Chapter 2

REVIEW OF LITERATURE

Carrot (*Daucus carota*) is a root vegetable, usually orange, purple, red, white or yellow in color, with a crisp texture when fresh. It is a rich source of β-carotene and contains other vitamins, like thiamine, riboflavin, vitamin B-complex and minerals. Kaur *et al.*, (2009) reported the consumption of carrot mainly as raw, juice, salads, cooked vegetable, sweet dishes etc. Fruit and vegetable juices have become important in recent years due to overall increase in natural juice consumption as an alternative to the traditional caffeine containing beverages such as coffee, tea, or carbonated soft drinks. Carrot pomace has good residual amount of all the vitamins, minerals and dietary fibre. Several researchers have reported the use of by-products utilization in snack foods. Reviewed literature is divided into various sections covering the utilization of by-product and microstructural studies.

2.1 Carrot by-products utilization

Carrot pomace is a by-product obtained during carrot juice processing. The juice yield in carrots is only 60-70%, and even up to 80% of carotene may be lost with left over carrot pomace. The nutritional characteristics of carrot pomace have been reported by several researchers.

Mckee and Latner, (2000) recommended fiber as an important component of diet. Fiber supplementation is reported to enhance the fiber content of a variety of foods ranging from cereal-based products to meats.
Stoll et al., (2003) reported the development of carotene-rich functional food ingredient through mechanical and enzymatic breakdown of the tissue of carrot pomace. The ingredients were used to prepare model beverages based on cloudy apple juice, aiming at sustainable carrot juice production. Contrary to synthetic beta-carotene supplements, the stability of the natural alpha- and beta-carotene in the beverages proved to be excellent after 20 and 24 weeks storage under moderate and even intense illumination at 23 and 19°C, respectively.

Fiber-rich fractions (FRFs) including insoluble dietary fibre (IDF), alcohol-insoluble solid (AIS), and water-insoluble solid (WIS) were isolated from carrot pomace through different methods (Chau et al., 2004). The study revealed that carrot pomace was rich in insoluble FRFs (50.1-67.4 g/100 g), which were mainly composed of pectic polysaccharides, hemicellulose, and cellulose. These insoluble FRFs, especially WIS, were significantly (P<0.05) higher functional properties, glucose-adsorption capacity, and amylase-inhibition activity than those of cellulose. The capacity of these FRFs to adsorb glucose and reduce amylase activity implied that they might help to control post-prandial serum glucose level. Moreover, the yield, composition, functional properties, and in vitro hypoglycemic effects among the three FRFs was affected by their preparation methods.

Schweiggert, (2004) studied the utilization of carrot pomace as a source of functional ingredients. The various aspects considered included under-utilization of carrot pomace generated as a by-product of carrot juice manufacture. Carrot pomace is a source of carotenoids and fiber. Health and functional properties associated with fiber and carotenoid compounds posses the recovery of bioactive and functional compounds from carrot pomace. Application of carrot pomace in functional foods and use of hydrolyzed carrot pomace as a functional ingredient in beverages have possibilities for obtaining bioactive oligogalacturonic
acids by enzymic breakdown of carrot pectin and future potential for increasing pomace utilization.

Nawirska and Kwasniewska, (2005) reported dietary fibre and its components in different samples (apple, black currant, chokeberry, pear, cherry and carrot pomace). The components of major importance were cellulose, hemicelluloses, lignin and pectins. The results revealed that each pomace sample, pectins occurred in the smallest amounts, and the content of lignin was very high (black currant and cherry pomace) or comparatively high (pear, chokeberry, and apple and carrot pomace).

Yoon et al., (2005) produced soluble-fibre hydrolyzate by using enzymes from carrot pomace. Carrot pomace was treated with a mixture of 1% NaOH and 2% acetic acid, and the pretreated sample was hydrolyzed by edible crude enzyme. The supernatant portion was then treated with 85% ethanol and separated into alcohol-soluble dietary fibre (ASDF) and alcohol-insoluble dietary fibre (AIDF). AIDF increased from an initial value of 3.3 g/100 g to 41.7 g/100 g carrot pomace after 96 h of reaction. The AIDF contained rhamnose, arabinose, mannose, galactose, glucose and a small amount of xylose. Monosaccharides (glucose, fructose, galactose, arabinose), cellobioisaccharides (cellopentaose, cellotetraose, cellotriose, cellobiose), and galactooligosaccharides (galactotetraose, galactotriose) were detected in the ASDF.

