CHAPTER – 16

DEVELOPMENT AND CHARACTERIZATION OF EXTRUDED SNACKS ENRICHED WITH GREEN LEAFY VEGETABLES

16.1. INTRODUCTION

Expanded crisp porous snacks are gaining recognition as well as appreciation these days due to their ready-to-eat nature, delicious taste and appealing look. These snacks have low nutritional value therefore it requires some improvement from functional point of view. Functionality is the key to these applications. Starch is the principle component of the extruded snacks, which is primarily responsible for their structural attributes. The chief sources of starch include rice, wheat, corn, oat, etc. Riaz (2000) found that starch based cereals exhibited change in patterns during extrusion. Digestibility of starch is basically dependent upon gelatinization profile. The formation of starch–protein complexes results in decreasing the protein solubility and enhancing the protein content (Wlodarczyk-Stasiak and Jamroz, 2008). Starch conversion has been discovered during extrusion (El-Samahy et al., 2007; Shirani and Ganesharanee, 2009). Starch provides substantial source of energy in our diet. Extrusion is a high-temperature short-time (HTST) cooking process that comprises of several unit operations including mixing, kneading, shearing, cooking, shaping and forming. Extrusion cooking is extensively used in starch–protein processing for the production of ready-to-eat extruded products. Ready-to-eat cereals, pet foods, confectionery products, all type-breakfast cereals, baby foods, macaroni-pasta products, extruded bread, modified starches, beverage powders, meat and cheese analogues, textured vegetable protein, blended foods such as corn starch, ground
meats are the popular snack foods among all age groups (Lui and Peng, 2005; Włodarczyk-Stasiak and Jamroz, 2008).

A basic transformation in extruded products includes starch gelatinization, protein denaturation and degradation of vitamins and pigments (Ding et al., 2006). High pressure, temperature and the shear forces during extrusion cooking disrupt starch granules and are responsible for the final structure. Higher the amylose content in starch, the additional energy is required to form a stiff gel, which leads to the formation of hard, less expanded extrudates. This improves retrogradation tendency by forming fragments which are enough soluble as shown in figure 16.1 (Kljak et al., 2015). A semi crystalline starch granules results in the expansion of extrudate, as the material passes through the extruder die and reaches the atmospheric temperature and pressure. Heat and shear during extrusion, changes the conformation of amino acid chain of protein and allows the alignment of denatured protein molecules in the direction of flow through extruder die. As a result, proteins form fibril type networks or insoluble protein aggregates that indulges to have unique functional characteristics and ultimately leads to good textural properties. Slight proteinaceous transformations occurred in corn or rice based extrudates, protein-rich source may be added to enhance such transformations leading to structural changes and nutritional benefits (Pitts et al., 2014). Thus, another important consequence next to starch transformation (gelatinization) is proteinaceous transformation (denaturation) during extrusion processing (Chang et al., 2011), which can basically be characterized by denaturation of amino acid chains.

During extrusion cooking, the changes in insoluble dietary fiber (IDF) were observed as a consequence of glycosidic bonds breakdown in long molecular chains and also depolymerization of long chain macromolecules of IDF (Jing and Chi,
2013; Li et al., 2012). The alteration in dietary fiber profile during extrusion may be attributed to soluble dietary fiber (SDF) formation from insoluble dietary fiber, formation of resistant starch and formation of transglycosidation based enzyme resistant indigestible glucans (Stojceska et al., 2009). The advantage of increased SDF in extruded foods is due to soluble fiber. Viscous gel (gelatinization) resulted from soluble fiber in small intestine slows down the glucose absorption, thus helps diabetic patients (Riaz, 2000). SDF is soluble in water and thus fermented by bacteria and stimulates colonic fermentation, reduces postprandial blood glucose as well as preprandial cholesterol levels, prevents constipation, facilitate toxin removal from the body and referred as anti-cancerous agents. IDF brings several health benefits like increasing bowel movement, protection against colorectal cancer and improves gut peristalsis (Elleuch et al., 2011). Consequently, the IDF degradation will results in enhancing the solubility of the dietary fiber. Both SDF and IDF have their own health benefits. (Jing and Chi, 2013). Plant materials are constantly rich sources of DF, which decreases the risks of diseases like diabetes mellitus, cancer and cardiovascular diseases (Long et al., 2014).

Various studies have been carried out by researchers to identify the optimum extruder conditions (temperature, moisture, pressure, frequency, feed rate) for better product recovery and maximum nutrient retention. Thermal and chemical processes are used to improve certain physicochemical properties, including conversion to SDF content of fibrous plant components (Cho, 2001; Long et al., 2014). Other aspects include modification of structure, improving the solubility, swelling power, water hydration, viscosity, and water holding capacity (WHC) are used to improve the various physicochemical properties of fibrous materials. The food components (14-
20% moisture) in the extruder barrel have to withstand high temperature, shear and pressure (Chang et al., 2011).

There are mainly two sources from which extruded products are prepared viz. rice meal and corn meal. Consumers like the unique texture and taste of corn (Zea mays). Therefore, several snack foods are prepared from corn. Corn contains 9.08% protein with 355 cal energy and appropriate amounts of other macro and micro nutrients (Santosa et al., 2008). Rice (Oryza sativa) flour is a desired ingredient in the extrusion industry due to its taste, white color, hypoallergenicity and ease of digestion (Kumar et al., 2010). Although the cost of rice is higher than that of corn and wheat, its application in value-added products could give the industry new advances, thus accelerating its demand. Distinctive functional properties of rice make it a desirable grain to be utilized in value-added products. Rice has different glycemic responses in different individuals (Wolever et al., 1990). It is being governed by various factors, such as amylose content, cultivar, processing, and cooking time. Rice contains 6.75% protein, 0.14% fat, 0.28% ash, 81.80% carbohydrate and 0.80% fiber (Shoar et al., 2010). Paddy is basically consumed in the form of rice, acquired from primary processing with the removal of husk. The by-products of rice milling include rice broken, rice husk and rice bran, which are generally underutilized. The rice broken was processed to rice flour, which was used by several researchers to develop extrudates due to its higher expansion. This may be due to higher starch content. Rice grains were first milled, grinded and sieved into different particle sizes, prior to be processed into various traditional products, breakfast cereals, snacks, and other extruded products (Kohlwey et al., 1995; Juliano and Hicks, 1996). The particle size distribution of rice flour also plays a salient role in its functional properties and ultimately the quality of end products (Chen et al., 1999). Rice flour has sober taste
and is almost odorless, colorless with hypo-allergenic properties. Rice flour came out to be the most suitable cereal to make gluten free products. (Gujral et al., 2003; Gujral & Rosell, 2004; Lopez et al., 2004).

Cereal grains being of lower protein content (apart from lysine), have a poor biological value due to their limiting amount of essential amino acid content. They are usually fortified with lysine or pulse protein to produce nutritious snack foods to attain the protein requirement. Shirani and Ganesharanee (2009) used chick-pea flour as one of the ingredient to improvise the functionality of cereal flours (like rice flour or corn flour). It can replace the limitation of lower protein content in pure cereal based expanded snacks.

Chickpea (Cicer arietinum) is a legume, widely used as functional ingredient in the food market due to its very high protein value (17–22%) in comparison to other legumes. India is the largest producer of chickpea. Chickpea is consumed in various forms like whole seed, sprouted seed, roasted chickpea, tempeh, and canned seed. An evaluation with legume (bean meal: Phaseolus Vulgaris L.) was successfully done to overcome the protein deficiency in snack foods (Korus et al., 2007). Increasing trend of improving dietary standards has accelerating among the educated consumers. Food consumption and life style of people changed and they preferred foods which are rich in nutraceuticals, dietary fibers, natural colorants (chlorophyll, carotenoid, lycopene etc.), minerals, vitamins, low in fat, and free of synthetic food additives (El-Samahy et al., 2007). Incorporation of underutilized food materials of plant origin like fruits and vegetable can improve the nutritional value of snack foods. Green leafy vegetables are rich sources of antioxidants and as per US Food and Drug Administration (FDA) andt can be used to preserve food by retarding deterioration, discoloration or rancidity (Nanditha and Prabhasankar, 2009). It has been reported that the antioxidants present
in foods at low concentrations can help in preventing cell damage, cancer, inflammation, aging and atherosclerosis (Alberto et al., 2012). Lee et al. (1978) found that nearly 30% of carotenoid was retained during extrusion of a corn based snack product at the barrel temperature of approximately 130°C. It is found that 38-73% of β-carotene was degraded during extrusion and the loss of β-carotene was increased with increasing in barrel temperature (125-200°C) and decreasing in barrel moisture (Guzman-Tello and Cheftel, 1990; Ying et al., 2015).

Many researchers across the world have used vegetable and fruit products such as fenugreek leaf, mulberry leaf, asparagus, onion, carrot pomace, tomato, apple, pear, orange, (Chang et al., 2011; Shirani and Ganesharanee, 2009; Charunuch et al., 2008; Shoar et al., 2010) as sources of fiber supplements in refined foods. There are several studies which favors the incorporation of green leafy vegetables in developed products like ready-to-eat expanded extrudates, Mathri, pasta and Thalipeeth (Gupta and Prakash, 2011; Shirani and Ganesharanee, 2009; Charunuch et al., 2008). Many factors are known that affect the quality of the final extruded product, which includes process parameters like extruder type, temperature profile of the barrel section, screw configuration, screw speed, feed rate and feed moisture. Several studies have been reported to optimize the process conditions and researchers have also examined the influence of the product (physical and chemical) parameters. The nutritional properties are important, but the consumer acceptability also depends on the physical and organoleptic properties of the snacks. Shoar et al. (2010) reported that physical parameters are affected by the proportion and type of the available starch, which eventually alters the size of air cells during extrusion. Incorporation of pigment rich substances into extruded snacks changes the chemical composition, by reducing the starch content and adding fiber and probably other polysaccharides. Thus, effect of
feed proportion on product parameters was studied on the basis of physico-chemical properties (weight per unit length, density, lateral expansion, moisture content, hardness, rehydration parameters and antioxidant property) and sensory characteristics of the extruded products, to optimize the proportion of ingredients used to formulate extruded products. Therefore, considering the importance of developing and optimizing extrudates, the present study was carried out to achieve following objectives:

1. To develop and characterize the extrudates
2. To optimize extrudates for achieving quality product using response surface methodology.
3. To study the effect of coating on optimized extrudate
4. To characterize the optimized coated extrudate

![Starch Transformation During Extruder Cooking](image)

*Source: Riaz, 2001*

**Figure 16.1. Depiction of starch transformation during extruder cooking**

### 16.2. Extrusion

#### 16.2.1. Extrusion processing

India has a diversified culture in which food habits differ from one region to other region. In some region, people prefer “Roti” (flat bread) as their daily diet, whereas in other region(s) people prefer boiled rice as their daily diet. Developing a
food product for such a diversified country is really a big deal. The need of Indian people to fulfill their daily calories can be achieved by developing a highly nutritious product. Diabetes obesity and other fatal diseases must be taken into account before developing a product, as these health problems are very common in people across the world. Health problems like chronic heart diseases (CHD), high blood pressure and osteoarthritis are arises due to eating habits and environmental factors. It is also due to consumption of significant amounts of high fat foods or fried foods. A snack food developed using proper ingredients may help to overcome these health related problem. Due to versatile nature of extrusion process, it becomes easy to incorporate functional ingredients to the food products. For this reason, an extruded snack food with additional functional compounds like leaf powders (radish and fenugreek leaves) would not only enhance the nutritional value but also lower the adverse effects of such fatty foods. The principle advantages of extrusion technology as compared to conventional techniques includes adaptability, energy efficiency, product characteristics, low cost, new foods, high productivity and automated control (Riaz, 2000).

An extrusion is a technique of giving desired shape to the mixed raw materials. Extrusion processing is a synergistic effect of a series of unit operations, in which the raw material is inserted in the feeding chamber, which comes out as the final product through the die opening. Extrusion is a process whereas; extruder is equipment which shapes the material to desired form under pressure and temperature. In some cases, further dressings of the product like sprinkling of vegetable oils with some spices may be done to increase the appearance, flavour and taste of the product. According to Harper (1979) and Riaz, (2000), a following terminologies are required to understand food extruder and extrusion processing-
- Feedstock- the mixture to be processed in an extruder.
- Barrel- A pipe like retainer in which screws of extruder turns.
- Screw- which rotates in a tightly fitting cylindrical barrel. Raw ingredients are pre-ground and blended (called pre-conditioning) before being placed in the feeding system of the extrusion screw.
- Flight- the helical upper conveying surface of the screw which pushes the product forward. Working mechanism of the flights is based on the screw pushes the food products forward and mixes the constituents into viscous dough like mass. The characteristic extruded structure to the material comes out due to the cross-linking and/or restructuring due to alignment of long molecules in food constituents and all this happens due to the high shear production in the material by the flights of the screw(s) during the conveying of raw materials.
- Shear- A working, mixing action that not only homogenizes but also heats the conveyed product. The food product is undergone high shear rates (because flights on screw are full) as it is conveyed forward by the action of the screw. The area under high shear rate allows aligning food molecular constituents giving rise to cross-linking, resulting in the extruded foods characteristic texture.
- Root- the solid or shaft part of the screw, around which the flight is wound.
- Vent- small opening in front of die plate in the extruder barrel which allows pressure and steam removal from the product.
- Die- As food mixture material starts moving through the extruder, the pressure within the barrel increases due to a restriction at the barrel discharge. This
termed as die (orifices or shaped openings), where the restriction is caused. Discharge pressures typically varied between 30-60 atm.

16.2.1.2. Extruder classification

Different extrusion equipments are required for processing high intermediate and low moisture feed mixtures. Low moisture extrusion can be executed with single screw or twin screw extruders, but high moisture extrusion can efficiently be performed with a twin screwed extruder. As low moisture extrusion is often used to make ready to eat breakfast cereals and snack foods, so single and twin screwed extruders are being equally used. Process parameters affect the extrudates of both twin screw and single screw extruders. Variables that can be modified using extruder include screw speed, throughput rate, temperature, feed composition and moisture content (Harper, 1979; Riaz, 2000).

As indicated by name, extruder consists of two screws. It is 1.5-2.5 times higher in cost as compared to single screw extruder. But it is having better filling, conveying, mixing, kneading, plasticization facility, uniformity in the finished product also better control of product quality, ability to process at lower moisture level and greater operating range. Twin screw extruders are mostly preferred in industries. Twin screw extruders divided into different zones like melting zone, a mixing zone, a degassing zone and a discharge zone. Again depending on the rotation direction of both the screws, the twin screw extruder may be again categorized as:

- Co-rotating twin screw extruder and
- Counter-rotating twin screw extruder.
In both cases the screws lie side by side to each other. The only difference in mechanism is that, in case of co-rotating twin screw extruder, the screws rotate in the same direction (as shown in the figure) and in case of counter-rotation twin screw extruder, the screws rotate in the opposite direction. The relative direction of rotation of the screws in twin screw extruder may be counter or co-rotating. Extruder with more than one screw is called the multi-screw extruder. Single screw extruder (with one screw) comprises three sections: feed, transition and metering (mixing zone, conveying zone and cooking zone). The extrusion screw sequentially conveys and heat food ingredients and works them into a continuous plasticized mass while rotating in a tightly fitting barrel. The screw can be designed either as a single piece or as a splined shaft that accepts screw sections of varying configurations to increase versatility and reduce the cost of replacing worn sections. When the screw rotates it creates the pumping action. The screw rotating in a tight barrel, creates high shear on the food material, which with the heating effect develops the plasticized mass (Riaz, 2000).

Ram extruder is entirely different from single screw, twin screw and multi screw extruders. This type of extruders has a piston instead of a screw(s) that creates pressure on the feed material when it is pressed and the material comes out through the die opening. The piston is also having a good conveying capacity and can create a high pressure as well. The process of feeding raw material in such type of extrusion is a batch process, and the melting capacity of the extruder is less, as a result these types of extruders are not generally used in industries. Hand extruders for making snack foods in homes or cottage scale industries are more commonly used as ram extruders (Riaz, 2000).
16.2.1.3. Different Parts of the Extruder

Extruder is composed of following principal components. A brief description (Harper, 1979; Harper, 1981; Riaz, 2000) of components is given below:

1. Feeding mechanism

This section of extruder is usually composed of a conical shaped part (hopper) to receive the material to be extruded. To permit a better flow and reduce bridging or to avoid choking of the material, the feeder is equipped with an agitator or a large exit for constant agitation. To regulate the feed rate, one controller presents just behind the hopper. This helps in maintaining constant uninterrupted feeding, which is essential for the proper functioning of the extruder and also to maintain the homogeneity in the quality of the extrudate.

