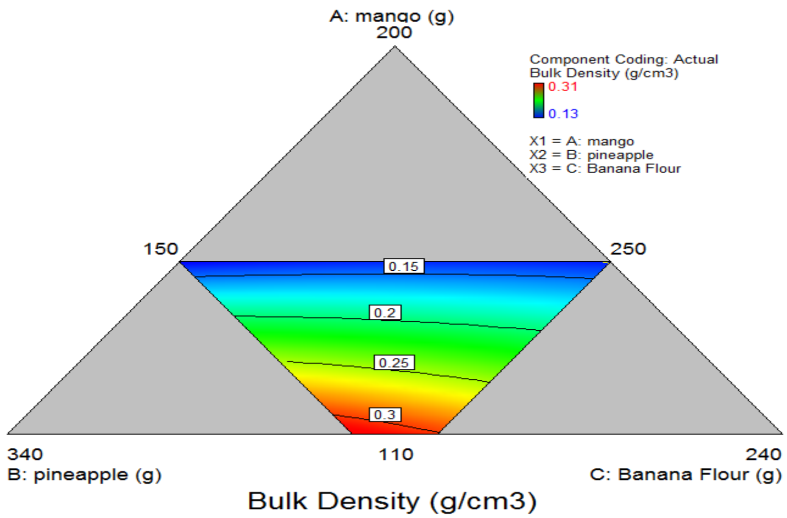


Figure 4.5: Contour graph for effect of variable on bulk density.

4.6.4 Protein

No external source of protein was added to the formulations and the principal source of protein was banana flour which consisted of 3.3g of protein per 100g. Thus the protein content varied between 1.1-1.4 g proteins per 100g of the porridge which is enough to match the dietary requirements of the target CKD patients. The low protein is essential for the patients so that they can replace the other portion of protein requirement with animal protein which has higher amino acid value compared to the plant protein source. The comparison between the developed porridge protein content and the available market porridges protein content is given in Figure 4.4. The value of protein in market porridge was procured from Health Canada Nutrition Database.

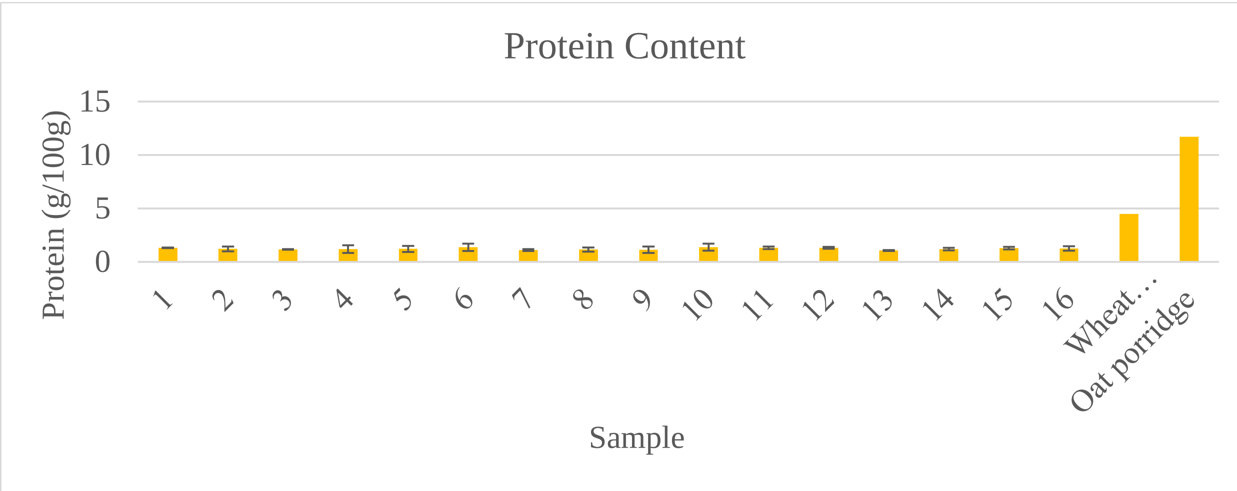


Figure 4.6: Comparison between protein content of developed and market porridge.

4.6.5 Texture

Hardness was measured to determine the texture of the developed porridge. Cubic and special quartic models were found to be significant using the lack of fit test (Table 4.9).

Table 4.9 Lack of fit test for Hardness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	24.15	8	3.02	2.54	0.1592
Quadratic	20.71	5	4.14	3.49	0.0981
Special Cubic	19.65	4	4.91	4.14	0.0756
Cubic	0.028	1	0.028	0.024	0.8839
Special Quartic	0.14	2	0.072	0.060	0.9420

Special quartic model was used for ANOVA test. The model F-value of 23.63 implied that the model is significant. There is only 0.02% chance that an F-value this large could occur due to noise. Values of Prob>F less than 0.0500 indicate model terms are significant. In this case B, C are mode significant (Table 4.10). The pred R-Squared of 0.7541 is in reasonable agreement with the Adj R-Squared of 0.9235 which states that this model can be used to navigate the design space. The final equation in terms of coded values for the special quartic model is as follows:

$$\textbf{Hardness} = -54.30*A + 54.23*B + 56.20*C + 160.46*AB + 151.22*AC + 2.85*BC + 750.08*A^2BC - 604.52*AB^2C - 587.01*ABC^2$$