Kumar et al., (2010) developed and characterized extruded product of carrot pomace, rice flour and pulse powder. Rice flour was added in different proportions (10 - 30%) to dehydrated carrot pomace and pulse powder (CPPP) mixture having equal ratio. The formulation was extruded at different moisture content (17 - 21%), screw speed (270 - 310 rpm) and die temperature (110 - 130°C). The lateral expansion, bulk density, water absorption index, water solubility index, hardness and sensory characteristics were measured
as responses. Significant regression models were established. The results indicated that CPPP proportion and moisture content significantly influenced (P<0.10) lateral expansion; temperature for water absorption index; screw speed and temperature for hardness and screw speed for sensory score.

Kumar et al., (2010) developed and characterized extruded product using carrot pomace and rice flour. Dehydrated carrot pomace was added in different proportions (10-30%) to rice flour. The formulation was extruded at varied moisture content (17-21%), screw speed (270-310 rpm) and die temperature (110-130°C). The experimental combinations were decided based on central composite rotatable design for four variables at five levels of each variable. The lateral expansion, bulk density, water absorption index, water solubility index, hardness and sensory characteristics were measured as responses. Significant regression models were established. The results indicated that pomace proportion, screw speed and temperature significantly influenced (P<0.10) lateral expansion; moisture content and screw speed for bulk density; pomace proportion and temperature for water absorption index and water solubility index, pomace proportion, screw speed and temperature for hardness and screw speed for sensory score. The compromised optimum condition obtained by numerical integration for development of extrudates were: carrot pomace of 11.75% in rice flour, moisture content 19.92%, screw speed 249.1 rpm and die temperature 114.3°C. Sensory evaluation revealed that carrot pomace could be incorporated into ready-to-eat expanded products up to the level of 11.75%.

Tangirala et al., (2012) modelled and characterized blended guava pomace and pulse powder based rice extrudates. The effect of guava pomace and pulse powder incorporation in to rice based extrudates on physical characteristics were studied. Guava pomace collected after juice extraction was dried and milled. It was then added with pulse powder-rice flour
blend at different combinations based on Central Composite Rotatable Design (CCRD). The independent variables were moisture content (17 – 21%), temperature (115 – 135°C), screw speed (230 – 270rpm), and varying proportion of rice, pulse and guava pomace. Higher feed moisture content resulted in extrudates with a higher density, lower expansion, higher water absorption index, lower water soluble index, and higher hardness. Higher barrel temperature resulted in reduced density, increased expansion, and water solubility index. Addition of guava pomace resulted in an increase in water absorption index, hardness and decreased bulk density, expansion and water solubility index. The study recommended that the guava pomace may be utilized up to the level of 10% to ready to eat snacks.

2.2 Pigeon pea

Pigeon pea (Cajanus cajan) belongs to family Fabaceae and commonly known as ‘Arhar’, ‘Tur’ or Red gram. Pigeon pea ranks sixth among pulse production in the world and it is one of the major legume (pulse) crop of the tropics and subtropics. Average world production of pigeon pea was 3.49 million tonnes in the year 2009 (FAO statistics, 2009). India is the largest producer of pigeon pea and contributes more than 75% of world production. Pigeon pea significantly contributes to meet the dietary requirements of crude fiber, ash, fat, magnesium, manganese, and copper (Faris & Singh, 1990).

Before cooking or other processing operations, it is necessary to remove the fibrous seed coat (hull) of pigeon pea in order to reduce the fibre content and palatability. Pulses have 11 – 14% seed coat (husk), 2-5% germ, and remainder endosperm (Kyiet et al., 1997). The hull of pigeon pea adheres tightly to the cotyledons through a gummy layer that does not allow separation of hull during milling, thus making the pulse difficult to mill. There are two approaches to remove hulls, namely wet and dry milling. Generally, the dry method of milling is used throughout the Indian subcontinent for milling of pigeon pea because the
quality of splits from wet milling is poor (Kurien & Parpia, 1968). During decupling, noticeable amounts of cotyledon material and germ are removed, which results in considerable losses (Siegal & Fawcett, 1976). In practice, traditional milling recovers only about 65-75%. Modern milling methods can recover 82-85% (Kyi et al., 1977). During milling of pigeon pea, yield was found to be only 76% against an estimated yield of 84% (Khare et al., 1966). The method of decupling significantly affects the formation of broken and powdered particles and in case of pigeon pea it varies between 9 – 24.6% for broken and 5.5-6.1% powder particles (Singh et al., 1992).