2. Screw

It is the vital part of the extruder, as it helps in regulating the degree of cooking and gelatinization, and also the quality of final product. Screw not only conveys the raw material from the feed section to the die, but also provides necessary pressure and shear to the material to form the structure of the extruded product. The quality of the final product is largely dependent on the screw speed.

3. Barrel or screw sleeves

Barrel is the main part of an extruder. The whole process of extrusion is performed in this section. Barrels hold the screw(s), the heating elements, heat sensors and die. Extruder screw is encased in the barrel and barrel must be sufficient strong to
bear the high pressure developed during extrusion. When the screw(s) rotate, a moderately high pressure generates in the chamber that is why the barrel material should be so selected and should be so thick that, the barrel can bear the pressure during extrusion cooking. Inner surface of the barrel may be smooth or contain grooves. Sleeves have usually straight or spiral grooves. Spiral grooves are more likely to impart high forward flow, while straight one hinder it. The later thus results in lower flow rate, but comparative more mechanical shear.

4. Heating arrangement

Heat is the fuel for the extruder. Heat is supplied through the extruder barrel to the feed during extrusion. Direct heating (by injecting steam) or indirect heating (with electric heaters, mounted on the barrels) is used. Depending upon the material used for extrusion, heat (or temperature) varies. The heat generally produced in an extruder is by the means of electric coils. A series of electric heating coils are arranged in the barrel, with which heating sensors are attached to monitor the temperature digitally. The barrel is also equipped with two water inlet and two outlets to maintain the temperature as well as to avoid damage due to high temperature. Heating may be also done by the injection of steams into the barrel, but that would not be efficient as compared to coils.

5. Die

The end of the screw sleeve is normally equipped with a die. Design of die directly influences the shape and texture of the finished product. It molds the product into the desired shape and works as a flow restrictor to increase the pressure in the cooking zone of extruder. It may be short, long, tapered or straight.
6. Knife or cutting mechanism

Ahead of the die, variable speed rotating knife is utilized for the formation of equal length extrudates. The product length is determined by the speed of cutting knife. Faster the speed, shorter will be the product.

Electric motor also termed as drive, rotates the shaft and the shaft further rotates the screws. The speed of the motor is regulated by a knob. Rotation per minute or RPM is one of the most important variables in every extrusion process which is regulated by that motor.

16.2.1.4 Expansion mechanism

Expansion is the consequence of the pressure difference developed between the inside pressure of the extruder and outside atmospheric pressure. Heat and pressure are developed while passing the food product through a barrel by means of restrictions in screw. There is a sudden decrease in pressure when the product got discharged into the outer atmosphere (out from the die), results in expansion of the product (Arhaliass et al., 2003). Starch cells are ruptured by excess vaporization of moisture. The amount of expansion depends on several factors, such as starch content of the product, inlet-outlet temperature, pressure, and the amount of feed moisture.

16.2.1.5. Bubble growth and bubble collapse

Extrudate expansion is based on the biaxial extension of individual bubbles. Bubble growth relies on the pressure difference between both sides of the barrel (Riaz, 2000). It is generally accepted that surface tension has a minor or negligible effect on expansion of polymer, with little effect on initial expansion. The rheological properties of the polymeric material have leading role in expansion, as they determine
the resistance of the bubble wall to create the pressure difference across interior and exterior of the bubble. Kokini et al., (1992) considered bubble growth in a viscous fluid and interrelated specific volume of the extrudate with the ratio between vapor pressure and melt viscosity. The correlation was poor at higher moisture contents, is due to shrinkage that occurred in the high moisture content extrudates. Cessation of bubble growth has a direct effect on the final texture of the expanded product. When the melt leaves the die orifice and water vapors flashes out, with the drop of temperature due to evaporative cooling, the extrudate which reaches a glassy state after crossing the rubbery region (retro gradation), and expansion stops.

When the bubble wall cannot withstand the pressure inside the bubble, it collapses, typically above 20% moisture content. This phenomenon of bubble collapse is decided by extrusion temperature and material rheological properties. The collapse occurs particularly at low extrusion temperatures. In terms of rheological properties, low melt viscosities facilitates the bubble collapse. As, in the high pressure zone viscous melt obtained from the free flowing feedstock has visco-elastic properties.

16.2.1.6. Extrusion: A unique processing (cooking) technique

Extruded foods and feeds are made from a diverse range of raw materials. These ingredients are similar in their general nature to the ingredients used in all other types of foods and feeds. They contain materials with different functional roles which play important role in the stabilization and formation of the extruded products and also provides preferable colour, flavour and also enhance nutritional qualities in different products. The transformation of raw materials during processing is one of the most important factors that distinguish one food process and food type from one another. For a particular product type, a selection of ingredient is processed through a
set processing regime. If conditions are in the ideal processing range, a stable extrudate will form with the normal product. Extrusion cooking is a specialized form of processing, which is unique in food and feed processing because of the conditions that are used to transform the raw materials.

A first feature that distinguishes extrusion cooking with conventional baking or dough processing is a relatively low moisture addition, generally 10–30% on a wet weight basis. Despite of this low moisture, the mass of raw materials (free flowing or low moisture powder/flour) is transformed into a fluid which is further subjected to a number of operations to mix and transform the native ingredients into new functional forms. Under these unusual process conditions, the physical features of raw materials such as the particle size, hardness and frictional characteristics of powders, lubricity and plasticizing power of fluids become more important than other food and feed processes.

A second feature that distinguishes extrusion cooking from other food processes is the use of very high temperatures, usually in the range 100–180ºC. The use of high temperatures reduces the processing time and allows a full transformation of raw material to its functional form in short duration, generally 30–120s.

Almost all extrusion cooking processes are operated continuously with raw materials that fed into the processing units. All food and feed products have basic structures that are formed by certain elements in the raw materials such as the biopolymers of starch and proteins in baked products or fat and sugar in confectionery. The structural elements form the three dimensional cages or nest of girders in which the other materials are held to form the product texture. Extruded products are formed from the natural biopolymers of raw materials such as cereal or
tuber flours that are rich in starch or oilseed, legumes and other protein-rich sources. The most commonly used materials are wheat and maize flours, but many other materials are also used such as rice flour, rye, potato, oats, barley, sorghum, tapioca, cassava, buckwheat, pea flour and other related materials.

If the extruded products are manufactured as texturized vegetable protein (TVP), the main ingredients will be selected from protein-rich materials such as pressed oilseed cake from soya, sunflower, rape, field bean, fava beans or separated proteins from cereals such as wheat (gluten). The native forms of the biopolymers were not designed for extrusion cooking and must be changed by processing to obtain a more useful polymer. All the natural biopolymers used in the ingredients listed above can be transformed into a fluid melt in the desired temperature and moisture range in an extruder. The skill in controlling the processing is to transform the polymers in a short period of time using the thermo-mechanical processing provided by the screw elements under the control of the die pressure. In a normal recipe, all the ingredients will interact with one another to affect the transformations taking place. Therefore, it is essential to understand the role of each individual material in the recipe and also to study the effect of any variation in an individual ingredient that affects the overall processing performance of the extruder (Guy, 2001).

16.2.2. Raw material for extrusion

16.2.2.1. Rice

Rice is an important cereal crop which forms an indispensable part of the diet worldwide, especially in tropical Latin America, East, South and South-east Asian region. More than one fifth of the calories is provided by rice consumption. In fact, India is the second largest producer of paddy (FAO, 2015). More than 70% of
produced paddy is processed through modern rice mills (71% of rice, 20% of husk and 5-8% of rice brokens and 6-7% of rice bran). In India, rice brokens are consumed as poor man’s staple food which is having the almost similar nutritional significance as that of whole rice. Rice is grown as an annual monocarpic plant, in tropical areas. Edible rice seed is 2–3 mm thick and 5–12 mm long.

Rice (Oryza sativa) is a cereal foodstuff which has importance as a part of diet. The production of rice in India was 131.27 million tonnes in the year 2009 against world production of 678.68 million tonnes (FAO, 2015). Paddy is basically consumed in the form of rice, obtained from primary processing with removal of husk. It contains 20-25% husk, 6% bran, and 75% rice. Rice kernel comprises of endosperm, germ and bran. Endosperm (80-84%) is fermentable, whereas, bran (10-14%) and germ (2-3%) are non-fermentable. The rice broken kernals accounts for 4.92 – 7.87 million tonnes which can have varying percentages (5-8% of whole rice).

The processing of paddy into rice involves the milling process by using shellers, hullers and modern rice mills. Modern rice mills accounts for more than 50%. Shellers and modern rice mills produces by-products (except animal feed), which are having good option for utilization. The major, by-products of rice mills are rice broken, rice husk and rice bran. Rice bran is basically used for extraction of oil; and the oil extracted from the bran is popularly known as rice bran oil (RBO) which is very popular these days. Broken rice, are used in flour form in traditional recipes or as animal feed due to non-availability of technology to convert it into a value added products. There are very lesser number of industrial processes for efficient utilization of broken rice, so there is a wide scope for the researchers to utilize these broken rice into value added product (Kumar, 2010). The rice brokens were ground to rice flour,
which were used by several researchers to develop extrudates as a basic material due to its higher expansion ratio.

**16.2.2.2. Extrusion studies using rice**

Numerous literatures are available on the utilization of rice in the production of extruded food products. The researchers used rice, corn, wheat, barley and other cereal flour for extrusion as a base material. The incorporation of vegetables, fruits and pulse proportions were reported. Gillespie (1971) reported the free flowing starch produced from wheat flour and/or corn flour and/or rice flour and/or potato flour as a substitute product for use in the food industry. The starting material was expanded in a continuous automatic pressure cooker-extruder and then dried, ground and sifted. Buchanan (1975) discussed the development of low cost infant foods in Asia and the product is based on rice, soy flour and sugar with added vitamins and minerals. It was designed as a complete food for infants and was suitable as a snack food for all age people.

Orr (1984) studied the role of twin extrusion cooking in the production of breakfast cereals. The use of twin-screw extruder cookers for manufacturing of flaked and expanded breakfast cereals was discussed. The fine maize grits or rice flour was suggested to be used instead of more expensive large grits or whole grains.

Rice flour and flours prepared from legumes (soybean, bengal gram, green gram, black gram) were mixed (rice: legume ratio, 75:25) and finally extruded in a Wenger X-5 extruder. Products were analyzed for expansion ratio, density, water absorption index, water solubility index, fracturability and breaking strength. The best quality product was obtained by extruding a rice bengal gram mixture at a feed rate of 27.2 kg/h with an exit temperature of 95 ± 2°C (Chauhan and Bains, 1988). Ruales et al.,
(1988) studied the nutritional quality of blended extruded foods of rice, soy and lupins. In the study, raw materials used were grits from polished rice (8-40 mesh), grits of dehulled soybeans (10-40 mesh), and debittered lupin flour. Rice: soybean (80:20 w/w) and rice: lupin (80:20 w/w) blends were adjusted to a moisture content of 22% and extruded in a single-screw extruder. The products obtained were ground to a particle size of 60 mesh and stored in nylon-polyethylene bags at 4°C prior to analysis for moisture, protein, carbohydrate, ash, fat, starch, dietary fiber, starch availability, minerals (Zn, Fe, Ca, Mg, Cu), nutrient density, fatty acid composition and amino acid composition.

The particle size and moisture content of rice flour affect the physical properties of the extrudate. The effect of moisture content (17-28%) and particle size (18-120 mesh) of rice flour on physical properties of extrudates were examined, using an autogenous single screw extruder. Expansion ratio increased and bulk density decreased as moisture content and particle size decreased. Cutting force decreased and air cell size became uniform as moisture content and particle size decreased. As moisture content increased, the yellowness and the water solubility index of extrudates decreased, while the lightness and the apparent viscosity increased. The degree of dextrinization was regulated by moisture content and particle size (Ryu and Lee, 1988).

Maga and Kim (1989) studied the co-extrusion of rice flour along with dried fruits and fruit juice concentrates. Dried fruits paste (prunes, raisins, figs and cranberries) at levels of 0, 10 and 20% and non-reconstituted juice concentrates (orange, pineapple, cranberry and grape) at levels of 0, 3.5 and 7.0% were blended with rice flour and water. The various extrudate properties (yield, density, expansion ratio, color, pH and overall sensory acceptability) were observed. Results indicated
that the extrudates containing dried fruits or juice concentrates compared favorably to those produced exclusively from rice. Incorporation of the vegetables, fruits and concentrates produced a significant reduction in extruder torque. Kim et al., (1989) studied the characteristics of extruded dried distiller grains (DDG) and flour blends. The longitudinal expansion index of extrudates increased significantly with increasing DDG.

Visessurakarn et al., (1991) studied the extrusion cooking of breakfast cereals by the use of rice brokens. Processing conditions for developing a broken rice-based breakfast cereal were: extruder temperature of 180°C; 2mm die; and initial moisture content of raw mix, 13%. The proportions of ingredients giving the highest acceptability score were: flour mix (comprising equal ratios of broken rice and maize flours) 83.8%, sugar 15%, salt 1% and cocoa powder 0.2%. This formulation per 100 g contains 3.63 g protein; 2.2 g fat; 2 g ash; 0.02, 0.02 and 0.8 mg vitamins B1, B2 and niacin, respectively; 3.0 mg Fe and 5.6% moisture. Moreover, this gives an acceptability score of 6.90 ± 0.79 on a 9-point hedonic test scale.

Abdel et al., (1992) examined the effect of extrusion cooking on the physical and functional properties of wheat, rice and faba bean blends. Blends of wheat flour/faba bean meal (W/F) and rice flour/faba bean protein concentrate (R/FP) were extruded in a laboratory Brabender extruder. Higher temperature affects the physical properties of wheat flour to faba bean meal. R/FP extrudates showed no effects when processed at higher moisture and temperature levels. Ming et al., (1993) studied the various factors affecting starch degradation of rice extruded by a twin-screw extruder. The effects of processing variables (feed moisture content, 11-19%; feed rate, 332-576 g/min; barrel temperature and screw speed and 110-210 rpm), flour particle size, rice varieties, and additives (monoglyceride, salt, sucrose and soy protein isolate) on
starch degradation in extruded rice flour were observed. Degree of starch degradation was determined using water solubility index (WSI), water soluble carbohydrate (WSC) and total dextrins (TD). WSI, WSC and TD increased with increasing screw speed and decreasing feed moisture content.

Bhattacharya and Prakash (1994) applied response surface methodology to design the experimental combination of blends of rice and chick pea flours. The extrusion process variables were: feed ratio, and temperature of die. Amalgamation of chick pea into rice flour decreased the torque and product expansion, while bulk density and shear strength increased. The temperature parameter had a linear effect on these parameters. Lee and Han (1997) optimized the extrusion process of rice, soy protein and fish mixture by response surface methodology. The effects of raw material composition, feed moisture content and die temperature on chemical, physical and sensory properties of extrudates produced by a single-screw extruder from mixtures of rice flour, isolated soy protein and file fish were evaluated. The extrudate prepared at die temperature greater than or equal to 130°C gave the highest sensory scores.

Ascheri et al., (1998) prepared snacks from mixtures of sweet potato flours and rice by applying thermoplastic extrusion. Response surface methodology was employed to determine effects of independent processing variables (feed moisture content, extruder temperature, mix formulation) on paste viscosity during extrusion. Initial paste viscosity (Brabender units) at 25°C and final viscosity at 50°C were highest in the rice snack mix and lowest in sweet potato alone. Hardness was also significantly affected by formulation and moisture content. Hardness was lower in rice than in sweet potato snacks. Water absorption and water solubility indices were affected by both formulation and moisture content. Sensory scores for flavour,
hardness and crunchiness were significantly higher ($P \leq 0.05$) for the rice snack as compared to the snacks prepared using 50 and 100% sweet potato flour. Overall, it was concluded that inclusion of sweet potato flour in extruded snacks made from rice flour had an adverse effect on their functional and sensory properties.