Table 4.10 ANOVA test for Hardness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	164.05	8	20.51	23.63	0.0002
Linear Mixture	140.05	2	70.03	80.70	< 0.0001
AB	2.24	1	2.24	2.58	0.1521
AC	2.31	1	2.31	2.66	0.1471
BC	2.001E-003	1	2.001E-003	2.306E-003	0.9630
A^2BC	13.58	1	13.58	15.65	0.0055
AB^2C	6.42	1	6.42	7.40	0.0298
ABC^2	4.22	1	4.22	4.87	0.0631
Residual	6.07	7	0.87		
Lack of Fit	0.14	2	0.072	0.060	0.9420
R-Squared	0.9643				
Adj R-Squared	0.9235				
Pred R-Squared	0.7541				

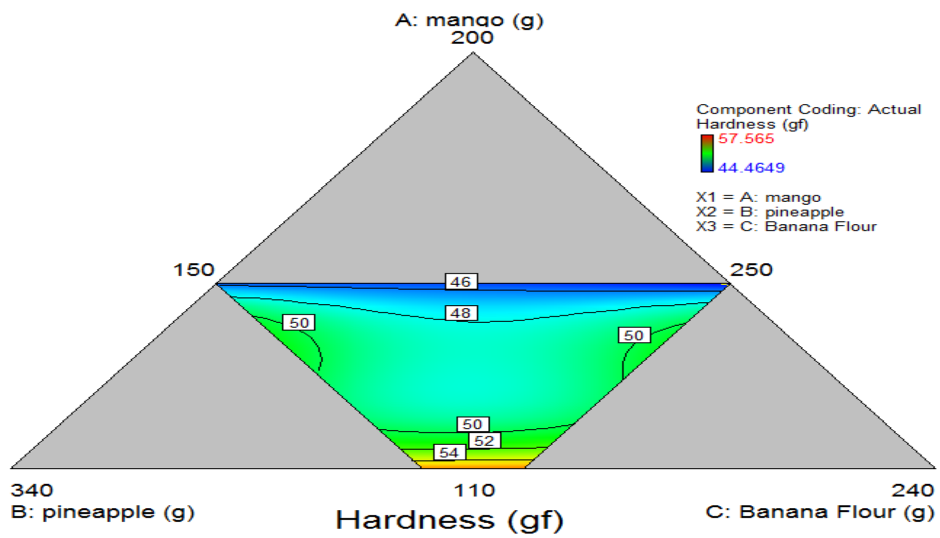


Figure 4.7 Contour graph of effect of variables on hardness of developed porridge.

Hardness was increased with an increase in banana flour content and the range varied between 44.47gf to 57.57gf (gram-force) (Figure 4.7). These results were similar to these found by Wutthikanon et al. (2011); the viscosity of instant porridges increased with the increase of modified banana flour. In a study done by Agama-Acevedo et al in 2009, an increase in adhesiveness, hardness and chewiness of pasta with an increase in banana flour substitution was reported. Similarly, Loypimai, & Moongngarm, (2013) also reported an increase in hardness with an increase in substitution of banana flour in the porridge.

4.6.6 Rehydration Ratio (RR)

Based on lack of fit test, cubic model was found to be significant. It was used for ANOVA analysis to measure the effect of variables on RR of the final product. The model F-value of 11.69 implied the model was significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of prob>F less than 0.0500 indicate model terms are significant. In this case AC interaction was most significant as freeze dried mango was more hygroscopic and banana flour has higher content of fibre. The lack of fit value of 0.39 implied the lack of fit was not significant relative to the pure error. The pred R-squared value of 0.8794 was in reasonable agreement with the Adj R-Squared value of 0.9850 (Table 4.12)

Table 4.11: Lack of fit test for RR

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	0.16	8	0.020	5.82	0.0341
Quadratic	0.11	5	0.022	6.39	0.0314
Special Cubic	0.091	4	0.023	6.76	0.0299
Cubic	1.312E-003	1	1.312E-003	0.39	0.5600
Special Quartic	0.077	2	0.039	11.45	0.0136

Table 4.12 ANOVA test

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	3.02	9	0.34	110.69	< 0.0001
Linear Mixture	2.86	2	1.43	472.39	< 0.0001
AB	0.072	1	0.072	23.93	0.0027
AC	0.050	1	0.050	16.63	0.0065
BC	7.748E-003	1	7.748E-003	2.56	0.1607
ABC	0.071	1	0.071	23.41	0.0029
AB(A-B)	0.060	1	0.060	19.95	0.0043
AC(A-C)	4.407E-004	1	4.407E-004	0.15	0.7159
BC(B-C)	0.074	1	0.074	24.32	0.0026
Residual	0.018	6	3.027E-003		
Lack of Fit	1.312E-003	1	1.312E-003	0.39	0.5600
R-Squared	0.9940				
Pred R-Squared	0.9850				
Adj R-Squared	0.8794				

The calculated rehydration ratios ranged from 2.02 to 3.41 as shown in Table 4.19 and Figure 4.8. The value increased with increase in banana flour content. The increase in rehydration may be due to the soluble dietary fiber existing in the banana flour, which is high in water holding capacity, and consequently enhancing the water absorption of the product. The results were similar to the previous study of Wutthikanon et al. (2011) who found that the hydration ratio of instant porridge samples added with modified banana flour were higher than those of instant rice. The water holding capacity of porridge relates to the physical state of starch, dietary fiber, and protein present in the banana flour, as well as being associated with the release of amylose which has the capacity to effectively bind water molecules. The rehydration ratio was also found to be higher than the selected market wheat and oat porridge (Figure 4.9).