When pigeon pea seed is processed to make dhal, its recovery ranges between 65 and 75%. The remainder by-product (25-35%), known as 'chunf' is a good source of concentrate ration to cattle (Faris & Singh, 1990). This by-product usually consists of 3-8% broken cotyledons, 5.5 - 6.1% powder, and 10% husk. Chunfs is used by dairy owners or feed mills to prepare cattle feeds. The powder and broken cotyledons are valuable sources of protein for cattle and poultry, and are sold at a higher price, when these are aspirated off husk (Kurien & Parpia, 1968).

Mueses et al., (1993) evaluated the possibility of using flour of pigeon pea in products prepared with rice and wheat flour. Three products were gruel, fruit-flavoured thick drink with and without 15% milk, cookies with blends of pigeon pea flour (extrusion-cooked) and wheat. The gruel and the fruit flavored products had high acceptability based on a sensory evaluation test. Cookies with 100% pigeon pea flour were unacceptable; however, mixtures of 75% wheat flour and 25% pigeon pea flour gave cookies of attractive appearance and good taste.

Torres et al., (2006) utilized fermented pigeon pea flour in a proportion of 5, 10, and 12% in pasta products. The products obtained had longer cooking times, higher cooking
water absorptions, higher cooking loss, and higher protein loss in water than control pasta (100% semolina). From sensory evaluations, fortified pasta with 5 and 10% fermented pigeon pea flour had an acceptability score similar to control pasta. Pasta supplemented with 10% fermented pigeon pea flour presented higher levels of protein, fat, dietary fiber, mineral, vitamin E, and Trolox equivalent antioxidant capacity than 100% semolina pasta and similar vitamins B₁ and B₂ contents. Protein efficiency ratio was improved after supplementation with 10% fermented pigeon pea flour.

Rampersad et al., (2006) studied the physico-chemical and sensory characteristics of flavored snacks from extruded cassava/pigeon pea flour. The effect of pigeon pea flour (PF) addition to cassava flour (CF) on the sensory and physico-chemical quality of extrudates was observed. Products with added PF were more yellow, had higher protein, bulk density, and water absorption index with lower expansion and water absorption index. Extrudate with 95% CF/5% PF had a suitable crisp to hard texture.

2.3 Rice

Rice (Oryza sativa) is a cereal foodstuff which forms an indispensable part of diet, due to significant biological value and digestibility. India is the second largest producer of paddy. The country produced 155.70 million tonnes in 2011 (FAO statistics, 2011). Paddy is mainly consumed in the form of rice obtained from primary processing. Paddy contains 20-25% husk, (including about 2% trash), 6% bran, and 75% rice (2% of the rice is very small pieces).

The processing of paddy to rice involves the milling by using hullers, shellers and modern rice mills. The by-products from the hullers do not have much option to convert to value added products. The sheller and modern rice mills generate by-products, which have good option for utilization. The main by-products of rice mills are rice broken, husk and bran,
which do not have mass acceptability in the country. Husk is being used for generating steam hard board etc. Rice bran is mainly used for oil extraction; and the oil is popularly known as rice bran oil (RBO). Broken rice is used in flour form in traditional recipes. The broken were ground to rice flour, which can be used to develop extrudates as base material due to higher expansion because of high starch content.

2.4. Extrusion studies

Extrusion causes the profound effect on the physical and functional properties of the extrudates by varying different operating characteristics. This leads to the development of variety of products with unique physical and functional properties. The researchers used rice, wheat, barley and other cereal flour for extrusion as a base material. The incorporation of fruits, vegetables and pulse powder has been reported. The development of valued added and fibre rich by extrusion process were also reported.

Gillespie, (1971) reported the development of free flowing starch substitute product for application in the food industry, which was produced from wheat flour and/or corn flour and/or rice flour and/or potato flour. The starting material was expanded in a continuous automatic pressure cooker-extruder and then dried, ground and sifted.

Buchanan, (1975) developed the products 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 young children. The ingredients were blended together then processed in a cooker-extruder, followed by a belt drier.

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.

**Chauhan and Bains, (1988)** studied the effect of some extruder variables on physicochemical properties of extruded rice-legume blends. Rice flour and flours prepared from legumes (soybean, bengal gram, green gram, black gram) were mixed (rice: legume ratio 75:25) and extruded in an extruder. Products were analyzed for physical characteristics (expansion ratio, density, water absorption index, water solubility index, fracturability, 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.

**Ruales et al., (1988)** studied the nutritional quality of blended extruded foods of rice, soy and lupins. The raw materials used in the study 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 fibre, starch availability, minerals (Zn, Fe, Ca, Mg, Cu), nutrient density, fatty acid composition and amino acid composition.