Yeh and Jaw (1999) studied the effects of feed rate and screw speed on extrudate properties and operating characteristics during single-screw extrusion cooking of rice flour. Rice flour was used as principle ingredient to inspect the effects of screw speed and feed rate on the specific energy input during single-screw extrusion cooking. Banerjee and Chakraborty (2000) revealed the thermal and shear effect on pressure requirement, extrusion energy and viscosity of dough. Effects of moisture and shear rate on rheological properties of the rice flour were also studied. Moisture content 15, 21, 27% (wet basis), extruder barrel temperature (120, 150, 180°C) and extruder screw speeds (100, 150, 200) rpm were considered as input variables. Screw speed was observed to be directly proportional to pressure and power requirement. Viscosity of the extruded dough increased with shear rate.

Guha et al., (2003) studied the impact of extrusion variables on the system parameters during extrusion of rice flour. The variables studied are mixing disk (MD) and reverse pitch screw element (RPSE); feed variables such as amylose content, sugar, salt and moisture of the feed and rice flour particle size; and extrusion operating variables such as barrel temp., feed rate and screw speed. Results showed that MD and RPSE affects the extrusion and extrudate properties. Marked effects were obtained for amylose, moisture content, feed rate, screw speed and barrel temperature. It was concluded that experimental design based on the Plackett-Burman theory can be applied efficiently to screen a large number of extrusion variables including discrete variables.
Mouquet et al., (2003) tested the ability of a 'very low-cost extruder' to produce instant infant flours at a small scale in Vietnam. Premixes containing rice (49.9-52.4%), soybeans (0-27.1%) and sesame seeds (0-5.7%) were extruded in this study. Extrusion of rice-sesame blends with low lipid and water contents (less than 6% dry basis and 10% wet basis, respectively) led to total starch gelatinization. Addition of soybean flour to extruded rice-sesame blends, together with milk powder, sugar, minerals and vitamins, resulted in a product with the appropriate macro and micronutrient balance. Young and Schwarz (2004) studied the physical and cooking properties of restructured grain extruded from selected cereal and legume flours. The cooking and physical properties of restructured grain (RGR) extruded from various cereal flours and legume meals were also investigated. RGR products were prepared, using a twin screw extruder, from brown rice, pearl barley, whole wheat, sorghum, foxtail millet, soybeans and adzuki beans. Changes in hardness of cooked RGR occurred slowly at 25°C and rapidly at 4°C.

Ding et al., (2005) examined the influence of extrusion conditions like feed rate, feed moisture content, screw speed, as well as the barrel temperature on the physicochemical properties (density, expansion, water absorption index (WAI), water solubility index (WSI) and sensory characteristics (hardness and crispness) of expanded rice snack. Accelerating feed rate results in higher expansion, lower WSI, and higher hardness, whereas increasing feed moisture content produced extrudates with a higher density, lower expansion, lower WSI, higher WAI, lower crispness and higher hardness. Speed of screw imparts marked effect on ant of the sensory and physicochemical characteristics of the extrudate.

Ding et al., (2006) also investigated effect of extrusion conditions on the functional properties (expansion, density, water absorption index (WAI), water
solubility index (WSI) and physical properties (density, expansion and textural characteristics). Similarly, Iabnoglu et al., (2006) investigated the effect of processing parameters on the expansion ratio, firmness, colour and sensory properties of a nutritionally balanced gluten-free extruded snack. Pansawat et al., (2008) extruded a formulation containing fish powder, rice flour, menhaden oil and vitamin E using a co-rotating twin-screw extruder at a feed rate of 10 kg/h. Primary extrusion (independent) variables were screw speed, temperature, and feed moisture. Feed moisture and screw speed decreased the pressure at the die, where as increased screw speed increased the product temperature at the die. Product density increased as feed moisture increased, but decreased with screw speed. Feed moisture, higher barrel temperature and screw speed decreased the motor torque whereas, screw speed increased the specific mechanical energy.

Stojceska et al., (2008) incorporated cauliflower by-products in cereal based ready-to-eat snacks as a new source of dietary fibre, antioxidants and proteins. Cauliflower powders at levels of 5–20% were formulated. The effect of cauliflower co-products on textural and nutritional characteristics and the processing effect on these parameters were studied. The incorporation of cauliflower powder significantly increased the dietary fibre and protein content. Sensory results indicated that cauliflower could be incorporated into ready-to-eat expanded products up to the level of 10%.

Yagci and Gogus (2008) applied response surface methodology to investigate the effects of extrusion conditions on moisture content, temperature, screw speed and also examine the changes in feed composition of the extruded snack food based on rice grit (in combination with fruit waste, durum clear flour and PDHF). The variability in process conditions affects the physical and functional properties of
extruded snacks. The sensory results revealed the production of acceptable extruded snacks prepared from the PDHF, fruit waste and durum clear flour in combination with rice grits.

Study was done with barley flour by adding functionalities via grape pomace (Altan et al., 2008b) and tomato pomace (Altan et al., 2008a) extruded in a co-rotating twin-screw extruder. Response surface methodology was employed to evaluate the independent variables, like die temperature, screw speed and pomace level on product responses (expansion, bulk density, texture and color). The product responses were affected by changes in temperature, pomace level and screw speed. The results suggested the production of acceptable barley flour and grape pomace based extruded snack food. The results indicated that tomato pomace can be extruded with barley flour to obtain an acceptable and nutritional snack.

Chakraborty and Banerjee, (2009) applied response surface methodology to study the effect of feed moisture and metering zone temperature on physical properties of extrudate. Moisture and temperature had significant effect on expansion ratio, which decreased significantly with increasing moisture content. The viscosity of rice green gram dough decreased which results in lesser power consumption due to increase in screw speed. Shirani and Ganesharanee, (2009) incorporated fenugreek polysaccharide for better physical and sensory quality characteristics of chickpea rice based extruded products with blending of 70:30 chickpea and rice. The extruded products were examined for their physical (moisture retention, hardness, expansion, water solubility index and water absorption index), sensory (texture, flavor, color, and overall acceptability) characteristics to evaluate their suitability as extruded snack products. Due to the bitter taste of fenugreek flour its incorporation was not accepted at levels more than 2% in extruded chickpea based products. The incorporation of
fenugreek, in the form of debittered polysaccharide was reported up to a level of 15% in a chickpea rice blend to get extrudates of acceptable physical and sensory properties.

Many researchers across the world have used vegetable and fruit products such as fenugreek leaf, mulberry leaf, asparagus, onion, carrot pomace, tomato, apple, pear, orange, (Chang et al., 2011; Shirani and Ganesharanee, 2009; Charunuch et al., 2008; Shoar et al., 2010) as sources of fibre supplements in refined food. Several studies favors the incorporation of green leafy vegetables in developed products like ready-to-eat expanded extrudates, Mathri, pasta and Thalipeeth (Gupta and Prakash, 2011; Shirani and Ganesharanee, 2009; Charunuch et al., 2008). Shoar et al. (2010) reported that physico-chemical parameters are related to the proportion and type of the available starch as it affects the size and number of air cells developed during extrusion. Fenugreek leaf powder as one of the ingredient of spice mix also has remarkable advantage for imparting sensory attributes and nutritional benefits (Ankita and Prasad, 2015a). Naidu et al. (2012) reported the role of fenugreek in lowering glycemic index.

16.2.3. Maize

Maize is one of the very important cereal grains in the world market after wheat and rice that provides nutrients to humans and animals. It serves as a common raw material for the production of starch (called corn starch), alcoholic beverages, oil and protein, food sweeteners (corn syrup and high fructose corn syrup (HFCS)) and more recently fuel. Maize is consumed in many forms in different parts of the world in the form of maize grits, polenta, corn bread, popcorn and maize flakes. The nutritional content of maize kernel is as follows: starch, 75%; protein, 8.9%; oil, 4%;
ash, 1.5%; sugars, 1.7%; fibers, 8.9% (www.bungemilling.com). Numerous literatures are available on the utilization of maize in the production of extruded food products.

16.2.3.1. Extrusion studies using maize

Garbar et al., (1997) studied that torque, specific mechanical energy and product temperature, and observed that there was no significant changes within the particle-size range (100–1,000 μm) but for each parameter, value dropped remarkably as the particle size increased above 1,000 μm. The highest moisture level, largest particle size (1,622 μm) and lowest screw speeds were the factors which results in 97.5% starch transformation (gelatinization). These conditions also showed the least expansion ratio and gave the hardest product.

Ilo and Berghofer (1999) reported the colour kinetics changes for yellow maize grits during extrusion cooking. Lightness (L*) and redness (a*) values depends on feed moisture content and barrel temperature. The yellowness parameter (b*) slightly depends on extrusion variables. Lightness parameter (L*) showed noticeable changes due to extrusion cooking and was selected as the best parameter in the modelling of extrudate during browning kinetics study. Rzedzicki et al., (2000) reported the influence of the moisture content on raw material. The physical properties of extrudates obtained from corn, semolina and oat bran, which was extruded using single screw extrusion cooker indicated that higher process temperature would lowered the water absorption of the product. The water absorption index increased with increase in moisture content of raw material and oat bran percentage. Higher bran content altered the density and also lowered the level of extrudate expansion.
Katiba Mezreb et al., (2003) reported the structural properties of two types of extruded flour products obtained from maize and wheat flour blend. Results showed that the increase in screw speed resulted in higher water solubility, greater longitudinal expansion and smaller structural patterns of the product. However, differences between the wheat and corn extrudates were evident at the various screw speeds examined.

Onyango et al., (2004) studied the effects of sucrose, glucose, fructose, maltose, feed moisture and screw speed on extrusion of lactic fermented and dried maize–finger millet blend. Results indicated that fermentation caused a reduction in expansion ratio, flour bulk density and water absorption index, but increased the specific volume, water solubility index and also darkened the extrudates. Increase in feed moisture reduced the expansion ratio, specific volume and yellowness but increased the extrudate bulk density, moisture content and darkness of the extrudates. An increase in sugar content reduced the moisture content, expansion ratio, water absorption index and specific volume of extrudates but increased the water solubility index and bulk density. The extrudates treated with monosaccharides were darker than extrudates treated with disaccharides.

Cristinadiaspaes and Maga, (2004) examined the effect of extrusion on essential amino acids profile and colour parameters of the whole-grain flours of Quality Protein Maize (QPM) and normal maize based extrudates. Extrusion diminishes the contents of the essential amino acids like isoleucine, leucine, lysine, threonine and valine as compared to their original flours (P < 0.05). Histidine, methionine, phenylalanine and tryptophan were not dissimilar for flours and extrudates of the same source (P > 0.05). QPM samples, either raw or extruded were significantly higher in lysine, methionine and tryptophan as compared to samples
obtained from normal maize ($P < 0.05$). Extrudates made from yellow QPM flours were lighter in color than their correspondent raw material ($P < 0.05$), which is different from that of yellow maize. This trend was also observed for redness ($a^*$ values) in extrudates, whereas white and yellow extrudates presented higher $b$ values (yellowness) as compared to their corresponding raw flour. The use of QPM flours in replacement of normal maize flours could provide maize extrudates with superior protein quality.

Thymi et al., (2005) reported the effect of varying feed rate, screw speed, product temperature and feed moisture content on structural properties of extruded corn grits. The apparent density, expansion ratio and porosity of extrudates were rely on feed moisture content, residence time and temperature and have not been affected by screw speed. More specifically, the apparent density of extruded products shows an increasing trend with feed moisture content and residence time while it decreased with the product temperature. Porosity and expansion ratio both parameters decreased significantly with feed moisture content and residence time while increase in temperature results in product of higher porosity and expansion ratio.

Aguilar-Palazuelos et al., (2006) studied the effects of extrusion barrel temperature and feed moisture content on the production of third-generation snacks expanded by microwave heating. A blend of potato starch, quality protein maize (QPM) and soybean meal (SM) was used in the development of the snacks by single screw extruder with RSM using central composite rotatable experimental design. The results indicated increased expansion ratio and decreased bulk density values with increase in barrel temperature.
Perez et al., (2008) reported the effects of endosperm hardness and extrusion condition on expanded product quality and flour dispersion viscosity value of an extruded maize/soybean (88/12) mixture. For the 88/12 (maize/soybean) mixture, it was observed that softer maize endosperm produce a more expanded product than the harder one. Texture scores were directly related with specific volume. The best extrusion conditions to obtain expanded products and precooked flour from an 88/12 maize/soybean mixture were 170°C and 14% moisture.

Mesa et al., (2009) blended the soy protein supplementation to increase the nutritional value of starch-based expanded snacks. Physical and microstructural properties of native corn starch–soy protein concentrate (CS–SPC) extrudates were studied with respect to the macromolecular changes in starch during extrusion. The effects of extruder screw speed (230 and 330 rpm) and SPC concentration (0, 5, 10, 15 and 20%) on various parameters were determined. Increasing the screw speed resulted in higher expansion, specific mechanical energy (SME) and lower mechanical strength while addition of 5–20% SPC led to lower SME and expansion, and higher mechanical strength. X-ray micrographs display smaller yet more number of cells, and the more thickening of cell wall with SPC addition. Hence, there is effect on rehydration properties as water absorption index increased and also water solubility index decreased with increase in the screw speed and SPC level.

16.2.4. Chick pea

India is the largest producer of chickpea. The country produced 6.33 million metric tons of paddy in 2007-2008 (FAO, 2015). Chickpea is mainly consumed in dhal form or flour obtained from primary processing. Kabuli types are grown in the temperate regions while the desi type chickpea is cultivated in the semi-arid tropics.
(Muehlbauer and Singh, 1987). Chickpea is grown in tropical, sub-tropical and temperate regions. Chickpea is consumed in various forms some of which are described below.

1. **Whole seed:** Chickpea is utilized for its nutritive seeds with high protein content, 25.3-28.9 %, after dehulling (Hulse, 1991; Huisman and Van der poel, 1994). The dry chick pea seeds are soaked overnight and cooked with salt and spices. The boiled seeds are fried with spices and are eaten with cereals, mostly in Africa. Chickpea seeds are consumed fresh as vegetables, fried, parched, roasted, and boiled; as snack food, sweet and condiments; seeds are ground and the flour is utilized as soup, dhal, and to make bread; prepared with pepper, salt and lemon it is served as a side dish.

2. **Sprouted seed:** The seeds are soaked in water and allowed to sprout overnight for 12 hours. The sprouted seeds are eaten raw or cooked form (Aykroyd and Doughty, 1982).

3. **Roasted chick pea:** Seeds are soaked in water for 1 h and dried and consumed particularly in eastern part India. The dried seeds are then mixed with little oil and water, and again dried. This dried seeds are roasted on heated sand.

4. **Tempeh:** This is prepared in combination with soybean. Tempeh is prepared by fermenting soaked, dehulled, and cooked chick pea seed with a Rhizopus mould. These seeds are spread on a mesh and the mould is grown on the surface and through the seed, forming a compact cake. The tempeh cake is cut into small pieces and fried before consumption.

5. **Canned seed:** The dried seeds are soaked in water for 24 h then cooked in the brine solution (very salty water) prior to canning. A small proportion of canned chickpea is utilized in Turkey and Latin America to develop fermented food.
16.2.4.1. Processing and byproducts

The processing of peas to dhal involves the milling by using hullers, shellers and modern dhal mills (>50%). The by-products from the hullers have limited option to convert it into a value added products. The sheller and modern dhal mills generate by-products, which have an excellent option for utilization. The main by-products of dhal mills are gram broken, husk and dhal flour, which do not have mass acceptability in the country. Husk is utilized for making steam hard board etc. Dhal brokens are mainly used for flour production; and the flour is popularly known as Besan (Chickpea flour). Broken dhal are used as animal feed possibly due to non-availability of technology for its conversion to value added products. There are no major industrial processes for efficient utilization of broken dhal, so there is wide scope for the research which utilizes these broken dhal and flour.

16.2.4.1.2. Dhal and Dhal mill by-products

The cotyledons of dry seeds excluding the seed coat are called dhal. In India and other Asian countries, chick pea is also consumed as dhal. Dhal is popular because it takes less time to prepare with acceptable appearance, texture, palatability, digestibility, and overall nutritional quality.