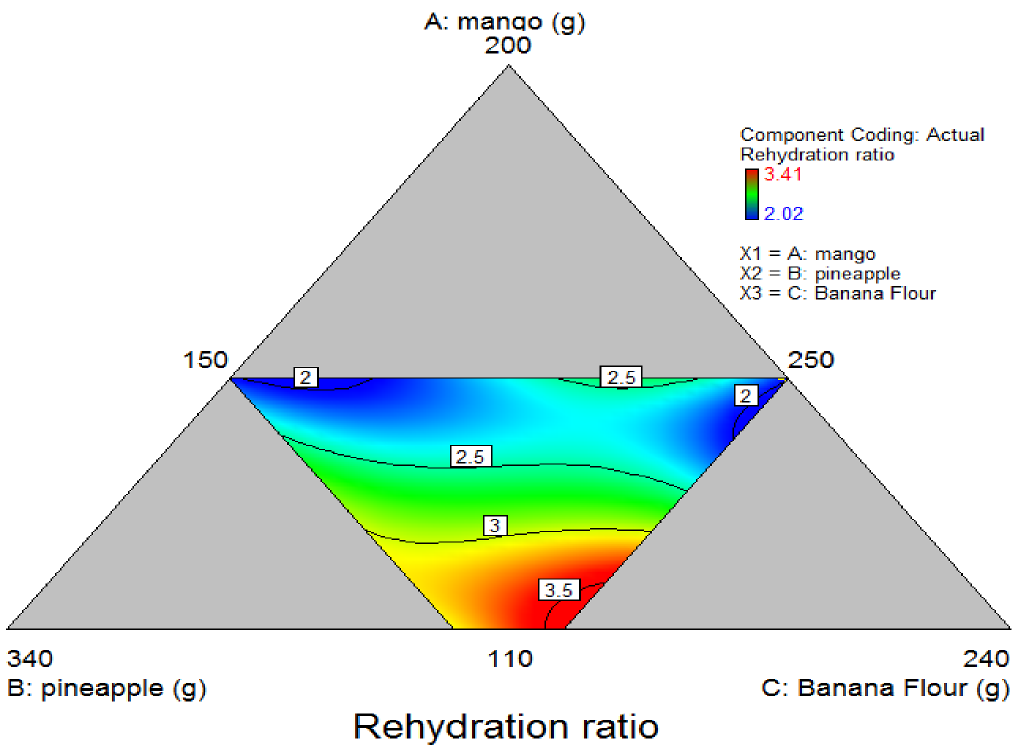


Figure 4.8: Contour graph for effect of variables on Rehydration Ratio (RR).

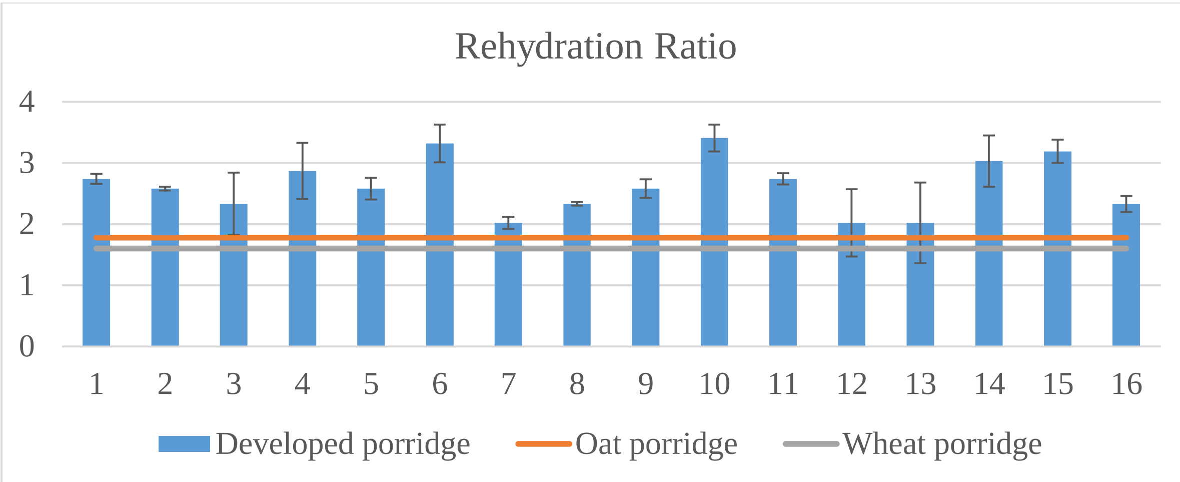


Figure 4.9: Relations between RR of developed porridge and market porridge

4.6.7 Antioxidant Value

The antioxidants are essential for CKD patients due to the various health effects they provide. The effect of variables on antioxidant content of final product was analysed using special cubic model based on lack of fit test (Table 4.13). The ANOVA test (Table 4.14) showed the model F-value of 62.68 which means the model was significant. There was only 0.01% chance that an F-value this large could occur due to noise. Values of Prob>F less than 0.0500 indicated significant model terms. In this model A, B and C are significant terms as they all are rich in antioxidants but C being most significant. The pred R-squared 0.8110 is in reasonable agreement with the Adj R-Squared of 0.9610 thus this model can be used to navigate the design space. The contour graph shows the effect of all variables on the final product (Figure. 4.10). The following equation was used for the special cubic model:

Antioxidant Activity: + 63.52*A + 66.12*B +85.55*C + 69.65*AB + 75.72*AC + 69.83*BC – 121.31*ABC