**Ryu an Lee, (1988)** examined the effects of moisture content and particle size of rice flour on physical properties of the extrudate. Effects 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. Increase in expansion ratio and decrease in bulk density was reported as the 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 of extrudates decreased, while the lightness
increased, the apparent viscosity increased and the water solubility index decreased. The degree of dextrinization was influenced by moisture content and particle size.

Maga and Kim, (1989) studied the co-extrusion of rice flour 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 blends obtained were extruded in a laboratory Brabender single-screw extruder. Extruder torque and 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 fruits and concentrates produced a significant reduction in extruder torque.

Kim et al., (1989) evaluated the properties of extruded dried distiller grains and flour blends. 0, 20, 50 and 100% of corn, wheat, rye, barley, sorghum and oat-derived distillers dried grains (DDG) were blended with corn, potato, rice and wheat flours, at a total moisture content of 22%, and extruded in a Brabender laboratory single screw extruder at barrel temperature of 170 or 210°C. Compression ratio of 3:1, screw operating at 100 rpm and a 3.175 mm die were used for all runs. In general, extruder torque requirement decreased with increasing levels of DDG, while product density increased. Extrudate longitudinal expansion index increased with increasing DDG. Yield and radial expansion either increased or decreased, depending on DDG type and amount.

Visessurakarn et al., (1991) used broken rice for breakfast cereals. Processing conditions for production of a broken rice-based breakfast cereal were extruder temperature 180°C; 2mm die; and initial moisture content of raw mix, 13%. 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 contained per 100 g 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 5.6g moisture, and gave an acceptability score of 6.90 ± 0.79 on a 9-point hedonic test scale.

Abdel et al., (1992) examined 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. Increasing feed moisture level reduced the torque in the barrel. Higher feed moisture level reduced expansion, density, product appearance and water solubility index of W/F extrudates. Higher temperature affected the physical properties of W/F in a similar way; R/FP extrudates showed no change in properties, when processed at higher moisture and temperature levels, respectively.

Ming et al., (1993) studied the factors affecting starch degradation of rice extruded by a twin-screw extruder. Effects of processing variables (feed moisture content, 11-19%; feed rate, 332-576 g/min; barrel temperature, 110-120 °C 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 studied. 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. Feed rate significantly affected WSC, when the feed moisture content and screw speed was greater than 15% and 160 rpm, respectively.

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 (ratio of the solids of rice and chick pea flour \( = 100:0 \), \( 90:10 \) and \( 80:20 \)), and (ii) temperature of die (100, 125 and 150°C). The torque during extrusion was measured, as well as product characteristics such as expansion ratio, bulk density and shear strength. Incorporation of chick pea into rice flour decreased torque and product expansion, but increased bulk density and shear strength. The temperature of the die had a linear effect on these parameters.

Lasekan et al., (1996) observed the influence of extrusion cooking on the nutritional value, storage stability and sensory characteristics of an indigenous maize-based snack food. Samples were analysed for available lysine loss, protein dispersibility index (PDI), changes in total carbonyls (lipid oxidation) and sensory characteristics during storage (at 25, 30 and 40°C). Extruded samples suffered low loss (10%) in available lysine but had an appreciable reduction in PDI. Storage at moisture contents above the monolayer region reduced greatly the total carbonyls in samples. However, total carbonyls of products were found to increase with increase in storage temperature. In addition, storage at high temperature (40°C) significantly reduced the sensory acceptance of the maize-based snack.

Lee and Han, (1997) evaluated the impact of raw material composition, feed moisture 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 fillet fish. Nitrogen solubility index, integrity index, rehydration ratio, density, lightness and external appearance of extrudates were measured as indices of the changes of physicochemical properties of extrudates. Increased amounts of rice flour (up to 30%) in feed mixtures resulted in increased rehydration ratio, but decreased density. Extrudate prepared at die temperature greater than or equal to 130°C gave the highest sensory scores.
Singh and Smith, (1997) compared the effect of the process variables, temperature and moisture on the extrusion behavior of wheat starch, whole wheat meal and oat flour. The extruder pressure, torque and specific mechanical energy and extrudate properties of expansion, water absorption index (WAI) and water solubility index (WSI) were analyzed. Second-order polynomials were used to model the extruder response and product properties of extruded wheat starch and whole wheat meal with the process variables and wheat germ oil (WGO) level. Wheat starch and meal behaved similarly but differed from oats in pressure, expansion, WSI and WAI in their response to moisture content and temperature. Addition of WGO to wheat starch increased the expansion, whereas it had little effect on the wheat meal. WGO increased the upper bound WSI and decreased the lower bound WAI for starch or meal.