When chick pea seed is processed to make dhal, its recovery ranges between 70 and 75%. The by-product (25-30%) (chunf) remaining is used as a good source of concentrate ratio to cattle. This by-product usually consists of 3-8% broken cotyledons, 5.5 - 6.1% powder, and 15% husk. Chunf is utilized by dairy owners or feed mills to prepare cattle feed. Powder and broken cotyledons are valuable sources of protein for cattle and poultry, and are sold at a higher price (Kurien and Parpia 1968). Bhattacharya and Prakash (1994) applied response surface methodology to
design the experimental combination of blends of rice and chick pea flours. Blends of rice and chick pea flours (containing 20% moisture), were extruded through a single-screw extruder. The extrusion process variables were: (i) feed ratio, and (ii) temperature of die. Addition of chick pea into rice flour results in reduction in torque and product expansion, but bulk density and shear strength, increased. Shirani and Ganesharanee (2009) included fenugreek polysaccharide for the physical and sensory characteristics of chickpea rice based extruded products. Based on preliminary assessment with proportions of chick pea and rice with a blend of 70:30 chickpea and rice was taken as the control for further studies. Control blend was then replaced with fenugreek flour at 2%, 5% and 10%, or fenugreek polysaccharide at 5%, 10%, 15% and 20%, was being extruded at the optimum processing conditions. The extruded products were assessed for their physical (expansion, hardness, moisture retention, water solubility index and water absorption index), sensory (flavor, texture, color and overall acceptability) characteristics to evaluate their suitability as extruded snack products. Owing to the bitter taste, addition of fenugreek flour was not considered acceptable at levels above 2% in chickpea based extruded products. The incorporation of fenugreek, in the form of debittered polysaccharide was suggested up to a level of 15% in a chickpea based rice blend to develop snack products of satisfactory physical and sensory properties.

16.2.5. Factors affecting the characteristics of extrudate products

16.2.5.1. Starch

It is the main component that provides the underlying structure of the finished product (Guy, 2001). Starch acts as the dominant polymer in most cereal systems, which plays a major role in expansion. The lower limit of starch content for good
expansion is 60 to 70%. Starch is made of amylose and amylopectin, which creates differences in expansion. Mercier and Feillet (1975) reported that higher amylopectin content help to develop light, elastic and homogeneous expanded textures, while higher amylose content results in less expanded and hard extrudates. According to some studies, 50% amylose leads to maximum expansion of starch. Amylopectin rich starches expand more than amylose based starches as the linear amylose chains align themselves in the shear field areas and consequently are difficult to pull apart during expansion. Amylopectin starches, at same moisture content are not as hard as amylose favoring their expansion (Kokini et al., 1992; Della Valle et al., 1997).

Starch granules are gelatinized and dispersed during extrusion, resulting in the formation of a continuous phase of the melt inside the extruder. Average molecular weight is decreased, which allows for optimum formation and stability of air cells at the die exit. Both amylose and amylopectin are needed to give the best expansion characteristics (Huber 2001).

16.2.5.2. Moisture

Water is the basic ingredient and main plasticizer in extrusion. It is needed for starch gelatinization and dispersion of ingredients. It aids in the formation of a viscous fluid from a free flowing form that is conveyed and cooked. Lowering down the moisture content of feed resulted in higher viscosity. Further, less moisture content in the product results in reducing the degree of expansion and hence, higher bulk density and smaller volume is achieved (Ding et al., 2005).
16.2.5.3. Fiber

Fibrous materials such as bran are part of the dispersed phase of extrudates, embedded in the starchy continuous phase (Guy, 2001). Fiber is chemically unaltered by the process, and it affects expansion of the product (Huber, 2001). The effect of fibers on extrudate expansion seems to be concentration dependent. Radial and axial expansion of rice flour extrudates increased with the addition 10% rice bran but decreased at higher levels (20% and 30%). It is reported that increasing the oat or wheat bran content in cornmeal up to 20% and 30% respectively, increased the bulk density and longitudinal expansion, but decreased the radial expansion. Similar observation were also reported for extruded cornmeal with added beet fiber (Lue et al., 2000). It is likely that at small concentration, the long and stiff fiber molecules align in the direction of flow in the extruder, reinforcing the expansion of feed material and uplifting its mechanical resistance in longitudinal direction.

The structural anisotropy becomes detrimental to the biaxial extensional properties of the extrudates, thereby lowering their radial expansion. Above a critical concentration, the fiber molecules interrupt the continuous structure of the melt, impeding its elastic deformation at the time of expansion. Fiber binds with the moisture present in the matrix, thus reducing its availability for expansion. Generally, soluble dietary fibres (SDF) and insoluble dietary fibres (IDF) are required by the body in the ratio 1:3.

16.2.5.4. Protein

Protein is one of the important contributing factors which influence the quality characteristics of extruded products as they related to structural integrity of protein matrix. Many types of proteins and protein enrichments may be added to extruded
snacks such as meat, dairy products and legume proteins. During extrusion, protein structures get disrupted under pressure, high shear and temperature (Harper, 1981). Protein solubility decreases with cross-linking reactions and covalent bonds formed at high temperatures (Areas, 1992).

The type of protein and additives added to the mix has an important impact on texture of the final product. During extrusion, polysaccharides form a separate phase which enhances protein aggregation in the direction of extrusion and reduce it in the direction perpendicular to extrusion. Protein–protein interactions may be enhanced by decreasing the temperature and secondly by macromolecular alignment. The crystalline aggregation tends to formation of parallel fibers of varying thickness and length. The interaction energy is possible for cross-linking of protein and other molecules due to the diversity of the amino acids. Therefore, hydrophobic, cation–mediated electrostatic interactions and covalent bonds also contribute to the stabilization of the network formed after extrusion (Areas, 1992). Previous researches claimed that new peptide bonds were responsible for extrudate structure and disulfide bonds had an insignificant impact on it (Burgess and Stanley, 1976). The structurally extruded soy meal appears like a coextensive fibrous strand embedded in porous expanded structure. Examination of such extrudate by differential staining light microscopy reveals carbohydrate inclusions and steam generated voids enclosed within a protein rich matrix (Kazemzadeh et al., 1982). Maurice and Stanely (1978) showed that protein level and second order protein effect accounts for 77% of the variation in product shear values.
16.2.6. Effect of Extrusion on Water sorption isotherm of extruded product

Isotherms (or curves) give information about the sorption mechanism and the interaction of food biopolymers with water. The moisture sorption isotherms are significantly important in predicting shelf stability, in estimating moisture changes which may occur during storage and employing improper packaging material.

The primary reason for rejection of these products by consumers is mainly the loss of crispness, which is determined by the amount of water absorbed during storage. One of the hypotheses concerning the loss of crispness assumes that water absorbed by the product dissolves intermolecular substances present in cell walls.

The study of aimed at the explanation of mechanisms of protein interaction with starch during extrusion cooking. Extrusion cooking resulted in the development of a new structured product. The extent of structural changes may be calculated using water vapour sorption.

Włodarczyk-Stasiak and J. Jamroz (2008) studied the sorption properties of starch–protein extrudates developed at varied process parameters, using water vapour adsorption/desorption. The results showed that the sorption isotherms of the raw materials and the extrudates had same shape. The raw material always displayed higher absorption of water vapour as compared to the extrudates. Irrespective to protein material, extrusion resulted in a lowering of water vapour monolayer capacity. Milder temperature conditions increases the water vapour monolayer value. It was also shown that the specific surface area of the extrudates increased markedly with increase in their water absorption capacity.
16.3. MATERIALS AND METHODS

16.3.1. Procurement of sample

Rice (Pusa 1121 Basmati) was procured from a mill, Sunam, India. The grains were cleaned to remove any adhered foreign materials like dirt, stones and grits. Grains were ground by domestic grinder (Sujata, New Delhi) into powder form, which were passed through 52 mesh for getting uniform particle size rice flour. The flour was stored in air tight plastic jar and further kept under refrigeration conditions till further use.

Chickpea grains (Chana Samarat-469) were procured from a mill, Sunam, India, which were cleaned to remove any adhered foreign materials like dirt, stones and grits. Grains were then brought to mill, where milled to powder form and then these were passed through 52 mesh for uniform particle size chickpea flour. Thus produced flour was stored in air tight plastic jar and stored under refrigeration condition till further use.

Corn flour was also obtained after milling of maize kernels (Commercial Makka-1006). Flour thus obtained was passed through 52 mesh for uniform particle size corn flour and was stored in air tight plastic jar and stored under refrigeration condition till further use.

Radish leaf powder was prepared using improved technique (Ankita and Prasad, 2015b) as discussed in chapter 9 and 14, which was added as the fourth major ingredient for the production of extrudates and stored in air tight plastic jar and stored under refrigeration condition till further use.
16.3.1.1. Preparation of sample

Figure 16.2 shows the process flow chart for the preparation of ready-to-eat coated extruded snack food. The ingredient formulation was done by trial and error method to proportionate radish leaf powder in the flour-powder blend preparation. Moisture content was adjusted by sprinkling the distilled water in ingredient mixtures. All mixed samples were screened repeatedly to reduce lumps formation due to addition of moisture. After mixing samples were stored in air tight polyethylene bags at room temperature.

Flour-powder mix (composite mix) was prepared into thirty formulations as per the design of experiments (DOE). Salt (1.25%) was added to each formulation and the composite mix was moisturized (18%). All the formulations were packed in air tight bags and kept in dessicators at ambient temperature (25°C) overnight (12 hours) for the stabilization of moisture.

16.3.1.2. Extruder cooking

Extrusion trials were performed employing a co-rotating twin-screw extruder (Kolkata, India). The main drive was supplied with 7.5 HP motor (400 V, 3 ph, 50 cycles). The barrel of the extruder received the feed from a co-rotating variable speed feeder. The barrel was provided with two electric band heaters and two water cooling jackets. A temperature sensor was fitted on the front die plate which was connected to temperature control unit placed on the panel board. The die plate of the die was fixed by a screw nut tightened by a special wrench provided. Screw speed was set at 320 rpm and internal (barrel) temperature maintained at 60°C and outside external (die) orifice temperature was adjusted at 120°C. The automatic cutting knife is fixed on rotating shaft.
16.3.1.3. Extrusion of samples

Figure 16.3 shows image of the twin screw extruder which was kept running for 30 minutes to stabilize the set temperatures and then the samples were then poured in to feed hopper and the feed rate was calibrated to 100 g/run for easy and non choking operation. The die diameter of 3 mm was selected as it is suitable as well as recommended by the manufacturer. The product was collected at the die end and packed in already numbered zipped lock packs and kept for proper storage after keeping them in hot air convective dryer. Figure 16.4 shows the pictorial view of flour-powder mix for preparation of extrudates as per DOE. Figure 16.5. shows pictorial view of prepared extrudates from flour-powder mix as per DOE.

![Process flow chart for the preparation of ready-to-eat extrudates](image-url)
16.3.1.4. Stabilization of moisture

All the samples were kept at 60°C in incubator (Macro Scientific works, New Delhi) for 12 hour duration for stabilization of moisture.

16.3.2. Characterization of extrudates

Physical, textural and sensory attributes were determined, which include lateral expansion (LE), weight per unit length (W/L), bulk density (BD), moisture content (MC), water absorption capacity (WAC), water solubility index (WSI), hardness (H), antioxidant activity (AOA) and sensory score for product acceptability for prepared formulations and further for the optimized extruded product. Experimental combinations in coded levels for corn flour, rice flour, chickpea flour and radish powder based extruded snacks are presented in table 16.2.

Figure 16.3. Image showing extruder
Table 16.1. Values of independent variables at five levels of the CCRD design

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Uncoded</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>+1</th>
<th>+2</th>
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<tr>
<td>Rice flour (%)</td>
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<td>50</td>
<td>75</td>
<td>100</td>
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<tr>
<td>Chickpea flour (%)</td>
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<td>24</td>
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<tr>
<td>Radish leaf powder (%)</td>
<td>X₄</td>
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<td>3</td>
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<td>6</td>
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</table>

Table 16.2. Experimental design in coded form for response surface analysis

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<th>No. of. Experiments</th>
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<td></td>
</tr>
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<tr>
<td>0 0 0 0</td>
<td>1</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

‘0’ is centre point of the parameter range, ‘±1’ for factorial points, and ‘±2’ for star points; x₁ – Corn flour (%), x₂ – Rice flour (%), x₃ – Chickpea flour (%) and x₄ – Radish leaf powder (%).
Figure 16.4. Pictorial view of flour-powder mix for preparation of extrudates as per DOE
16.3.2.1. Physical characteristics

Moisture content (g/g) (Ranganna, 1997) and weight per unit of extrudate length (g/cm) were calculated. Lateral expansion (LE) is the ratio of difference between the diameter of the extrudate sticks and the diameter of die exit to the diameter of die exit, which was measured according to Kumar et al., 2010. The
diameter of extrudate was estimated as the mean of 3 random measurements made by means of a vernier caliper and die diameter was determined using screw gauge.

Extrudates bulk density was determined by a seed displacement method using mustard seeds as the displacement medium. The seeds were poured into a graduated marked cylinder. The cylinder was tapped soundly three times. The weight of each sample was weighed with an electronic balance. The bulk density (g/cm$^3$) was estimated by dividing the weight of the extrudates by the volume displaced. Thus, bulk density (BD) (g/cm$^3$) was measured by weighing the quantity of extrudates required to fill the marked volume of glass cylinder (1000 cm$^3$) according to Lui and Peng, 2005.

**16.3.2.2. Mechanical characteristics**

Hardness (H) is a textural parameter, which gives the measure of the force (g) required to make first rupture to the extruded product. It comes under mechanical properties and was determined by crushing method using TA-XTA texture analyzer (Stable Micro Systems Ltd., UK; housed at Department of Food Engineering and Technology, Sant Longowal Institute of Engineering and Technology, Punjab, India) equipped with a cell load of 500 kg. An extrudate 40mm long was compressed with a probe. The graph gives a force-distance plot, and the maximum peak height of the resultant recorded curve for each sample is taken as hardness. Setting of texture analyzer is as follows: Probe type: three point bend rig, Pre-test speed: 1.00 mm/s, Test speed: 5 mm/s, Post-test speed: 10 mm/s, Distance: 30 mm, and Trigger force: 5 N, test mode: compression were the parameters used in this study (Shirani and Ganesharanee, 2009).
16.3.2.3. Rehydration characteristics

Water absorption capacity (WAC) and water solubility index (WSI) were measured using the technique according to Anderson et al., (1969); Shirani and Ganesharanee, (2009). The ground extrudates were suspended in distilled water for 30 minutes at room temperature with gently intermittent stirring, and then centrifuged at 3000rpm for 15 minutes. The WSI (%), the weight of dry soluble solids in the supernatant, is expressed as a percentage of the original weight of sample. The WAC (g/g), the weight of gel obtained after removal of the supernatant, is expressed as weight of obtained gel per gram of the extrudate.

16.3.2.4. Antioxidant activity

Antioxidant activity was measured in terms of free radical scavenging activity by the 1,1-diphenyl-2-picrylhydrazil (DPPH) method according to Naidu et al., (2011) and Nithya et al., (2013). Briefly, 1g sample was extracted for 2 h with 10 ml of 80% methanol in mortar pestle\textsuperscript{1} The mixture was centrifuged at 1400 rpm for 20 min and the supernatant was decanted. This methanolic extract (0.1 ml) was added to 3 ml of a 0.001 M DPPH. A control sample was prepared as above without extract, and methanol was employed for the baseline correction. Changes in the absorbance of the samples were measured at 517 nm.

$$\textit{Radical scavenging activity, } \% = 1 - \frac{OD_{\text{control}}}{OD_{\text{sample}}} \times 100$$ \hspace{1cm} (16.1)

16.3.2.5. Sensory characteristics

Sensory analysis was conducted for all the samples. Twelve panelists were asked to assess the developed extrudates. The results were compiled using a Hedonic Rating Test (1 – Dislike extremely, 5 – Neither like nor dislike and 9 – Like
extremely) in accordance with their opinion for color, texture, taste, and overall acceptability.

16.3.3. Compromised optimum condition

The compromised optimum condition for the development of ready-to-eat extrudates was then determined using design expert software (Statease, Design Expert 7). The final product would be considered optimum, if the sensory score and antioxidant activity are as high as possible, whereas remaining parameters should be in range. Therefore, compromised optimum condition criteria applied for numerical technique optimization were as follows: (1) maximum sensory score for product acceptability and antioxidant activity; (2) lateral expansion, weight per unit length, bulk density, moisture content, water absorption capacity, water solubility index, hardness should be in range.