Table 4.13 Lack of fit test for AA

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	9.73	8	1.22	254.47	< 0.0001
Quadratic	5.67	5	1.13	237.08	< 0.0001
Special Cubic	5.03	4	1.26	263.22	< 0.0001
Cubic	0.48	1	0.48	100.81	0.0002
Special Quartic	1.35	2	0.67	140.74	< 0.0001

Table 4.14 ANOVA test for AA

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	211.28	6	35.21	62.68	< 0.0001
Linear Mixture	206.59	2	103.29	183.84	< 0.0001
AB	0.74	1	0.74	1.32	0.2806
AC	0.89	1	0.89	1.59	0.2396
BC	1.30	1	1.30	2.32	0.1623
ABC	0.63	1	0.63	1.13	0.3159
Residual	5.06	9	0.56		
Lack of Fit	5.03	4	1.26	263.22	< 0.0001
R-Squared	0.9766				
Adj R-Squared	0.9610				
Pred R-Squared	0.8110				

The amount of antioxidants varied in the range of 81.57-94.88% activity in the final product. The percentage was found to increase with an increase in the amount of banana flour in the mixture. Similar results were reported by Choo & Aziz (2010) for banana flour incorporated noodles, where they found an increase in antioxidant activity and total phenol content with increase in banana flour content owing to the presence of phenolic compounds in banana flour. Loypimai & Moongngarm, (2015) also reported an increase in antioxidant activity with an increase in banana flour substitution.

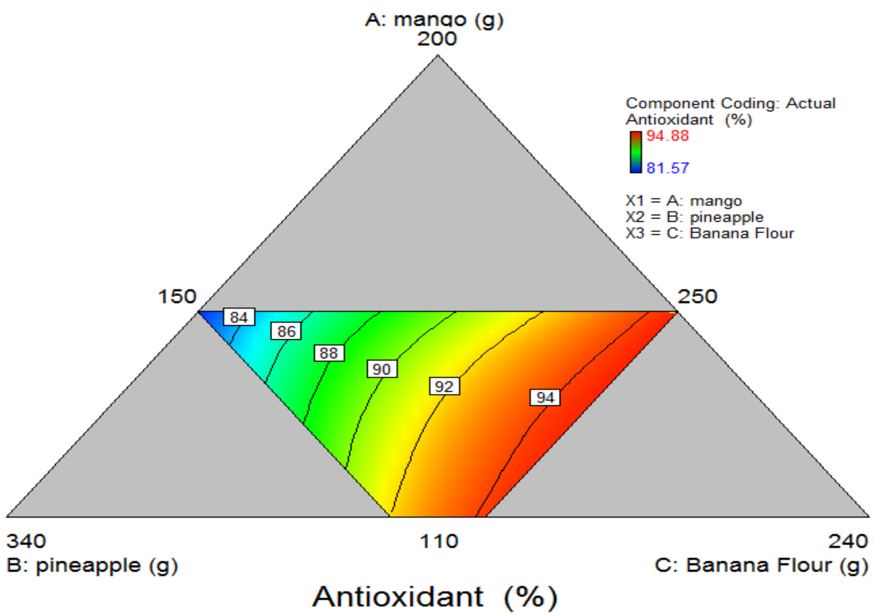


Figure 4.10 Contour graph for Antioxidants.

4.6.8 Color

Whiteness Index

In order to measure the color response a whiteness index was measured. Linear and special quartic models were found to be significant based on lack of fit test (Table 4.15). The ANOVA analysis was done based on a special quartic model built using following equation:

$$\textbf{Whiteness index} = +34.67*A + 96.47*B - 2.80*C - 28.92*AB + 118.32*AC + 4.73*BC + 736.16*A^2BC - 674.78*AB^2C + 50.22*ABC^2$$

Table 4.15 Lack of fit test for Whiteness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	107.70	8	13.46	45.75	0.0003
Quadratic	58.33	5	11.67	39.65	0.0005
Special Cubic	56.21	4	14.05	47.76	0.0004
Cubic	7.64	1	7.64	25.97	0.0038
Special Quartic	30.34	2	15.17	51.56	0.0005

The model F-value of 20.49 implies that the model is significant. There is only a 0.03% chance that an F-value this large could occur due to noise (Table 4.16). Values of Prob>F less than 0.0500 indicate model term are significant. In this case A, B and C are significant terms. The model is significant enough to navigate the design space based on its R-Squared and Adj R-Squared values.

Table 4.16 ANOVA Test for Whiteness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	745.00	8	93.12	20.49	0.0003
Linear Mixture	667.64	2	333.82	73.45	< 0.0001
AB	0.073	1	0.073	0.016	0.9029
AC	1.41	1	1.41	0.31	0.5947
BC	5.512E-003	1	5.512E-003	1.213E-003	0.9732
A^2BC	13.09	1	13.09	2.88	0.1335
AB^2C	8.00	1	8.00	1.76	0.2262
ABC^2	0.031	1	0.031	6.804E-003	0.9366
Residual	31.81	7	4.54		
Lack of Fit	30.34	2	15.17	51.56	0.0005
R-Squared	0.9590				
Adj R-sqaured	0.9122				
Pred R-Sqaured	0.7131				

The whiteness index was found to decrease as the content of banana flour increased. The values for different formulations are given in Table 4.7 and Figure 4.11. For whiteness index, the results were similar to that documented by Loypimai & Moongngarm, (2013). The amount of banana flour altered the appearance of the raw sheet and cooked noodles by making them appear darker. The darkness was caused by the polyphenol oxidases (PPO) catalyzing oxidation of phenolic compounds during pre-gelatinization of banana flour.