Yeh and Jaw, (1999) studied the effect of feed rate and screw speed on operating characteristics and extrudate properties during single-screw extrusion cooking of rice flour. Rice flour was used to examine effects of feed rate and screw speed on the specific energy input during single-screw extrusion cooking. Torque, raised by decreasing screw speed or increasing feed rate, was found to be a power law function of the ratio of feed rate to screw speed (Fr/Ss) with $R^2 > 0.94$. Specific mechanical energy (SME) calculated from torque also was a power law function of Fr/Ss with $R^2 > 0.84$ and negative power law indices. The intrinsic viscosity correlated well with the degree of gelatinization, WAI, and cooking loss, and appeared to be a good index of the extrudate properties.

Banerjee and Chakraborty, (2000) analyzed the shear and thermal effect on extrusion energy, pressure requirement and viscosity of dough. The effect of moisture and shear rate on rheological properties of the rice flour was also studied. Moisture content 15, 21, 27% (wet basis), extruder barrel temperature (120, 150, 180°C) and extruder screw
speeds (100, 150, 200rpm) were considered as input variables. Regression analysis showed that moisture content and temperature were negatively correlated with developed pressure and specific power requirement. 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) applied the Plackett-Burman experimental design during extrusion of rice flour. The variables studied included: extruder hardware variables such as mixing disk (MD) and reverse pitch screw element (RPSE), feed variables, such as moisture, sugar, salt and amylose content of the feed and rice flour particle size; and extrusion operating variables such as barrel temperature, feed rate and screw speed. System parameters determined were torque, specific mechanical energy and residence time, while target product parameters included bulk density, water solubility index and paste viscosity. Results showed that screw configuration, particularly the presence of MD and RPSE, affected extrusion and extrudate properties. Marked effects were obtained for amylose and moisture content, feed rate, screw speed and barrel temperature. A combination of high barrel temperature in the presence of RPSE and MD using low amylose content in feed was found to be desirable to achieve high water solubility index in the extruded product.

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. 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, which was required. 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.
Plahar et al., (2003) developed a high protein weaning food by standardized extrusion cooking process using peanuts, maize and soybean. The factors evaluated included the effects of blend formulation, extrusion temperature and feed moisture content on ease of extrusion and product quality characteristics. Results revealed that bulk density and hardness increased while expansion index decreased with increase in feed moisture content. At a fixed range of feed moisture content, product bulk density and firmness decreased while expansion index increased with increasing extrusion temperature. For ease of extrusion and best product quality in terms of sensory attributes and cooking properties, the extrusion parameters were blend formulation of 75% maize, 10% peanut and 15% soybean: feed particle size of 300–400 μm extruded using a screw speed of 500 rpm, with a feed rate of 4.6 kg/min, feed moisture content of 16–18%, and extrusion temperature of 100–105°C. Pairwise comparison of the sensory attributes of porridges prepared from milled samples of the weaning foods showed significant differences between extruded products and existing traditional counterparts, with very high scores for all sensory attributes of the extruded products, especially extruded raw (non-roasted) blend samples.

Sacchetti et al., (2004) studied the effect of extrusion temperature and feed composition on the functional, physical and sensory properties of chestnut and rice flour-based snack-like products. The effects of chestnut flour content and extrusion temperature on functional (water adsorption index, water-holding capacity and water solubility index) and physical (density, moisture content and colour) properties of the extrudates were investigated. Since chestnuts are particularly rich in sugars, the flour content limited the gelatinization and the expansion of the product, moreover the combined effect of flour content and temperature enhanced the browning reactions. Chestnut flour was found to be suitable for the extrusion-cooking process adopted, if properly mixed with rice flour. The chestnut flour (30%)
produced a snack-like product, at a processing temperature of 120°C with limited density and browning.

Young and Schwarz, (2004) examined the physical and cooking properties of restructured grain extrudates from selected cereal and legume flours. The cooking and physical properties of restructured grain (RGR) extrudates 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. In comparison to milled rice, RGR had lower L and a values; upon cooking, brightness increased slightly, whereas yellowness and redness decreased. Hardness, gumminess and chewiness were lower in cooked RGR than milled rice, but springiness and cohesiveness were higher. Changes in hardness of cooked RGR occurred slowly at 25°C but rapidly at 4°C.