16.3.4. Coating of extruded snack food

Oil blend comprised of palm oil (48.72%), linseed oil (5.84%), sunflower oil (21%) and rice bran oil (24.44%) and spice mix (combination made with fenugreek powder (10%) and chat masala (75%) (salt 10%, dry mango powder (amchoor), 5%, <10% black salt , cumin, coriander, black pepper, pomegranate seeds, mint, red chillies, dried ginger, muskmelon, mint leaves, nutmeg, bishop’s weed, cloves and asafetida) were the two variables in the coating process. Developed fenugreek leaf powder prepared using improved technique (Ankita and Prasad, 2015a) as discussed in previous chapters 8, 14. Oil blend was sprinkled using squeezable sprinkle bottle and spice mix was spread over the optimized extrudates into thirteen formulations as per DOE. Thereafter, the extrudates were mixed in a way to ensure the uniform mixing over individual extrudate. Figure 16.6 shows the process flow diagram for the
coating of optimized extrudates. SEM was carried out for the extrudates and Figure 16.7 shows the pictorial view of gold coating machine used before putting the extrudates in SEM (Scanning Electronic Microscope). Figure 16.9 shows pictorial view of coated extrudates as per second design of experiments (DOE) for the coating of optimized extrudates.

Figure 16.6. Process flow diagram for the coating of optimized extrudates

Figure 16.7. Pictorial view of gold coating machine used before putting the extrudates in SEM (Scanning Electronic Microscope)
16.3.5. Design of experiments for extrudate development

The experimental design was a CCRD comprising of varying corn flour, rice flour, chickpea flour and radish leaf powder. Composite mix samples (formulations) were prepared from these raw ingredients (independent variables) and their effect on responses weight per unit length, density, lateral expansion, moisture content, hardness, rehydration characters, antioxidant activity and sensory attributes of products was studied. Between two and four replicates of each measurement were made.

Total No. of experiments = \(2^k + 2 \times k + \text{Central points}\)

for \(k = 4\), Total number of experiments = \(2^4 + 2 \times 4 + 6 = 30\)

Five different levels for each experiment in coded form are, -2, -1, 0, 1, and 2 (\(\alpha = 2^{k/4}\))

The range and levels of experimental variables investigated are presented in the table 16.1. The experimental design in coded form for RSM including central value (zero level) chosen for experimental design are shown in table 16.2. Experimental combinations in coded and uncoded levels for corn flour, rice flour, chickpea flour and radish powder based extruded snacks are tabulated in table 16.3.

16.3.5.1. Statistical analysis of responses

A completely randomized design was used to evaluate the results and Analysis of Variance (ANOVA) was carried out to compare the mean values. All highly significant (\(p\)) differences are reported at \(p = 0.01, 0.05, 0.1\) levels. The responses of extruded extrudates snack food samples with four independent variables for different
Experimental conditions were related to coded variables (xi, i = 1, 2, 3 and 4) by a second degree polynomial (Equation 16.1) as given below:

\[
Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{44} x_4^2 + \\
\beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{14} x_1 x_4 + \beta_{23} x_2 x_3 + \beta_{24} x_2 x_4 + \beta_{34} x_3 x_4 + \varepsilon
\]  

(16.1)

Where, Y is the response (dependent variable) which comprises physico-chemical and sensory parameters; x_1, x_2, x_3 and x_4 are the coded values of corn flour (g), rice flour (g), chick-pea flour (g) and radish leaf powder (g) respectively. The coefficients of the polynomial were represented by \(\beta_0\) (constant), \(\beta_1, \beta_2, \beta_3, \beta_4\) (linear effects); \(\beta_{12}, \beta_{13}, \beta_{14}, \beta_{23}, \beta_{24}, \beta_{34}\) (interaction effects); \(\beta_{11}, \beta_{22}, \beta_{33}, \beta_{44}\) (quadratic effects); and \(\varepsilon\) (random error).

Data was modeled by non-linear regression analysis and the statistical significance of the terms was examined by analysis of variance for each response. The statistical analysis of the data of three dimensional plotting was performed using Design Expert Software (Statease 7.0). The adequacy of the regression model was checked by \(R^2\) (the coefficient of multiple determination, a measure of the amount of variation around the mean explained by the model), Adjusted \(R^2\) (a measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model), predicted \(R^2\) (a measure of how good the model predicts a response value). Coefficient of determination \(R^2\) is defined as the ratio of the explained variation to the total variation and is measure of the degree of fit. It is also the proportion of the variability in the response variables, which is accounted for by the regression analysis. When \(R^2\) approaches unity, the better the empirical model fits the actual data. The smaller the value of \(R^2\), the less relevance the dependent variables in the model have in explaining the behavior variation. The models were then used to
interpret the effect of various predictors (terms) on the response. Model sum of squares (Model SS) is the sum of the squared residuals for terms in the model. These terms are being used to estimate effects. Term sum of squares is the sum of the squared deviations from the mean due to the effect of this term. This is the number of model parameters, including the intercept (if present), minus one. Term degrees of freedom associated with this term. The mean square (or variance) associated with the model. It is the \( \text{SS}_{\text{Model}} / \text{DF}_{\text{Model}} \). The multiple correlation coefficient computed as \( 1 - \frac{\text{SS}_{\text{residual}}}{(\text{SS}_{\text{model}} + \text{SS}_{\text{residual}})} \). Adequate precision is a measure of the range in predicted response relative to its associated error, in other words a signal to noise ratio. Its desired value is 4 or more. The F-value for a term is the test for comparing the variance associated with that term with the residual variance. The analysis of variance (ANOVA) tables were developed and the effect and regression coefficients of individual linear, quadratic and interaction terms were determined. The significances of all terms in the polynomial were assessed statistically by evaluating the F-value at probability (p) of 0.01, 0.05 and 0.1 (Myers and Montgomery, 2002; Montgomery, 1997; Design expert version 7). The regression coefficients were then employed to make statistical calculation to generate three dimensional plots of the regression model. The significance of each coefficient was determined using the F value and P value. The bigger the F value and the smaller the P value, the more significant are the corresponding coefficients.
Table 16.3. Experimental combinations in Coded and Uncoded (actual) levels for corn flour, rice flour, chickpea flour and radish powder based extruded snacks

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<th>Exp No.</th>
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</tr>
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</table>
16.3.6. Experimental design for coating of extrudates

Response Surface Methodology (RSM) was again used for the preparation of functional extrudates. Figure 16.8 shows pictorial view of coated extrudates as per DOE. For the optimization of process conditions, the experiments were conducted according to second order Central Composite Rotatable Design (CCRD).

\[ \text{Total No. of experiments} = 2^k + 2 \times k + \text{Central points} \]

Hence, for \( k=2 \), Total number of experiments = \( 2^2 + 2 \times 2 + 5 = 13 \)

Five different levels for each experiment in coded form are -1.41, -1, 0, 1, and 1.41(\( a=2^{k/4} \)).

16.3.6.1. Statistical analysis of responses

The responses of extrudates with two independent variables for different experimental conditions were related to coded variables \((x_i, i = 1 \text{ and } 2)\) by a second degree polynomial (Equation 16.1.1) as given below:

\[ Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 \cdot x_2 + \epsilon \tag{16.1.1} \]

where, \( x_1 \) and \( x_2 \) are the coded values of oil blend (%) and spice mix (%) respectively. The coefficients of the polynomial were represented by \( \beta_0 \) (constant), \( \beta_1, \beta_2 \) (linear effects); \( \beta_{12} \), (interaction effects); \( \beta_{11}, \beta_{22} \) (quadratic effects); and \( \epsilon \) (random error).

16.3.4. Characteristics of optimized products

16.3.4.1. Fourier Transmission Infrared Spectroscopy (FTIR)

Infrared spectra of the powdered sample was recorded at room temperature using FTIR spectrometer (SPECTRUM-2000, Perkin Elmer, USA) in the range 700–
4000 cm⁻¹. The sample was placed directly in the sample holder. A background was collected before each sample was analyzed then subtracted from the spectra of sample prior to analysis. After every scan, a new reference background spectrum was taken. The ATR crystal cleaned with hot water and acetone was examined for spectral authenticity in order to avoid the chance of any contamination error.

16.3.4.2. Microstructure analysis

Scanning electron micrographs of functional fractionated leaf powders and uncoated and coated extrudates was acquired in the range of 500 to 3500 magnifications using scanning electron microscope (Jeol JSM-6100, Jeol Ltd, Tokyo, Japan). The sample for acquiring the micrographs was prepared and mounted on double sided tape on the used aluminum stubs. Further, adhered sample was coated with gold - palladium (60:40) at an accelerated voltage of 15 kV under vacuum. A digital camera head cooled with a Peltier mechanism was present for capturing the image by microscope.
Figure 16.8. Pictorial view of coated extrudates as per DOE
The moisture content of extrudate was determined by gravimetric method, by keeping the sample overnight in a hot air oven in which temperature was fixed at 105±2°C. The adsorption curves indicate the hygroscopic equilibrium states of a given product. Their determination constitutes an essential stage for better understanding the problems of modeling the drying processes. Using an experimental approach, these equilibrium (adsorption) curves can be determined by the saturated salt solutions method. Another application of the adsorption isotherms is in the calculation of the drying time of hygroscopic substances (Kouhilla et al., 2001). In addition, isotherms give significant information to other processes which include packaging and storage (Cassini et al., 2006).

16.4. RESULTS AND DISCUSSION

Experiments were conducted to investigate the effect of various product parameters i.e. corn flour (predominant binding agent and puffing agent in the expansion process of extrudates); rice flour (a puffing agent in the expansion process of extrudates); chickpea flour (a protein source) and radish leaf powder (dietary fiber source) on extruded product characteristics and optimization of these variables was carried out to develop nutritionally rich, organoleptically acceptable extrudates using RSM. Trial was conducted to observe the effect of radish leaf powder on extrudate characteristics. From the trial run, it was observed that the sample containing 7-10% radish leaf powder was not of a good quality in terms of crunchiness and expansion. The expansion of that particular product was lowest, the taste and flavor was also not good. From the observation next trial was run with radish leaf powder ranging 0-6% and the quality in terms of expansion was found good. On the basis of previous observation next trial was carried out for six samples and analyzed for expansion,
crunchiness, taste, appearance, mouthfeel and overall acceptability, which were found best. So, final range was set at 0-6%.

Variation of responses lateral expansion, weight per unit length, bulk density, moisture content, water absorption capacity, water solubility index, hardness, antioxidant activity, sensory taste, sensory appearance, sensory mouth feel and sensory overall acceptability of extrudate samples with four independent variables (corn flour, rice flour, chickpea flour and radish leaf powder) is shown in table 16.1,16.2,16.3.

A complete second order models (Equation 16.1) was tested for its adequacy to decide the variation of responses with independent variables. To aid visualization of variation in responses with respect to processing variables, series of three dimensional response surfaces (Figures 16.9 to 16.20) were drawn using design expert software (Statease 7.0).

16.4.1. Physical characteristics

The physical attributes of extrudates prepared from powder-flour mix at thirty ingredient formulations with corn flour, rice flour, chickpea flour and radish leaf powder were studied (Table. 16.4).

16.4.1.1. Weight per unit length

For an extruded snack, this parameter is an important organoleptic property. The weight per unit length of extrudates was in the range of 1.33 to 2.25 g/10cm length depending upon varying levels of four independent variables. The response plots for weight per unit length as a function of four variables are shown in the figure 16.9. The results obtained were modeled according to a polynomial quadratic
equation in order to identify the effect of variables. The Adequate Precision value of 6.922 indicates that the model can be used to navigate the design space as it is greater than 4.0 (Montgomery, 1997). The Model F-value of 2.508 implies that model is significant ($P < 0.05$). $R^2$ and Adjusted $R^2$ values of the model are 0.701 and 0.421, respectively. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on weight per unit length data, in which $X_1$, $X_2$, $X_3$ and $X_4$ indicate corn flour, rice flour, chickpea flour and radish leaf powder respectively. Chickpea powder ($X_3$) and radish leaf powder ($X_4$) are showing significant effect with the weight per unit length of the extrudates being tested. Interaction effect of ($X_4$) radish powder and chickpea powder ($X_3$) is also showing linear significant effect with the response and indicates convex variation on the response. The terms having $p \leq 0.01$ considered highly significant terms, the terms having $p \leq 0.05$ as significant and terms having $p \leq 0.1$ as less significant, rest all the terms considered as non-significant (Table 16.5). Including only significant terms, following equations was developed.

\[
\text{Weight per 10 cm length} = Y_1 = 1.72 + 0.08X_3 + 0.14X_4 + 0.015X_3X_4 \quad (16.2)
\]

It is evident from the Eqn. 16.2 and Table 16.5 that chickpea powder ($X_3$) is showing significant ($p \leq 0.1$) positive effect on the weight per unit length of the extrudates being tested, while radish leaf powder ($X_4$) is showing highly significant positive effect ($p \leq 0.01$) and the other two variables corn flour and rice flour are not significant. Interaction effect of radish powder and chickpea powder is also effecting significantly ($p \leq 0.01$) and is dominating in a positive manner on the response. It implies among four variables, only presence of chickpea flour and radish powder seems to affect and imparting towards weight in linear manner. This may be due to
higher levels of dietary fiber and proteins in chickpea flour (Shirani and Ganesharanee, 2009) and also in radish leaf powder compared to rice and corn.

Figure 16.9. Variation of weight per unit length with respect to corn flour, rice flour, chick pea flour and radish leaf powder in powder-flour based extrudates.
16.4.1.2. Bulk density

Bulk density is one of the major physical properties. It is measure of density of the material when packed or stacked. So, this parameter is of very much importance when the material is going to be developed at large scale. Bulk density of packed particles depends upon geometry, surface properties and size of individual particles. The bulk density, which considers expansion in all directions, ranged from 115 to 192 kg/m$^3$ for corn flour, rice flour, chickpea flour and radish leaf powder made extrudates. Table 16.5 shows the coefficient of model and other statistical attributes of bulk density. The Adequate Precision value of 11.690 shows that the model can be utilized to navigate the design space since it is greater than 4.0 (Montgomery, 1997). The Model F-value of 5.518 implies that model is significant ($P = 0.001$). $R^2$ value of the model is 0.834. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on bulk density data.

Bulk density $= Y_2 = 158.5 + 6.30X_1 + 9.92X_4 - 1.18X_1^2 - 6.47X_2^2 - 3.60X_3^2 + 2.81X_4^2 + 4.83X_1X_3 - 2.74X_1X_4 - 0.80X_2X_3 - 1.39X_2X_4 + 0.89X_3X_4$  \hspace{1cm} (16.3)

Following were the observations from above Eqn. 16.3 and table 16.5, the model coefficient is positive for corn flour ($X_1$) ($p \leq 0.1$) and radish leaf powder ($X_4$) ($p \leq 0.001$), which showed linear relation with bulk density. Among these significant variables, as magnitude of coefficient of radish leaf powder ($X_4$) is dominating variable followed by corn flour ($X_1$). Quadratic terms of rice flour ($X_2^2$) and chickpea flour ($X_3^2$) were significant and showed negative quadratic effect on bulk density which indicates concave shaped variation. Interaction term $X_1X_3$ indicated positive
effect on bulk density and showed convex shaped variation with change in value of variables.

Figure 16.10. Variation of bulk density with respect to corn flour, rice flour, chick pea flour and radish leaf powder in powder-flour based extrudates
Table 16.4. Effect of independent variables on values of responses (physical, chemical parameters and sensory attributes)

<table>
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where, WL- weight per unit length (g/10cm); BD- bulk density (kg/m³); LE- lateral expansion (%); HD-hardness (g); MC- moisture content (% d.w.b.); WAC- water absorption capacity (g/g); WSI- water solubility index (%); AOA- antioxidant activity (%); ST- sensory taste; SA- sensory appearance; SM- sensory mouthfeel and SOA- sensory overall acceptability
### Table 16.5. ANOVA for physical and chemical parameters (responses)

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<td>HD(Y₄)</td>
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<td>9.92***</td>
<td>-13.26*</td>
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Level of Significance: * P<0.1, **P<0.05, *** P<0.01, ns not significant; df: degrees of freedom
As evidenced in figure 16.10, the increase in bulk density by feed composition is directly related to increase in amylose fraction of starch in mixture fraction provided by corn flour ($X_1$) during extrusion. With the addition of radish leaf powder, bulk density increased. More the corn flour incorporation in the feed, makes the extrudate having lesser porosity, as similar observed by Kumar et al. (2010). However, bulk density first increase with increasing corn flour and chickpea flour ($X_1X_3$) and maximum value of bulk density will occur in the selected range, followed by decrease in the bulk density. Bulk density decreased due to reduction of elasticity of dough. With increase in chickpea flour, bulk density of extrudate initially decreased but further it increases. It is due to high protein and dietary fiber contents of chickpea compared to rice and corn which results in decrease of expansion ratio and increases the bulk density of extrudate (Shirani and Ganesharanee, 2009). (Ding et al., 2006 and Kumar et al., 2010) studied the opposite behavior of bulk density and lateral expansion with the change in process variables in accordance with obtained results.