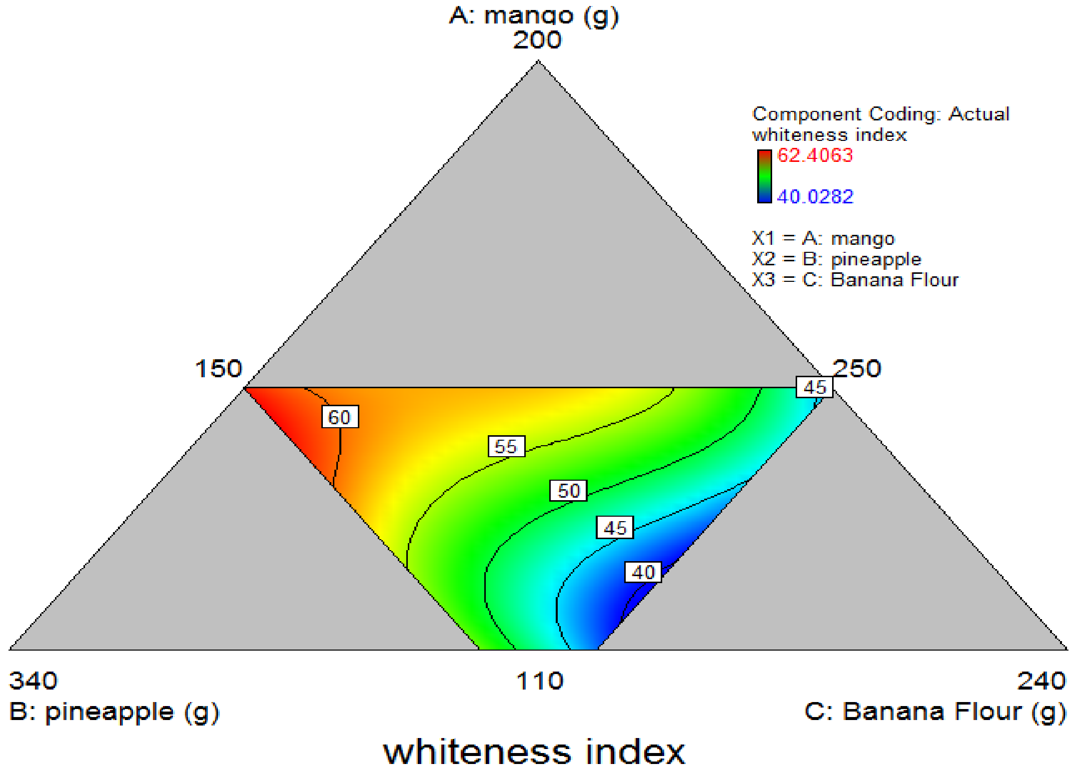


Figure 4.11: Contour graph for Effect of variables on whiteness index of final product.

4.6.9 Sensory Evaluation

The sensory analysis of the product was done for the overall acceptability (Table 4.19) based on color, texture and flavor of the product. The acceptability score was recorded separately for all the components (Figure 4.12), the mean score was found to be in the range of 6.93-7.57. The most acceptable formulation had 25% mango powder; 50% pineapple crush and 25% banana flour. Thus the formulations with higher amount of fruit had higher acceptability. The quadratic and cubic models were found to be significant based on lack of fit test (Table 4.17). Cubic model was used for ANOVA test (Table 4.18).

Table 4.17: Lack of fit test for Sensory Evaluation

Source	Sum of Squares	df	Mean Square
Linear	0.11	8	0.014
Quadratic	0.043	5	8.688E-003
Special Cubic	0.041	4	0.010
Cubic	7.428E-003	1	7.428E-003
Special Quartic	0.012	2	5.780E-003

Table 4.18: ANOVA test for Sensory Evaluation

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	0.73	9	0.081	65.71	< 0.0001
Linear Mixture	0.62	2	0.31	252.37	< 0.0001
AB	0.010	1	0.010	8.47	0.0270
AC	6.358E-004	1	6.358E-004	0.51	0.5006
BC	0.011	1	0.011	9.08	0.0236
ABC	2.514E-003	1	2.514E-003	2.03	0.2041
AB(A-B)	1.896E-003	1	1.896E-003	1.53	0.2622
AC(A-C)	0.021	1	0.021	16.67	0.0065
BC(B-C)	0.017	1	0.017	13.71	0.0101
R-Squared	0.9900				
Adj R-Squared	0.9749				
Pred R-Squared	0.7873				

The model F-value of 65.71 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of Prob>F less than 0.0500 indicate model terms are significant. In this case A, B, AB, BC are more significant model terms. The model was built using the following equation:

Sensory Evaluation = +15.15*A + 9.36*B +1.42*C – 18.30*AB – 3.97*AC + 6.72*BC + 11.33*ABC – 6.23*AB(A-B) – 14.33*AC(A-C) – 8.86*BC(B-C)

Increasing levels of banana flour lowered the sensory acceptability with respect to color, flavor and texture because of increasing amount of fibre. Increasing levels of freeze dried mango powder improved the color, flavor and aroma scores of fruit licorice. Texture values were found to be more significantly affected by interactions of banana flour and pineapple crush. The effect of variables and mean score is shown in Figure. 4.13.