Ding et al., (2005) studied the effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. The effect of extrusion conditions, including feed rate (20–32%), feed moisture content (14–22%), screw speed (180–320 rpm), and barrel temperature (100–140°C) was observed on the physicochemical properties (density, expansion, water absorption index (WAI), and water solubility index (WSI) and sensory characteristics (hardness and crispness) of expanded rice snack. Increasing feed rate resulted higher expansion, lower WSI, and higher hardness, whereas increasing feed moisture content produced extrudates with a higher density, lower expansion, higher WAI, lower WSI, higher hardness and lower crispness. Higher barrel temperature increased the extrudate expansion but reduced density, increased the WSI and crispness of extrudate. Screw speed had no significant effect on the physicochemical properties and sensory characteristics of the extrudates.
Ding et al., (2006) investigated the effect of extrusion conditions, including feed rate (20–32 kg/h), feed moisture content (14–22%), screw speed (180–320 rpm), and barrel temperature (100–140°C) on the functional properties (density, expansion, water absorption index (WAI), and water solubility index (WSI)) and physical properties (density, expansion and textural characteristics) of an expanded wheat snack. Feed rate influenced hardness increase and decrease in energy to puncture the extrudates. Moisture content resulted higher density, lower expansion, lower WAI, higher WSI, higher hardness and lower puncture energy. But screw speed caused slight reduction of density and hardness of wheat extrudate when the values were increased. Higher barrel temperature reduced density, WAI, and hardness, but increased the WSI and puncture energy of extrudate.

Iabnoglu et al., (2006) investigated the effect of screw speed (220–340 rpm) and feed rate (22.0–26.0 kg/h, db) on the firmness, expansion ratio, colour and sensory properties of a nutritionally balanced gluten-free extruded snack. Regression equations describing the effect of each variable on the responses were obtained. Results indicated that feed rate and screw speed both had an effect on the firmness of the product at 95% confidence interval (CI). The interaction between the two factors was also found to be significant at 95% CI. The effect of screw speed was significant whereas the quadratic effect of feed rate was found significant on the lateral expansion (95% CI). Lateral expansion increased as screw speed increased. The results indicated that changes in the extrusion variables did not affect the flavour and overall acceptability of the final product at 95% CI for the feed rate and screw speed.

Yagci and Gogus, (2008) used response surface methodology to investigate the effects of extrusion conditions including moisture content (12–18%), temperature (150–175°C), screw speed (200–280 rpm), and change in feed composition[durum wheat flour (8–20%), partially defatted hazelnut flour (PDHF) (5–15%) and fruit waste (3–7%) contents] on
the physical and functional characteristics of the extruded snack food based on rice grit in combination with fruit waste, durum clear flour and PDHF. Response variables were bulk density, porosity, water absorption and water solubility indices. The product responses were most affected by changes in PDHF content and to a lesser extent by fruit waste content. Increasing PDHF content caused increase in bulk density and water solubility index, but decrease in porosity and water absorption index of the extruded snacks.

Pansawat et al., (2008) extruded a formulation containing rice flour, fish powder, menhaden oil and vitamin E at a feed rate of 10 kg/h using a co-rotating twin-screw extruder. Primary extrusion (independent) variables were temperature (125–145°C), screw speed (150–300 rpm) and feed moisture (19–23 g/100 g db). Response surface methodology (RSM) was used to study the effects of extrusion conditions on secondary extrusion variables (product temperature, pressure at the die, motor torque, specific mechanical energy input and mean residence time) and physical properties of the extrudates. Second-order polynomial models were computed and used to generate contour plots. Feed moisture and screw speed decreased pressure at the die, whereas increased screw speed increased product temperature. Higher barrel temperature, feed moisture and screw speed decreased motor torque. Longer mean residence times were observed at lower screw speeds. Product density increased as feed moisture increased, but decreased with screw speed. Increased feed moisture decreased radial expansion.

Stojceska et al., (2008) incorporated cauliflower by-products as a new source of dietary fibre, antioxidants and proteins in cereal based ready-to-eat expanded snacks. Dried and milled cauliflower at levels of 5–20% was added to the formulation mix. The samples were processed in a twin-screw extruder with a combination of parameters including: solid feed rate of 20–25 kg/h, water feed adjusted to 9–11%, screw speed of 250–350 rpm and
process temperatures 80–120°C. Pressure, torque and material temperature during extrusion were recorded. Extrusion cooking significantly (P<0.0001) increased the level of phenolic compounds and antioxidants but significantly (P<0.001) decreased protein in vitro digestibility and fibre content in the extruded products. The expansion indices, total cell area of the products, wall thickness showed negative correlation to the level of cauliflower. Sensory test panel indicated that cauliflower could be incorporated into ready-to-eat expanded products up to the level of 10%. The sensory evaluation suggested the production of acceptable extruded snacks from the extrusion of PDHF, fruit waste and durum clear flour in combination with rice grit.