16.4.1.3. Lateral expansion

Expansion is the most significant physical property of the snack food. Starch is the chief component of cereals which plays most important role in expansion process. Starch present in cereal grains is major source of energy in the diet and starch change has important nutritional effects during extrusion. An important consequence of starch change is related to expansion. Higher amylopectin content produces highly expanded products having thin cell walls, thus they may crumble easily while dense products (amylose rich) are often hard (Riaz, 2000). The measured expansion of extrudates ranged from 308.33 to 541.67% (Table 16.5). Table 16.5 shows the coefficient of model and other statistical attributes of lateral expansion. The Adequate Precision value of 8.746 indicates that the model can be used to navigate the design
space as it is greater than 4.0 (Montgomery, 1997). The Model P-value implies that model is significant (P < 0.001). R² value is 0.805. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on lateral expansion data. The coefficient of corn flour (X₁) and chickpea flour (X₃) is negative indicated inverse relation with lateral expansion and quadratic terms of radish leaf powder (X₄) is negative indicates the concave shaped variation. Interaction terms show negative sign which indicates concave shaped variation (Figure 16.11).

\[
LE = Y_3 = 482.50 - 13.13 X_1 - 15.07 X_3 - 13.26 X_4 - 14.18 X_4^2 - 29.18 X_1X_3 - 18.75 X_1X_4 - 27.08 X_3X_4
\]  

(16.4)

Following observations can be made from Eqn. 16.4, the linear term of corn flour (X₁), chickpea flour (X₃) and radish leaf powder (X₄) effecting highly significantly (p < 0.01) with a negative coefficient due to degree of starch gelatinization which is because of conversion of starch and increase dietary-fiber contents. Quadratic terms of radish leaf powder (X₄) is negative indicates the concave shaped variation. Expansion ratio decreases with increasing chickpea flour (X₃) to a limit and further starts increasing. It is due to higher levels of protein and dietary fiber in chickpea (X₃) as compared to rice and corn (Shirani and Ganesharanee, 2009). Protein content influences the expansion process through their ability to affect water distribution in the matrix and also their macromolecular structure and confirmation, affects textural (expansion) properties of melt. Increase in viscosity and reduction in the availability of water (water activity), decrease the available steam which is responsible for expanding cells during the flashing process. Thus, it decreases the gelatinization degree of starch as well as the expansion ratio of products (El-Samahy et al., 2007). Rice flour produced the most expanded products due to the higher
starch and lower fiber as well as fat content compared to corn ($X_1$) (Shoar et al., 2010). The similar findings have been reported by Kokini (1992).

Figure 16.11. Variation of lateral expansion with respect to corn flour, rice flour, chick pea flour and radish leaf powder in powder-flour based extrudates
16.4.1.4. Hardness

Mean hardness values, i.e. the force necessary to deform the sample and is commonly evaluated parameter while determining solid, semisolid and viscoelastic food product’s texture. The hardness of extrudates was in the range of 687.290 to 1800.000 g which rely upon the varying levels of four independent variables (Table 16.5, Figure 16.12), whereas, higher range of 1697.85 to 2375.12 g hardness was observed by Fang et al., 2014.

Table 16.5 shows that the coefficient of model and other statistical attributes of hardness. The Adequate precision value of 7.717 signifies that the model can be used to navigate the design space as it is greater than 4.0 (Montgomery, 1997). The F-value of model is 2.756 that implies that model is significant (P < 0.05). R² and Adjusted R² values of the model are 0.720 and 0.459, respectively. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on WAC data.

\[
\text{Hardness} = Y_4 = 1388.15 - 94.37X_3 - 77.76X_1^2 + 81.21X_3^2 + 186.20X_1X_2 + 93.52X_2X_3 \ (16.5)
\]

All the terms present in the above Eqn. 16.5 are insignificant except chickpea flour in negative manner. It may be due the addition of chickpea protein and starch, which reduces the hardness of extrudates. Hardness can be affected due to basic transformations occurring during extrusion which include protein and starch transformations. Shirani and Ganesharanee, (2009) studied that hardness decreased with addition of chickpea in the extrudates. Stojceska et al. (2009) concluded hardness enhanced due to which is possibly due to the result of reduced expansion.
Similarly, values of hardness decrease with wheatgrass fortified steamed rice were reported (Das et al., 2014).

Figure 16.12. Variation of hardness with respect to corn flour, rice flour, chickpea flour and radish leaf powder in powder-flour based extrudates
16.4.1.5. Moisture content

The moisture content of extrudates ranged from 7.16 to 7.93% d.w.b., (Table 16.5, Figure 16.13). Table 16.5 shows the coefficient of model and other statistical attributes of moisture content. The Adequate precision value of 4.70 signifies that the model can be employed to navigate the design space as it is greater than 4.0 (Montgomery, 1997). The Model F-value of 2.948 implies that model is significant (P < 0.05). R² of the model is 0.733. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on weight per unit length data.

\[ MC = Y_5 = 7.24 - 0.10 X_4 + 0.06 X_1^2 + 0.13 X_2^2 + 0.08 X_4^2 - 0.11 X_1 X_2 \] (16.6)

The linear term as radish powder (X₄) is showing significant (p≤ 0.05) and negative effect on the moisture content of extruded snacks. It implies addition of radish leaf powder to extrudates decrease their moisture content as similar reported by Santosa et al., (2008).
Figure 16.13. Variation of moisture content with respect to corn flour, rice flour, chick pea flour and radish leaf powder in powder-flour based extrudates
16.4.1.6. Water absorption capacity

Water absorption capacity (WAC) measures the amount of water absorbed by starch that can be employed as an indicator of starch gelatinization (Anderson et al., 1969). The WAC of the extrudates ranged from 6.14 to 7.26 g/g (Table 16.5, Figure 16.14). Table 16.5 shows the coefficient of model and other statistical attributes of WAC. The Adequate precision value of 9.739 signifies that the model can be used to navigate the design space as it is greater than 4.0 (Montgomery, 1997). The Model F-value of 8.537 implies that model is significant ($P < 0.01$). $R^2$ and Adjusted $R^2$ values of the model are 0.888 and 0.784, respectively. Considering all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on WAC data.

\[
WAC = Y_6 = 6.34 + 0.16 X_1 - 0.13 X_2 - 0.06 X_3 - 0.13 X_4 + 0.08 X_1^2 + 0.12 X_4^2 - 0.08 X_1X_4 + 0.07 X_2X_3 - 0.09 X_3X_4
\]  

(16.7)

The linear terms of all the independent variables are significant ($p \leq 0.05$) with all variable effecting negatively except corn flour ($X_1$). WAC responded negatively highly significant ($p \leq 0.01$) with radish powder ($X_4$). This may be attributed to relative decrease in starch content and competition of absorption of water between leaf powder and available starch (Altan et al., 2008b). A similar study reported a decrease in water absorption capacity when the ratio fiber/corn starch increased in extrusion of corn fiber and corn starch blend. WAC is due to solubilization of loosely bound gelatinized starch from the extrudate surface (Nithya et al., 2013) and also on extent of the retrograded starch network surrounding the gelatinized starch (Resmini and Pagani, 1983).
Figure 16.14. Variation of water absorption capacity with respect to corn flour, rice flour, chick pea flour and radish leaf powder in powder-flour based extrudates
16.4.1.7. Water solubility index

Water solubility index (WSI) is employed as an indicator of degradation of molecular components. It measures the amount of soluble polysaccharides released from the starch components after extrusion (Ding et al., 2005). The WSI of the extrudates ranged from 3.67 to 5.83% (Table 16.5).

Table 16.5 shows the coefficient of model and other statistical attributes of WSI. The Adequate precision value of 6.102 indicates that the model can be used to navigate the design space as it is greater than 4.0 (Montgomery, 1997). The Model F-value of 2.674 implies that model is significant (P < 0.05). \( R^2 \) value of the model is 0.714. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on WSI data.

\[
WSI = Y_2 = 5.19 - 0.19 X_1 - 0.21 X_1^2 - 0.23 X_2^2 - 0.21 X_4^2 + 0.29 X_2 X_3 - 0.21 X_2 X_4 \tag{16.8}
\]

Among the linear terms, corn flour \((X_1)\) is dominating significantly in negative order \((p < 0.1)\) (Eqn. 16.8, Figure 16.15). With the increase in corn flour \((X_1)\), solubility decreases and maximum value of WSI will occur in the selected range of corn flour \((X_1)\). Results obtained for WSI are related with lateral expansion in terms of corn flour \((X_1)\) (Kumar et al., 2010). Also, WSI of extrudates with only corn was approximately twice that of wheat extrudates at lower concentrations was revealed by Stojceska et al. (2009).
Figure 16.15. Variation of water solubility index with respect to corn flour, rice flour, chick pea flour and radish leaf powder in powder-flour based extrudates.
16.4.1.8. Antioxidant activity

The antioxidant activity of the extrudates made from powder-flour mix ranged from 19.072 to 73.711% (Table 16.5, Figure 16.16). The response surfaces for antioxidant activity as a function of independent variables have been shown in Figure 16.16. Table 16.5 shows the coefficient of model and other statistical attributes of antioxidant activity. The Adequate precision value of 11.471 signifies that the model can be used to navigate the design space since it is greater than 4.0 (Montgomery, 1997). The Model F-value of 3.254 implies that model is significant (P < 0.1). R² value comes out to be 0.838. The significance of each coefficient can be decided using the F and P value. The bigger the F value and the smaller the P value, the more significant the corresponding coefficient. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on antioxidant activity data. The antioxidant activity of the extrudates is affected by the independent variables which is clear from the following relations:

\[
\text{AOA} = Y_8 = 36.00 + 2.51 X_1 + 4.25 X_3 + 3.06 X_4 + 3.79 X_1 X_2 - 5.00 X_1 X_4 \\
- 6.88 X_2 X_3 + 8.12 X_3 X_4
\]  

(16.9)

The higher value of correlation coefficient indicated the suitability of the model for predicting the antioxidant activity of extrudates, which means 83.82% of the variability of the response could be explained by this model. Long et al., 2014 studied regression for extrudates for which higher values of the determination coefficient and adjusted determination coefficient indicated a good compatibility between the experimental and predicted data. The Eqn. 16.9 indicates the antioxidant activity increased as the linear term of corn flour (X₁), chickpea flour (X₃) and radish leaf powder (X₄) and is positively significant. Interaction effects of X₁X₂ (corn flour
and rice flour) and $X_3X_4$ (chickpea flour and radish leaf powder) are showing positive effect which indicates convex variation. Similar results were obtained (Naidu et al., 2011; Nithya et al., 2013; Gumul et al., 2010; Korus et al., 2007).

Figure 16.16. Variation of antioxidant activity with respect to corn flour, rice flour, chickpea flour and radish leaf powder in powder-flour based extrudates
16.4.1.9. Sensory evaluation

Sensory evaluation plays an important role in measuring characteristics and acceptability of food products. Sensory evaluation can have a great influence on improving the organoleptic attributes of a product, including appearance, flavor, and texture. Additionally, it can also provide the development technologist with useful information in order to help achieve and control quality, at a level which is particularly acceptable to the consumers.

The degree of liking of a product is tested by hedonic analysis. In contrast to descriptive evaluation, untrained consumers are asked to score a product subjectively. A common method is to use a nine-point hedonic scale, extending from dislike extremely to like extremely. Four sensory attributes, including taste, appearance, mouth feel and overall acceptability were rated for all extruded snack items.

The subjects were seated in sensory booths with appropriate ventilation and lighting. During 1-hour session subjects were presented with triplicates of each of the three stimuli. First, the extruded product was rated in terms of visual senses via color and appearance. Next, these were rated on texture basis by breaking by hand and finally, these products were ingested and evaluated on the basis of taste, texture, mouth feel and overall acceptability attributes.

All the scores for the coded samples were then collected and then samples were decoded and the data and comments for all samples were collected from sensory evaluation sheets was evaluated. The separate score and comments obtained for each custard samples and the results thereof are presented. Four of the independent variables viz. corn flour (predominant binding agent and puffing agent in the expansion process of extrudates); rice flour (a puffing agent in the expansion process
of extrudates); chickpea flour (a protein source) and radish leaf powder which adds functionality; influence sensory scores as follows.

16.4.1.9.1. Sensory taste

The sensory taste of the extrudates made from powder-flour mix ranged from 6.250 to 8.333 (Table 16.6, Figure 16.17) depending upon the varying levels of raw material formulations. The response plots for taste as a function of raw material formulations has been shown in the Figure 16.17. The results were obtained after performing different experiments as per CCRD to identify the effect of significant variables. Table 16.6 shows the coefficient of model and other statistical attributes of sensory taste. The Adequate precision value of 12.780 signifies that the model can be used to navigate the design space since it is greater than 4.0 (Montgomery, 1997). The Model F-value of 12.340 implies that model is significant ($P < 0.001$). $R^2$ value of the model is 0.920. Considering all above criteria, the quadratic model that describes the effect of independent variable precisely fitted on sensory taste data.

Sensory taste $= Y_1 = 8.18 - 0.18X_1 + 0.15X_2 + 0.28X_3 - 0.24X_1^2 - 0.17X_2^2 - 0.17X_3^2 - 0.30X_4^2 - 0.12X_2X_3 - 0.23X_3X_4$ (16.10)
Figure 16.17. Variation of sensory taste with respect to corn flour, rice flour, chick pea flour and radish leaf powder in powder-flour based extrudates
High value of the correlation coefficient (92.01%) indicated suitability of the equation for predicting the sensory taste of functional extrudates. In Eqn. (16.10), the coefficients of the first order term in the equation with coded variables indicated that the taste of the product increases highly significantly ($p \leq 0.01$) with rice flour and chickpea flour, whereas corn flour is showing adverse effect for all the extrudates as were acceptable by the panelists. Quadratic terms are showing inverse relation with the response and a maximum value of sensory taste will occur in the selected range.

16.4.1.9.2. Sensory appearance

The sensory appearance of the extrudates made from powder-flour mix ranged from 6.083 to 7.750 (Table 16.6). The response plots for appearance as a function of powder-flour mix are shown in Figure 16.18. Table 16.6 shows the coefficient of model and other statistical attributes of sensory appearance. The Adequate precision value of 7.284 signifies that the model can be employed to navigate the design space as it is greater than 4.0 (Montgomery, 1997). The Model F-value of 4.531 implies that model is significant ($P < 0.1$). \( R^2 \) is 0.809. The significance of each coefficient can be determined using the $F$ and $P$ value. The bigger the $F$ value and the smaller the $P$ value, the more significant the corresponding coefficient. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on sensory appearance data. Following relationships was developed with the coded values of independent variable:

\[
\text{Sensory appearance} = Y_2 = 7.60 - 0.17 X_1 + 0.24 X_3 - 0.18 X_1^2 - 0.19 X_2^2 - 0.18 X_3^2 - 0.14 X_4^2 + 0.14 X_1X_3 - 0.14 X_2X_4 - 0.14 X_3X_4 \quad (16.11)
\]
Figure 16.18. Variation of sensory appearance with respect to corn flour, rice flour, chick pea flour and radish leaf powder in powder-flour based extrudates.
The regression coefficient of the model was 80.88%. In Eqn. 16.11 the sensory appearance increases significantly (p ≤ 0.1) with the addition of chickpea flour (X_3) mainly. Quadratic terms are showing negative behavior, which indicates concave variation in the selected range with respect to response.