Table 4.19 Effect of process variables on final product sensory quality.														
Run	**ER**	**BD (g/cm^3)**	**Protein (g/100 g)**	**Hardness (gf)**	**RR**	**AA (%)**	**L***	**a***	**b***	**WI**	**Score for Color**	**Score for Texture**	**Score for Flavor**	**Sensory Evaluation**
1	2.54±0.13	0.22±0.03	1.32±0.03	49.63±0.13	2.74±0.08	94.62±0.01	44.38±0.10	11.25±0.52	4.89±0.24	43.05±0.97	8.80±0.03	6.00±0.12	6.00±0.01	6.93±0.05
2	2.42±0.09	0.20±0.03	1.22±0.22	48.86±0.28	2.58±0.03	91.8±0.04	55.45±0.39	10.49±0.53	2.35±0.34	54.17±2.01	8.00±0.03	7.00±0.04	7.00±0.09	7.33±0.05
3	2.75±0.31	0.15±0.01	1.16±0.03	45.98±1.87	2.33±0.51	89.79±0.18	58.04±0.33	9.61±1.01	1.57±1.04	56.93±1.03	7.80±0.01	7.20±0.08	7.20±0.18	7.40±0.09
4	2.13±0.19	0.25±0.02	1.20±0.35	49.72±2.12	2.87±0.46	87.68±0.16	59.83±0.12	12.54±0.81	2.74±0.98	57.83±1.32	7.40±0.02	7.50±0.05	7.50±0.04	7.47±0.04
5	2.42±0.32	0.2±0.03	1.22±0.29	48.13±1.03	2.58±0.18	91.75±0.03	55.31±0.04	10.49±0.86	2.61±0.85	54.03±0.93	8.00±0.05	7.00±0.04	7.00±0.21	7.33±0.10
6	2.21±0.05	0.3±0.01	1.37±0.35	54.37±0.98	3.32±0.31	93.64±0.08	50.08±0.74	19.29±0.13	0.51±0.20	46.48±2.13	8.60±0.04	6.30±0.10	6.20±0.04	7.03±0.06
7	2.35±0.04	0.13±0.01	1.12±0.09	45.32±0.42	2.02±0.10	87.10±0.20	60.32±0.82	6.57±0.62	3.23±0.49	59.65±0.20	7.20±0.02	7.60±0.18	7.60±0.08	7.47±0.09
8	2.68±0.10	0.15±0.02	1.16±0.19	46.65±1.84	2.33±0.03	89.72±0.67	58.25±0.32	9.65±0.29	1.60±0.29	57.12±2.01	7.80±0.06	7.20±0.13	7.20±0.12	7.40±0.10

9	2.17± 0.19	0.19± 0.04	1.14± 0.31	50.70 ±1.36	2.58± 0.15	85.65 ±0.28	60.15 ±0.36	9.93± 0.31	2.84± 0.23	58.83 ±0.64	7.00± 0.10	7.60± 0.09	7.70± 0.06	7.43± 0.08
10	2.29± 0.02	0.31± 0.03	1.37± 0.33	57.57 ±1.19	3.41± 0.22	93.62 ±0.03	50.04 ±0.51	13.69 ±0.42	2.61± 0.02	48.13 ±0.33	8.60± 0.04	6.30± 0.02	6.20± 0.02	7.03± 0.03
11	2.55± 0.13	0.22± 0.02	1.32± 0.12	50.40 ±1.59	2.74± 0.09	94.82 ±0.08	43.86 ±0.29	11.03 ±0.19	3.16± 0.04	42.7± 0.66	8.80± 0.02	6.00± 0.01	6.00± 0.01	6.93± 0.01
12	2.97± 0.42	0.13± 0.03	1.32± 0.10	44.47 ±1.46	2.02± 0.55	94.88 ±0.25	44.40 ±0.15	8.55± 1.04	3.32± 0.43	43.15 ±0.28	8.80± 0.11	6.00± 0.01	6.00± 0.01	6.93± 0.04
13	1.98± 0.05	0.13± 0.03	1.07± 0.04	45.67 ±0.51	2.02± 0.66	81.57 ±0.43	63.56 ±0.19	8.60± 0.20	3.43± 0.29	62.41 ±0.12	6.80± 0.01	7.90± 0.10	8.00± 0.08	7.57± 0.06
14	2.13± 0.07	0.25± 0.02	1.20± 0.12	49.63 ±2.01	3.03± 0.42	87.68 ±0.48	59.93 ±0.48	12.29 ±0.12	2.94± 0.17	57.99 ±1.92	7.40± 0.02	7.50± 0.13	7.50± 0.06	7.47± 0.07
15	2.49± 0.17	0.27± 0.02	1.30± 0.12	48.71 ±1.25	3.19± 0.19	92.55 ±0.29	41.42 ±0.64	12.53 ±0.35	2.87± 0.03	40.03 ±0.31	8.50± 0.12	6.70± 0.15	6.50± 0.13	7.23± 0.13
16	2.64± 0.21	0.17± 0.01	1.25± 0.21	47.93 ±2.01	2.33± 0.13	92.14 ±0.35	52.32 ±0.61	9.65± 0.51	1.60± 0.29	51.33 ±0.42	8.20± 0.09	6.8±0. 04	6.8±0. 05	7.27± 0.06