**Altan et al., (2008)** developed blended barley flour and grape pomace based extrudates. Response surface methodology using a central composite design was used to evaluate the effects of independent variables, namely die temperature (140–160°C), screw speed (150–200 rpm) and pomace level (2–10%, db) on product responses (expansion, bulk density, texture and color). Multiple regression equations were obtained to describe the effects of each variable on product responses. The product responses were most affected by changes in temperature, pomace level and to a lesser extent by screw speed. The results suggested the production of acceptable barley flour and grape pomace based extruded snack food.

**Mesa et al., (2009)** developed soy protein-fortified expanded extrudates using normal corn starch. Physical and microstructural properties of native corn starch–soy protein concentrate (CS–SPC) extrudates were investigated in relation to the macromolecular changes in starch during extrusion. The effect of extruder screw speed (230 and 330 rpm) and SPC concentration (0, 5, 10, 15 and 20%) was determined. Increasing screw speed resulted in higher specific mechanical energy (SME) and expansion, and lower mechanical strength. On
the other hand, addition of 5–20% SPC led to lower SME and expansion, and higher mechanical strength. X-ray micrographs showed smaller yet more cells, and thickening of cell wall with SPC addition. Water absorption index increased and water solubility index decreased with increase in screw speed and SPC level.

Shannon et al., (2010) evaluated the effect of protein, moisture content and barrel temperature on the physicochemical characteristics of pea flour extrudates. The effects of protein content (6%, 12% or 18%, db), moisture content (15, 18 or 21%, wb), temperature (set temperature of the final barrel section—100, 120 or 140°C) and a leavening agent (0.5% sodium bicarbonate) on the direct expansion characteristics of pea flour were determined with a twin-screw, co-rotating extruder. The various levels of protein were obtained by blending air-classified pea starch (6% protein, 85% starch) and pea flour (24% protein, 56% starch). Extrusion of pea flour containing 6% protein and 15% moisture at a set temperature of 120°C resulted in expansion indices (EIs) of 3.3 and 3.6, respectively, in the absence or presence of the leavening agent. EI decreased but bulk particle densities and hardness increased with increase in protein or moisture content. Lysine losses were proportionally lower at higher protein and moisture contents.

Meng et al., (2010) studied the effect of feed moisture content (16–18%), screw speed (250–320 rpm), and barrel temperature (150–170°C) on extruder system parameters (product temperature, die pressure, motor torque, specific mechanical energy (SME) and physical properties (expansion, bulk density, hardness) of a chickpea flour-based snack by using RSM. Second-order polynomials were used to model the extruder responses and product properties as a function of process variables. Product temperature and die pressure were affected by all three process variables, while motor torque and SME were only influenced by screw speed and barrel temperature. All three variables affected product responses significantly. Desirable
products, characterized by high expansion ratio and low bulk density and hardness, were obtained at low feed moisture, high screw speed and medium to high barrel temperature. It was demonstrated that chickpeas can be used to produce nutritious snacks with desirable expansion and texture properties.

Stojceska et al., (2010) evaluated the advantage of using extrusion processing for increasing dietary fibre level in gluten-free products and the study reported the increase in level of total dietary fibre in gluten-free products by using extrusion technology and by incorporating a number of different fruits and vegetables, such as apple, beetroot, carrot, cranberry and gluten-free flour cereal. The materials were added at the level of 30% into the gluten-free balanced formulation (control) made from rice flour, potato starch, corn starch, milk powder and soya flour. Different process conditions, such as water feed rate 12%, solid feed rate 15–25 kg/h, screw speed 200–350 rpm, barrel temperatures: 80°C at feed entry and 80–150°C at die exit were used. Pressure, material temperature and torque were monitored during extrusion runs. The results indicated that extrusion technology has the potential to increase the levels of total dietary fibre in gluten-free products made from vegetables, fruits and gluten-free cereals.