16.4.1.9.3. Sensory mouthfeel

The mouthfeel of the extrudates made from powder-flour mix ranged from 6.083 to 8.333 (Table 16.6). The response surfaces for mouthfeel as a function of four variables have been shown in Figure 16.19. The terms having p ≤ 0.01 were considered as highly significant terms having p ≤ 0.05 as significant only. Table 16.6 shows the coefficient of model and other statistical attributes of sensory mouthfeel. The Adequate precision value of 7.043 signifies that the model can be utilized to navigate the design space as it is greater than 4.0 (Montgomery, 1997). The F-value of is 5.411 which implies that model is significant (P < 0.001). R^2 value is 0.835. The significance of each coefficient can be determined using the F and P value. The bigger the F value and the smaller the P value, the more significant the corresponding coefficient. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on sensory mouthfeel data. The effect of the independent variables on the mouthfeel of functional extrudates is clear from the following relations:

Sensory mouth feel = Y_1 = 7.99 - 0.17 X_1 + 0.15 X_3 - 0.25 X_4 - 0.31 X_1^2 - 0.35 X_2^2 - 0.36 X_4^2 + 0.21 X_1 X_4 \quad (16.12)
Figure 16.19. Variation of sensory mouth feel with respect to corn flour, rice flour, chick pea flour and radish leaf powder in powder-flour based extrudates
The regression coefficient ($R^2$) for the model was 83.47%. Eqn. 16.12 quadratic model revealed that out of four variables, only chickpea flour ($X_3$) has significant effect on mouthfeel of the final product. It is evident that the mouthfeel significantly ($p \leq 0.05$) decreased with the addition of corn flour ($X_1$) and rice flour ($X_2$) but chickpea flour ($X_3$) is giving positive significant $p \leq 0.1$ effect, while radish leaf powder ($X_4$) addition is also highly significant in adverse manner ($p \leq 0.01$). However, maximum value of response will occur in the selected range of corn flour ($X_2$) and radish leaf powder ($X_4$).

### 16.4.1.9.4. Overall acceptability

The overall acceptability was obtained by aggregating the sensory values of taste, appearance and mouth-feel. The OAA (Over All Acceptability) of the extrudates ranged from 6.433 to 7.967 (Table 16.6). The results were obtained after performing different experiments as per CCRD and the effect of significant variables whether were investigated according to the polynomial quadratic equation. Table 16.6 shows the coefficient of model and other statistical attributes of sensory overall acceptability. The Adequate precision value of 7.973 signifies that the model can be utilized to navigate the design space as it is greater than 4.0 (Montgomery, 1997). The Model P-value implies that model is significant ($P \leq 0.001$). $R^2$ value of the model is 0.924. The significance of each coefficient can be determined using P value. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on sensory overall acceptability data. The response plots for OAA as a function of four variables has been shown in figure 16.20. The quadratic relations for OAA after considering the significant terms are:
In Eqn. (16.13) the linear effect of chick pea (X_3) has highly significantly (p< 0.01) positive effect and corn flown (X_1) showing adverse effect on the overall acceptability of extrudates. A maximum value of acceptability will occur in the selected range of corn flour (X_1). Desirable taste and overall acceptability was obtained when starch cream soups and pure starch soup was replaced with 0.5% fenugreek (Ravindran and Matia-Merino, 2009). Dehydrated greens incorporated with 8 and 12% levels lowered the scores of all the attributes of the product. The quality of appearance received the lowest score of 5.7 for 12% greens incorporated thalipeeth. Finally, 4% incorporation of *Amaranthus paniculatus* and *Peucedanum graveolens* greens with no detrimental effects on sensory quality and increased the nutrient density of mathri and thalipeeth. Value addition to the traditional products can be a valuable approach to combat micronutrient malnutrition (Gupta and Prakash, 2011).

Sensory overall acceptability = \[ Y_4 = 7.84 - 0.39 \, X_1 + 0.19 \, X_4 - 0.13 \, X_1^2 - 0.20 \, X_2^2 - 0.15 \, X_4^2 + 0.24 \, X_1 \, X_2 + 0.17 \, X_1 \, X_3 - 0.18 \, X_2 \, X_3 - 0.20 \, X_2 \, X_4 - 0.28 \, X_3 \, X_4 \quad (16.13) \]
Figure 16.20. Variation of sensory overall acceptability with respect to corn flour, rice flour, chickpea flour and radish leaf powder in powder-flour based extrudates
Table 16.6. ANOVA for sensory attributes (responses)

<table>
<thead>
<tr>
<th>Coefficient of model terms of sources</th>
<th>Responses (Y)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ST (Y₁)</td>
<td>SA(Y₂)</td>
<td>SM(Y₃)</td>
<td>SOA(Y₄)</td>
</tr>
<tr>
<td>Model</td>
<td>8.18***</td>
<td>7.60***</td>
<td>7.99***</td>
<td>7.84***</td>
</tr>
<tr>
<td>Corn flour</td>
<td>-0.18***</td>
<td>-0.17**</td>
<td>-0.17**</td>
<td>-0.39***</td>
</tr>
<tr>
<td>Rice flour</td>
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<td>-0.04 ns</td>
<td>-0.12 ns</td>
<td>0.01 ns</td>
</tr>
<tr>
<td>Chickpea flour</td>
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<td>0.24***</td>
<td>0.15*</td>
<td>0.01 ns</td>
</tr>
<tr>
<td>X₄-Radish leaf powder</td>
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<td>0.19***</td>
</tr>
<tr>
<td>X₁ X₂</td>
<td>0.00 ns</td>
<td>0.03 ns</td>
<td>0.08 ns</td>
<td>0.24***</td>
</tr>
<tr>
<td>X₁ X₃</td>
<td>0.00 ns</td>
<td>0.14*</td>
<td>-0.08 ns</td>
<td>0.17**</td>
</tr>
<tr>
<td>X₁ X₄</td>
<td>0.05 ns</td>
<td>0.09 ns</td>
<td>0.21**</td>
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<tr>
<td>X₂ X₃</td>
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<td>-0.05 ns</td>
<td>-0.01 ns</td>
<td>-0.18***</td>
</tr>
<tr>
<td>X₂ X₄</td>
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<td>-0.14*</td>
<td>0.02 ns</td>
<td>-0.20***</td>
</tr>
<tr>
<td>X₃ X₄</td>
<td>-0.23***</td>
<td>-0.14*</td>
<td>0.03 ns</td>
<td>-0.28***</td>
</tr>
<tr>
<td>X₁²</td>
<td>-0.24***</td>
<td>-0.18***</td>
<td>-0.31***</td>
<td>-0.13**</td>
</tr>
<tr>
<td>X₂²</td>
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<td>-0.19***</td>
<td>-0.35***</td>
<td>-0.20***</td>
</tr>
<tr>
<td>X₃²</td>
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<td>-0.18***</td>
<td>-0.10 ns</td>
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<tr>
<td>X₄²</td>
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<td>-0.14*</td>
<td>-0.36***</td>
<td>-0.15***</td>
</tr>
<tr>
<td>R²</td>
<td>0.920</td>
<td>0.809</td>
<td>0.835</td>
<td>0.924</td>
</tr>
<tr>
<td>Adeq. Precision</td>
<td>12.780</td>
<td>7.284</td>
<td>7.043</td>
<td>17.622</td>
</tr>
</tbody>
</table>
16.4.2. Compromised optimum condition

The compromised optimum condition for the development of ready-to-eat extrudates was then determined numerical optimization technique using design expert software (Statease, Design Expert 7). The final product would be considered optimum, if the sensory score are as high as possible, whereas remaining parameters should be in range. Therefore, compromised optimum condition criteria applied for numerical technique optimization were as follows: (1) maximum sensory score and antioxidant activity for product acceptability and antioxidant activity; (2) lateral expansion, weight per unit length, bulk density, water absorption capacity, moisture content, water solubility index and hardness in range are presented (Table 16.7). The optimum condition obtained for the development of extrudates snacks were: corn flour 43.27%, rice flour 37.60%, chickpea flour 18.00% with radish leaf powder 3.99%. Similarly, extrusion was done using mulberry leaves and optimized at 5% addition (Charunuch et al., 2008). Shirani and Ganesharanee, (2009) revealed that fenugreek, could be added up to a 15% in a chickpea–rice blend to develop snacks with lower glycemic index. Pictorial view of coated extruded snacks as per DOE (thirteen formulations) is shown (Figure 16.8).

Optimization of extrudates formulation in respect of corn flour (A), rice flour (B), chick pea flour (C) and radish leaf powder (D) were carried out and found that the sensory scores in terms of taste, appearance, mouthfeel and over all acceptability were 8.6, 8.2, 8.6 and 8.5, respectively (Table 16.8).

Table 16.9 presents actual values of independent variables at five levels of the CCRD design for optimizing coating material used to extrudates coating. Experimental design in coded form for response surface analysis is shown in table 16.10.
Experimental combinations in coded and uncoded levels for oil and spice mix as coating material to optimized extruded extruded snacks (table 16.11).

16.4.3. **Characteristics of coated optimized extrudates**

Sensory properties of the developed optimized extruded products with coating are presented (Table 16.12).

16.4.3.1. **Sensory taste**

The sensory taste of the coated extrudates ranged from 6.250 to 8.333 (Table 16.13) depending upon the varying levels of oil blend and spice mix. The response plots for taste as a function of raw material formulations has been shown in the figure 16.21. Table 16.13 shows the coefficient of model and other statistical attributes of sensory overall acceptability. The Adequate precision value of 7.29 signifies that the model can be employed to navigate the design space since it is greater than 4.0 (Montgomery, 1997). The Model P-value implies that model is significant (P < 0.001). $R^2$ value of the model is 0.874. The significance of each coefficient can be determined using P value. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on sensory overall acceptability data. The results were obtained after performing different experiments as per CCRD to identify the effect of significant variables alone.

Sensory taste = $Y_1 = 8.66 + 0.26 X_1 + 0.27 X_2 - 0.33 X_1^2 - 0.41 X_2^2$ (16.14)

In Eqn. (16.14) the linear and quadratic effects are significant, whereas, oil blend ($X_1$) and spice mix ($X_2$) both show (p≤ 0.05) positive effect on the overall acceptability.
Table 16.7. Physical properties of the developed optimized extruded products

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Optimized extruded products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight/ 10cm length, g/10cm</td>
<td>1.38±0.02</td>
</tr>
<tr>
<td>Bulk density, Kg/m$^3$</td>
<td>121.87±2.27</td>
</tr>
<tr>
<td>Lateral expansion, %</td>
<td>353.33±16.67</td>
</tr>
<tr>
<td>Moisture content, % d.w.b.</td>
<td>7.78±0.21</td>
</tr>
<tr>
<td>Hardness, g</td>
<td>1036.92±148.28</td>
</tr>
<tr>
<td>Water absorption capacity, g/g</td>
<td>7.26±0.13</td>
</tr>
<tr>
<td>Water solubility index, %</td>
<td>5.83±0.24</td>
</tr>
</tbody>
</table>

Table 16.8. Sensory properties of the developed optimized extruded products

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Optimized extruded products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensory taste</td>
<td>8.00±0.64</td>
</tr>
<tr>
<td>Sensory appearance</td>
<td>8.33±0.43</td>
</tr>
<tr>
<td>Sensory mouth feel</td>
<td>7.93±0.50</td>
</tr>
<tr>
<td>Overall acceptability</td>
<td>8.15±0.51</td>
</tr>
</tbody>
</table>
Table 16.9. Actual values of independent variables at five levels of the CCRD design

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Uncoded</th>
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</thead>
<tbody>
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<td></td>
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</tr>
<tr>
<td>Oil (%)</td>
<td>$X_1$</td>
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</tr>
<tr>
<td>Spice mix (%)</td>
<td>$X_2$</td>
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</table>

Table 16.10. Experimental design in coded form for response surface analysis

<table>
<thead>
<tr>
<th>Coded variables</th>
<th>Combinations</th>
<th>Replications</th>
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<tr>
<td>$\pm 1$ $\pm 1$</td>
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<td>$\pm 1.414$ 0</td>
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<td>0 $\pm 1.414$</td>
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<tr>
<td>0 0</td>
<td>5</td>
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</tbody>
</table>

‘0’ is for centre point of the parameter range investigated ‘$\pm 1$’ for factorial points, and ‘$\pm 1.414$’ for star points; $x_1$ – Oil (%), $x_2$ – Spice mix (%)
Table 16.11. Experimental combinations in coded and uncoded levels for oil and spice mix as coating material to optimized extruded snacks

<table>
<thead>
<tr>
<th>Expt. No.</th>
<th>Coded variables</th>
<th>Uncoded variables</th>
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<tbody>
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<td></td>
<td>$x_1$</td>
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<td>7</td>
<td>0</td>
<td>-1.41</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>1.41</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 16.12 Effect of independent variables on values of responses (sensory attributes)

<table>
<thead>
<tr>
<th>Expt. No.</th>
<th>Sensory attributes</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Appearance(Y₁)</td>
<td>Texture(Y₂)</td>
<td>Taste(Y₃)</td>
<td>Overall Acceptability(Y₄)</td>
</tr>
<tr>
<td>1</td>
<td>7.85±0.21</td>
<td>7.48±0.26</td>
<td>7.61±0.59</td>
<td>7.75±0.46</td>
</tr>
<tr>
<td>2</td>
<td>8.08±0.10</td>
<td>7.45±0.22</td>
<td>7.79±0.52</td>
<td>7.72±0.19</td>
</tr>
<tr>
<td>3</td>
<td>8.57±0.33</td>
<td>8.35±0.43</td>
<td>7.74±0.82</td>
<td>8.05±0.44</td>
</tr>
<tr>
<td>4</td>
<td>8.35±0.34</td>
<td>8.20±0.67</td>
<td>8.19±0.51</td>
<td>8.45±0.52</td>
</tr>
<tr>
<td>5</td>
<td>7.73±0.40</td>
<td>7.37±0.423</td>
<td>7.56±0.62</td>
<td>7.57±0.34</td>
</tr>
<tr>
<td>6</td>
<td>8.20±0.30</td>
<td>7.60±0.24</td>
<td>8.62±0.13</td>
<td>8.10±0.25</td>
</tr>
<tr>
<td>7</td>
<td>7.73±0.38</td>
<td>7.53±0.25</td>
<td>7.34±0.68</td>
<td>7.64±0.51</td>
</tr>
<tr>
<td>8</td>
<td>8.72±0.29</td>
<td>8.88±0.29</td>
<td>8.51±0.32</td>
<td>8.53±0.52</td>
</tr>
<tr>
<td>9</td>
<td>8.58±0.19</td>
<td>8.63±0.10</td>
<td>8.84±0.18</td>
<td>8.65±0.15</td>
</tr>
<tr>
<td>10</td>
<td>8.78±0.19</td>
<td>8.75±0.22</td>
<td>8.40±0.36</td>
<td>8.56±0.31</td>
</tr>
<tr>
<td>11</td>
<td>8.82±0.13</td>
<td>8.72±0.31</td>
<td>8.66±0.23</td>
<td>8.68±0.25</td>
</tr>
<tr>
<td>12</td>
<td>8.87±0.08</td>
<td>8.78±0.31</td>
<td>8.65±0.31</td>
<td>8.67±0.37</td>
</tr>
<tr>
<td>13</td>
<td>8.85±0.08</td>
<td>8.83±0.14</td>
<td>8.73±0.25</td>
<td>8.70±0.36</td>
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</tbody>
</table>
Table 16.13. ANOVA for sensory attributes (responses) for coated extrudates

<table>
<thead>
<tr>
<th>Coefficient of model terms of sources</th>
<th>ST(Y₁)</th>
<th>SA(Y₂)</th>
<th>SM(Y₃)</th>
<th>SOA(Y₄)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>8.66***</td>
<td>8.78***</td>
<td>8.74***</td>
<td>8.65***</td>
</tr>
<tr>
<td>Oil blend</td>
<td>0.26**</td>
<td>0.08ns</td>
<td>0.02ns</td>
<td>0.14***</td>
</tr>
<tr>
<td>Spice mix</td>
<td>0.27**</td>
<td>0.29***</td>
<td>0.44***</td>
<td>0.29***</td>
</tr>
<tr>
<td>X₁²</td>
<td>-0.33***</td>
<td>-0.38***</td>
<td>-0.62***</td>
<td>-0.40***</td>
</tr>
<tr>
<td>X₂²</td>
<td>-0.41***</td>
<td>-0.25***</td>
<td>-0.26***</td>
<td>-0.27***</td>
</tr>
<tr>
<td>XX₂</td>
<td>0.07ns</td>
<td>-0.11ns</td>
<td>-0.03ns</td>
<td>0.11**</td>
</tr>
<tr>
<td>R²</td>
<td>0.874</td>
<td>0.932</td>
<td>0.985</td>
<td>0.983</td>
</tr>
<tr>
<td>Adeq. Precision</td>
<td>7.295</td>
<td>11.179</td>
<td>22.105</td>
<td>19.491</td>
</tr>
</tbody>
</table>

Level of Significance: * P<0.1, **P<0.05, *** P<0.01, ns not significant; df: degrees of freedom

16.4.3.2. Sensory appearance

The sensory appearance of the extrudates ranged from 6.083 to 7.750 (Table 16.13). The experimental data fitted into the quadratic model. The response plots for appearance as a function of oil blend (X₁) and spice mix (X₂) are shown in figure 16.22. Table 16.13 shows the coefficient of model and other statistical attributes of sensory appearance. The Adequate precision value of 11.179 indicates that the model
can be used to navigate the design space as it is greater than 4.0 (Montgomery, 1997).