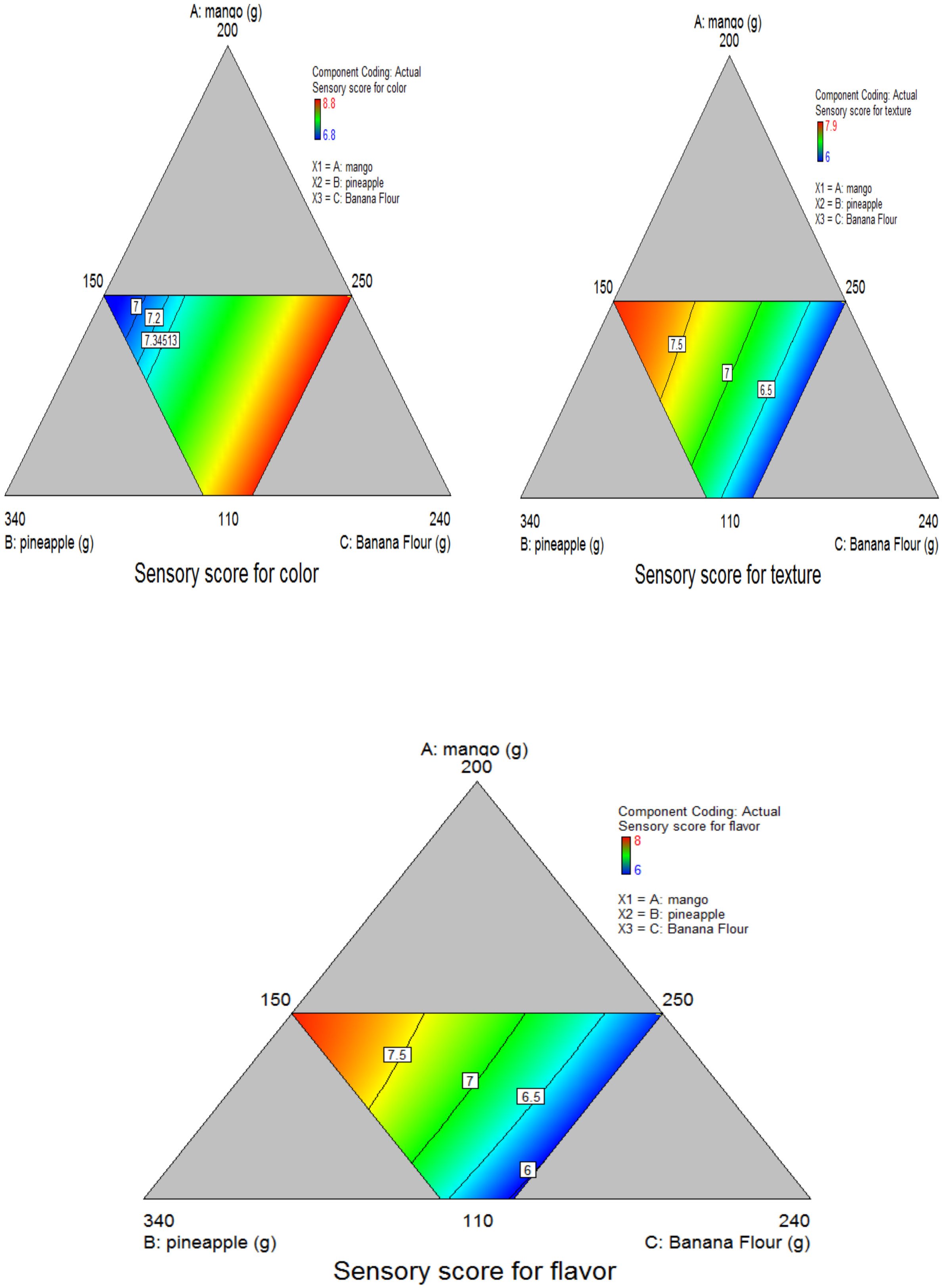


Figure 4.12: Sensory score based on color, texture and flavor of the final product.

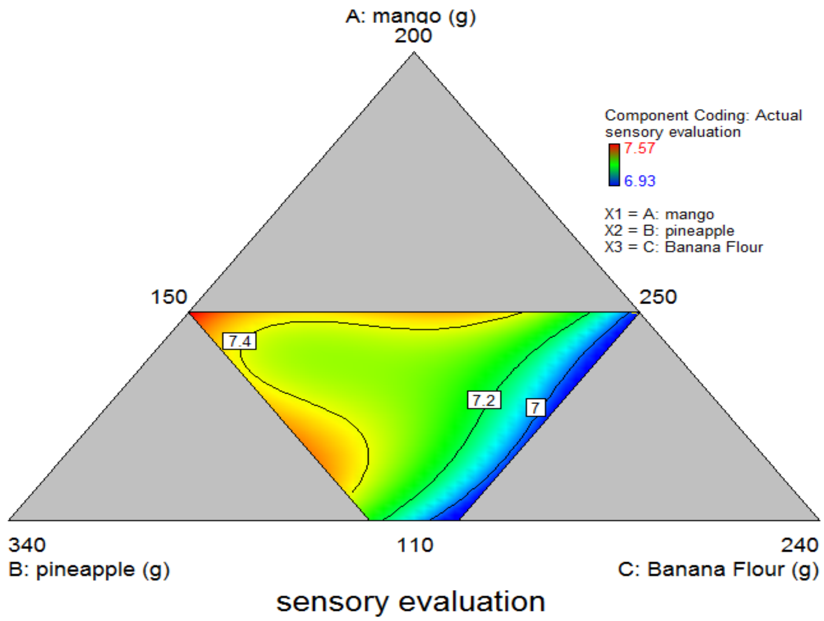


Figure 4.13 Overall Score for the developed instant fruit porridge.