The Model Model is significant with P value < 0.001. $R^2$ value of the model is 0.932. The significance of each coefficient can be determined using P value. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on sensory appearance data.

Following relationships developed with the coded values of independent variable:

Sensory appearance = $Y_2 = 8.78 + 0.29 X_2 - 0.38 X_1^2 - 0.25 X_2^2$ (16.15)

In Eqn. (16.15) the linear effect of spice mix ($X_2$) is positively significant ($p \leq 0.01$), indicates oil blend ($X_1$) has adverse effect on the sensory appearance may be due to oil stickiness which does not appear as good.

Figure 16.21. Variation of sensory taste with respect to oil blend and spice mix as coating parameters for extrudates
16.4.3.3. Sensory mouth feel

The mouth feel of the extrudates ranged from 6.083 to 8.333 (Table 16.13). The response surfaces for mouthfeel as a function of oil blend ($X_1$) and spice mix ($X_2$) has been shown in figure 16.23. Table 16.13 shows the coefficient of model and other statistical attributes of sensory overall acceptability. The Adequate precision value of 22.105 signifies that the model can be employed to navigate the design space as it is greater than 4.0 (Montgomery, 1997). The value of $R^2$ is 0.98. The significance of each coefficient can be decided using P value. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on sensory overall acceptability data, in which A, B, C and D indicate corn flour, rice flour, chickpea flour and radish leaf powder respectively.

The terms having $p\leq 0.01$ were considered as highly significant terms having $p\leq 0.05$ as significant only. The effect of the independent variables on the mouth feel of functional extrudates is clear from the following relations:
In Eqn. 16.16 the linear effect of spice mix ($X_2$) is again positive and highly significant ($p \leq 0.01$), indicates having excellent mouthfeel whereas, oil blend ($X_1$) has adverse effect on the sensory mouth feel may be due to oil stickiness.

### 16.4.3.4. Sensory overall acceptability

The overall acceptability was obtained by aggregating the sensory values of taste, appearance and mouthfeel. The OAA (Over All Acceptability) of the extrudates ranged from 6.433 to 7.967 (Table 16.13). Table 16.13 shows the coefficient of model and other statistical attributes of sensory overall acceptability. The Adequate precision value of 19.49 signifies that the model can be employed to navigate the design space as it is greater than 4.0 (Montgomery, 1997). $R^2$ value of the model is 0.983. The significance of each coefficient can be decided using P value. Considering, all above criteria, the quadratic model that describes the effect of independent variable accurately fitted on sensory overall acceptability data, in which $X_1, X_2, X_3$ and $X_4$ indicate corn flour, rice flour, chickpea flour and radish leaf powder respectively.

The response plots for OAA as a function of two variables has been shown in figure 16.24. The quadratic relations for OAA after considering the significant terms are:

Sensory overall acceptability $= Y_4 = 8.65 + 0.14 X_1 + 0.29 X_2 - 0.40 X_1^2 - 0.27 X_2^2 + 0.11 X_1 X_2$ \hspace{1cm} (16.17)

In Eqn. (16.17) the linear effect of oil blends ($X_1$) and spice mix ($X_2$) has highly significantly ($p \leq 0.01$) positive effect on the overall acceptability. Quadratic effect is also significant positively ($p \leq 0.05$) showing combined effect stimulates the
sensory acceptability of the extrudate. Adding radish leaf powder as one the ingredient of spice mix (B) also has remarkable advantage for imparting sensory attributes and nutritional benefits as well (Ankita and Prasad, 2014b). Naidu et al., 2011 reported role of fenugreek for lowering glycemic index. Addition of 10% dehydrated fenugreek to wheat flour raised the contents of protein (10.5%), dietary fibre (12.7%) (Hooda and Jood, 2005).

![Image](image1.png)

**Figure 16.23** Variation of sensory texture with respect to oil blend and spice mix as coating parameters for extrudates

![Image](image2.png)

**Figure 16.24** Variation of sensory overall acceptability with respect to oil blend and spice mix as coating parameters for extrudates
16.4.5. Characteristics of optimized coated extrudates

Development of optimized conditions for coating of optimized extruded product with oil content ($X_1$) 50.78% and spice mix ($X_2$) 70.48% and is listed in table 16.14. Proximate analysis (Naidu et al., 2011) was done for optimized extrudates and listed in table 16.15. Crude fiber content was found to be 11.381% as appropriate amounts and the protein content was also found 15.200% in appreciable amounts whereas, 6.8-16.30% dietary fiber and 10.5-14.8 % protein was reported in mathri and thalipeeth, respectively containing 4% dehydrated leaf powder (Gupta and Prakash, 2011). The studies are in agreement of previous findings (Santosa et al., 2008; Long et al., 2014; Shoar et al., 2010).

Chlorophyll (20.860mg/100g), β-carotene (0.062μg/100g) and antioxidant activity (35.50%) values with energy value of 329.485 calories of coated extrudates were remarkable and role of added leafy powders shows significant benefits. β-carotene content of 1.19 mg/100g and 1.12 mg/100g was found in theelipeth and mathri containing 4% dehydrated leaf powder respectively (Gupta and Prakash, 2011). Similar observations have been reported by Kumar, (2010) who incorporated dehydrated carrot in extruded snacks and who incorporated dehydrated Peucedanum graveolens in wheat based papads.

Optimized condition criteria applied for numerical technique optimization were as follows: (1) oil blend (in range) and (2) spice mix (in range) for product acceptability and thus physical and sensory properties of the obtained product are presented in table 16.16, 16.17.
Table 16.14 Development of optimized conditions for coating of optimized extruded product

<table>
<thead>
<tr>
<th>Optimised independent variables</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>5.78</td>
</tr>
<tr>
<td>Spice Mix</td>
<td>7.48</td>
</tr>
</tbody>
</table>

Table 16.15 Proximate analysis (optimized, extruded snacks)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Optimized extruded snacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>9.48±0.08</td>
</tr>
<tr>
<td>Total Carbohydrates (%)</td>
<td>58.72±3.18</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>15.20±0.68</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>3.75±0.18</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>1.46±0.60</td>
</tr>
<tr>
<td>Crude Fiber (%)</td>
<td>11.38±1.80</td>
</tr>
<tr>
<td>Chlorophyll (mg/100g)</td>
<td>20.86±0.23</td>
</tr>
<tr>
<td>β-Carotene (μg/100g)</td>
<td>0.06±0.02</td>
</tr>
<tr>
<td>Antioxidant activity (%)</td>
<td>35.50±2.12</td>
</tr>
<tr>
<td>Energy (calories)</td>
<td>136.71±8.89</td>
</tr>
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</table>
Table 16.16. Physical properties of coated optimized extruded products

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Optimized extruded snacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight/length, g/10cm</td>
<td>1.62±0.02</td>
</tr>
<tr>
<td>Lateral expansion, %</td>
<td>441.67±16.67</td>
</tr>
<tr>
<td>Hardness, g</td>
<td>885.85±80.45</td>
</tr>
<tr>
<td>Bulk density, kg/m³</td>
<td>118.45±0.86</td>
</tr>
<tr>
<td>Water absorption capacity, g/g</td>
<td>7.26±0.13</td>
</tr>
<tr>
<td>Water solubility index, %</td>
<td>5.83±0.24</td>
</tr>
</tbody>
</table>

Table 16.17. Sensory properties of coated optimized extruded products

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Optimized extruded snacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensory taste</td>
<td>8.87±0.17</td>
</tr>
<tr>
<td>Sensory appearance</td>
<td>8.87±0.33</td>
</tr>
<tr>
<td>Sensory mouth feel</td>
<td>8.78±0.29</td>
</tr>
<tr>
<td>Overall acceptability</td>
<td>8.68±0.47</td>
</tr>
</tbody>
</table>
16.4.5.1. Scanning Electron Microscopy

A beam of electrons was made to pass through the extrudates coated with a gold film (makes it conductor) as a result of electron penetration, the scanning of extrudates was done electronically. SEM investigation includes study i.e. macroscopy, microscopy, evaluation of physicochemical parameters and phytochemical screening. Optimized extrudate and its SEM image is shown in figure 16.25. Starch granules of varying sizes were observed on the outer surface of dry extrudates. Uncoated extrudates seemed as compact particles. Similar results were reported by Long et al., 2014. It is rough, irregular and full of holes as observed by Chen and Luh, 1999. Optimized coated extrudate and its SEM image are shown in figure 16.26. The entire surface of coated extrudates seems to be coated with a smooth oil film. Numerous small holes and cracks, which would facilitate rapid water penetration, were present on the surface. The starch granules within the extrudates appear to be slightly swollen and irregular in size and shape, perhaps indicating the level of gelatinization during the extrusion process.

![Figure 16.25 SEM image of optimized extrudates at 300X, 500X and 1000X and pictorial view of optimised extrudates](image-url)
16.4.5.2. FTIR spectroscopy study

IR spectroscopy is a powerful technique which provides fingerprint information on the chemical composition of the extrudates giving information regarding the functional groups at particular wave number (reciprocal of wave length). Fourier Transform (FT), radiant power data is recorded as a function of time. This study has wide applicability in structure elucidation, which are either synthesized chemically or of natural origin (Baravkar and Kale, 2011; Doyle, 1992).

Figure 16.27 shows the various functional groups present in the extrudates which appearing in form of bands due to molecular vibrations. Regions of stretching and bending includes (-C-O-CH2-) stretching, bending (C-H) bending, and C-O, C=C
Figure 16.27. FTIR spectroscopy for the raw ingredients and the optimized extrudates
(ring) stretching, ring vibrations of carbohydrates in wave number range 1200-100 cm\(^{-1}\), tocopherol (1089-1058 cm\(^{-1}\)), Symmetric -C-H bending of methyl group (1400-1330 cm\(^{-1}\)), C-C (ring) stretching and C-H (ring) bending, stretching of -C-H of the CH\(_2\) and CH\(_3\) aliphatic groups of fatty acids (1485-1425 cm\(^{-1}\)), C=O, C-N stretching of amide I, N-H, C-O bending and C-C, C-N stretching of amide II, C=C (ring) stretching, C-C, C-O bending (1690-1485 cm\(^{-1}\)), protein beta sheet (1639-1613 cm\(^{-1}\)), C=O stretching of carbonyl groups (ketone, esters and acids) (1800-1700 cm\(^{-1}\)). Work on presence of various groups at respective wave numbers is illustrated by Kaya-Celiker et al., 2014; Jaiswal et al., 2015; Lecellier et al., 2015.

16.5. CONCLUSION

The overall acceptability scores of different exdrudates were greater than 8 showing an above par sensory acceptability. The optimum conditions obtained by numerical optimization for successful development of extrudates were as corn flour 40.10%, rice flour 39.77%, chick pea flour 18.00% and radish powder 3.99%. Sensory evaluation results signify that the chickpea flour and radish leaf powder can be incorporated into ready-to-prepare products at significant levels without altering their acceptability. The application of oil and spice mix coating have further improved the acceptability and nutritional attributes in order to get a functional extrudates.
SUMMARY AND CONCLUSION

The outcome of present research investigation on hot air drying kinetics, moisture sorption isotherm and product characterization of selected green leafy vegetables resulted in the development of different optimized leaf powders from spinach, mustard, fenugreek and radish leaves. The obtained leaf powders were fractionated and characterized. The final characterized leaf powders were used in the development of ready to prepare product (sarson ka saag) and the ready to eat product (expanded extrudates with enhanced acceptability and nutrition). The recovery of leaves was found to be in the range 37.53 to 45.75 % and having the moisture content of fresh leaves ≥87.77% (w.b). Chlorophyll content of fresh leaves ranged from 107.34 to 178.25 mg/100g with maximum amount reported in spinach. β-carotene content of fresh leaf samples was found to be in the range of 4.50 mg/100g to 7.59 mg/100g.

In the present study efforts have been made to process the selected leaves into shelf stable form with maximum retention of quality characteristics. The dehydrated leaves both blanched and unblanched were converted into the powdered form followed by their fractionation and characterization on the basis of chemical, physical and optical parameters. As expected dehydration process was governed by the subjected pretreatment, dehydration temperature and exposure time during dehydration operation. The results revealed that temperature of 90°C was not acceptable for the dehydration process of leaves. The activation energy of green leafy vegetables was calculated from the temperature range of 50°C to 90°C.
Drying kinetic of the blanched and unblanched spinach leaves at five selected temperatures was studied. Experimental data fitted to various mathematical models showed Page model coming up as the best fit model. Diffusivity and activation energy values were calculated from the selected temperature range. Combination temperature not only saves the drying time but also improves drying rate, nutritional and functional characteristics of dehydrated leafy vegetables. Thus the combination temperature of $80^\circ C$ for one hour and $60^\circ C$ for the rest two hours was derived and chosen for carrying out the drying of spinach for three hours. Combination temperature of $70^\circ C$ for one hour and $60^\circ C$ for the rest two hours was similarly chosen for carrying out the drying of fenugreek. Combination temperature of $80^\circ C$ for one hour and $70^\circ C$ for the rest two hours was chosen for carrying out the drying of radish leaves. Mustard leaves were selected as acceptable for blanching treatment and drying temperature of $70^\circ C$ as per the desired quality characteristics required for the ready to prepare food product (Saag). Leaf powder obtained at a particular dehydration temperature without any treatment reflected better acceptability which was further improved upon fractionation by the use of 60 BSS (250 µm) sieve. Blanched mustard leaf powder dried at $70^\circ C$ was selected for the development of ready to prepare saag (an important Indian delicacy).

Spinach leaf powders (mixed and fine fractions) were studied for moisture sorption isotherms (curves) important for carrying out shelf life studies. Further, mathematical models were used to ascertain the adequacy of experimental data fitted to several model equations. Different equations (Smith, Polynomial, BET, Hailwood and Horbin and GAB) are used to describe the adsorption isotherm of shelf stable dehydrated powders. The data from sorption isotherms showed goodness of fit with GAB and Polynomial models on the basis of $R^2$ and E%. Thermodynamic functions
(differential enthalpy or heat of sorption, differential entropy and free energy) calculated from moisture sorption isotherms that allow the interpretation of experimental results in accordance with the statement of theory. These parameters were determined from the equilibrium data at different temperatures and their dependence was seen with respect to equilibrium moisture content.

Powdered samples were characterized on the basis of micro-structure, physical, chemical, optical and advanced analytical characteristics. The leaves of mustard and spinach are considered to be healthier meals and are used as major ingredients in traditional Indian cuisine (*sarson ka saag* often consumed with *makki ki roti*). The developed and characterized ingredients of saag (mustard powder, spinach powder and Corn flour supplemented corn starch) were used in different proportions as per the identified limits to fix the level of ingredients that were optimized by Response Surface Methodology. RSM as an efficient statistical optimization technique was effectively applied in the development and optimization of ready to prepare saag mix. The proportion of ingredients in optimized saag was found to be 14.18: 6.28: 12.76 for mustard powder, spinach powder and Corn flour supplemented corn starch, respectively.

The expanded extruded product was also developed from different leaf powder and flour mix. Addition of leaf powder to traditional starchy expanded snacks enhances its nutritional properties. Flours (corn flour, rice flour and chickpea flour) and powders (radish leaf powders) in different proportions were used as per the identified limits to fix the level of ingredients optimized by Response Surface Methodology for the development of crisp low density extruded snacks. The optimized extrudates were further subjected for the optimization of the levels to be used for the oil and spice mix as coating material to improve the acceptability as well
as the nutritive and functional values. The physico-chemical properties (weight per unit length, density, lateral expansion, moisture content, hardness, rehydration parameters and antioxidant property) of the extruded products were measured.