4.6.10 Statistical Optimization

Statistical analysis was done to optimize the process. The optimization was done using Design Expert 9.0.4 software to increase the quality of the final product. The optimum conditions maximized the antioxidant value and sensory properties and minimized the protein level in the final product by keeping the amount of mango and pineapple maximum to increase sugar content and color, and banana flour minimum to increase whiteness index and decrease hardness. The constraints (Table 4.20) were set to maximize the acceptability in terms of sensory value along with higher nutritional profile as a potential diet for CKD patients. These constraints with optimum process conditions generated 2 solutions (Table 4.21).

Table 4.20: Optimization Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Mango powder	maximize	110	150	1	1	3
B:Pineapple crush	maximize	250	300	1	1	3
C:Banana Flour	minimize	150	200	1	1	3
Protein	minimize	1.5	2	1	1	3
Hardness	is in range	44.4649	57.565	1	1	3
Antioxidant	maximize	81.57	94.88	1	1	3
Whiteness index	is in range	40.0282	62.4063	1	1	3
Sensory Score	maximize	6.93	7.57	1	1	3

Table 4.21: Optimized Solutions

Number	Mango powder (%)	Pineapple crush (%)	Banana Flour (%)	Protein (g/100g)	Hardness (gf)	Antioxidant (%)	whiteness index	sensory evaluation	Desirability
1	25.00	48.40	26.60	1.29	45.51	85.27	59.12	7.44	0.70
2	23.60	50.00	26.40	1.26	50.41	84.52	61.94	7.42	0.67

The optimized results showed sensory score of 7.421 and 7.442. The general recommendation is to maximize antioxidant value by maximizing fruit content. Higher levels of hardness were found to reduce the acceptability of the final product thus it was optimized to intermediate levels. The protein content was found to be 1.3 g/100g of the product. All optimization solutions indicate that the sample will be well accepted based on sensory score. The optimization results helped in fulfilling the objective of the study by increasing the quality of instant porridge in order to serve as a potential diet for CKD patients.

4.7 Conclusions

After complete evaluation of all the attributes for physico-chemical parameters like texture, color, antioxidant value and protein content, it was found that there was a strong relationship between the antioxidant values and the levels of the fruit ingredients (banana flour, mango powder and pineapple crush). Banana flour had a negative effect on the texture and the whiteness index of the developed porridge. Also expansion ratio was found to be affected by the amount of pineapple and banana flour. The optimum range for maximum acceptability of the extruded instant porridge was found to be 25% mango, 50% pineapple, and 25% banana flour. Successful utilisation of tropical fruits with added functionality in porridge production will definitely open up new dimensions to food industries to increase food options for CKD patients.

CHAPTER 5 GENERAL CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

5.1 General Conclusion

Extrusion processing has received great attention by food scientists due to its potential to develop new products by preserving food with minimal loss of sensory and nutritional qualities of foods. This research has demonstrated that extrusion-drying combination process can be used as an effective means of producing speciality products without significant loss in product quality. It has versatile applications in the food as well as pharmaceutical industries. It can be used in confectionary, bakery, cereal production and snack food industries. The objective of this thesis was to investigate the applicability of extrusion-drying combination process in developing fruit products for special needs without the use of cereal or pulse flours. The ability of the extrusion process to retain the quality parameters of the raw material in the final product and the application of extrusion processing to develop healthy food products with benefits for special needs were demonstrated.

The specific research was carried out in two stages, the first part was mainly focused on developing licorice type fruit candy with high protein under optimised processing conditions using freeze dried mango powder, pineapple, almond flour, whey protein and potato starch as main ingredients. Based on the processing conditions optimized in the first part, a study was carried out with some changes in the temperature conditions of extrusion for the development of an instant porridge mix. The results and findings of this research are summarized below:

The effect of temperature and screw speed on fruit formulation was found to be high thus the severity of the processing conditions was kept optimal. The temperature range was kept between 60-140^{O}C for both products in order to minimize the caramelization effect. The physical and chemical characteristics of the developed products were measured. In high protein licorice type candy the higher amount of fruit content was found to affect the texture, color, and antioxidant value and water activity of the product. The antioxidant value, firmness, color and water activity were found to increase with an increase in fruit content however there was a decrease in the toughness value with an increase in fruit content. Interestingly, in the fruit porridge the expansion ratio, bulk density and rehydration ratio were found to increase with an increase in fruit content. Banana flour tends to impart darker color to the final product, also the hardness was increased with an increase in banana flour content. The formulation variables significantly influenced the subsequent drying process. Increased fruit content in the product increased the drying time when the final end point was based on achieving a water activity below 0.75. Increasing the protein content decreased the drying time of the product.

The ultimate objective of this product development product was to ensure good sensory quality and adequate comparison to the quality of similar market products. The results from the present study suggest that both the developed products licorice type fruit candy and fruit porridge mix could be obtained with superior sensory quality by the application of appropriate extrusion-drying conditions and optimizing the amount of raw material used in the formulation along with superior nutritional values. Also the texture of the developed products was found to be similar to or better than the market product in terms of toughness, firmness and chewiness.

5.2 Suggestions for Future Research

This work demonstrated several interesting results related to product development under specified extrusion conditions. The following are the recommended aspects for future research in extrusion processing on fruit product development.

1. Evaluation of complete nutritional profile of prepared products with regards to special needs requirements.
2. Measuring the quality parameters of the product at different temperature – screw speed combinations.
3. Evaluating the influence of packaging and use of preservatives on the shelf life of developed product using extrusion processing.
4. Preparing diets for other special need requirements.
5. Carrying out feeding trials to ascertain the effectiveness of the developed product for the intended purpose.

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