Lazou and Krokida, (2010) studied structural and textural properties of extruded corn and corn–lentil mixtures as a result of process conditions, including extrusion temperature (170–230°C), feed rate (2.52–6.84 kg/h) and feed moisture content (13–19% wb). Lentil was used in mixtures with corn flour at a ratio of 10–50% (legume/ corn). Apparent density increased with feed rate, moisture content and material ratio and decreased with temperature, while expansion ratio showed an opposite behavior. Modulus of elasticity increased with feed composition and decreased with extrusion conditions. Number of peaks during compression decreased with extrusion temperature and feed composition. Similar
behavior was also found for sensory evaluated structural and textural characteristics. The examination of macrostructure confirmed the effects of extrusion conditions and feed composition on structural and textural properties. The properties correlation revealed critical relationships among instrumental and sensorial characteristics. Hence, simple power model equations were developed, which enable their prediction and consequently the design of extruded snacks with acceptable quality characteristics.

Lobato et al., (2010) investigated the development of extruded puffed functional ingredient with oat bran and soy flour. The work was aimed to utilize minimum amount of corn starch to attain good textural properties. The proportions of the feed ingredients and the processing conditions (extruder temperature, moisture, and inulin) were optimized. Applying experimental design to study the effect of feed ingredients on expansion and textural properties of extruded product, the formula containing 250g/kg corn starch, 375 g/kg soy flour, and 375 g/kg oat bran was selected as the best between tested. Using this blend and applying factorial design, the best process conditions (250 g/kg moisture; 45 g/kg inulin and 130°C) were chosen. The optimization step temperatures higher than 130°C were tested and showed that temperature, 160°C increased the radial expansion ratio and decreased hardness the most. The obtained puffed product had 212.6 g/kg fiber, 281.0 g/kg protein, and a caloric value of 319.1 kcal/100 g, which was well accepted by the panelists.

Shoar et al., (2010) studied the physico-chemical characteristics of extruded snacks enriched with tomato lycopene. In this study, crisp low density extruded snacks were manufactured from corn, wheat and rice, with or without dried tomato skin or paste powder extruded at temperatures of 140, 160 or 180°C. Lycopene content and the physico-chemical properties (expansion, density, hardness, colour parameters and percentage of moisture loss) of the extruded products were measured. Lycopene retention was higher in products
containing tomato skin powder and significantly lower when wheat flour was used to make the snacks. Increase in the processing temperature improved the physicochemical characteristics of the snacks but had no significant effect on lycopene retention (P > 0.05).

**Cavada et al., (2011)** evaluated the effect of the addition of wild legumes (*Lathyrus annuus* and *Lathyrus clymenum*) on the physical and nutritional properties of extruded products based on whole corn and brown rice. Samples were obtained with a Brabender single screw extruder. The physical characterization of the expanded products was performed by the measurement of density, expansion, solubility and specific mechanical energy consumption (SMEC). Results showed that expansion, solubility and SMEC were higher for rice blends than for corn blends, while density followed an inverse trend. Addition of legumes caused a decrease of expansion and an increase in solubility in both rice-containing and corn-containing samples. With only 15% of legume replacement, a significant increase in protein, fiber, and mineral content was obtained. Protein digestibility was in the range of 82–84% whereas mineral availability was in the range of 6.4–12.1% range for iron and 10–18.6% for zinc.

**Nayak et al., (2011)** investigated the effect of extrusion on the antioxidant capacity and color attributes of expanded extrudates prepared from purple potato and yellow pea flour mixes. Expansion ratios of the extruded products varied from 3.93 to 4.75. The total antioxidant capacities (TAC) of the extruded products, using DPPH assay, were 3769 to 4116 μg trolox equivalent/g dry weight sample and not significantly different (P > 0.05) from their respective raw formulations. The total phenolic contents (TP) of the extruded products varied from 2088 to 3766 μg of gallic acid equivalent/g dry weight sample and retained 73 to 83% of the TP from the raw formulations after extrusion. The total anthocyanins contents (TA) in the extrudates were 0.116 to 0.228 mg of malvidin-3-glucosides/g dry weight sample.
Compared with their raw formulations, significant losses (60 to 70%) of the TA in the extruded products occurred due to extrusion cooking. Browning indices and color attributes such as brightness, chroma, and hue angle agreed with degradation of anthocyanins in the extruded products. However, extrusion cooking retained antioxidant capacities of the raw formulations in the extruded products either in their natural forms or degraded products with radical scavenging activity. This study demonstrated the potential for the production of puffed extruded food products with the improved antioxidant content from colored potatoes and pulse formulations.

Norajit *et al.*, (2011) studied the effect of the addition of hemp powder on the physicochemical properties and energy bar qualities of extruded rice. Extruded rice/hemp mixtures were prepared by mixing defatted and whole hemp powders with rice flour at varying hemp levels (0, 20, 30 and 40%). The bulk densities of the extruded rice/hemp samples increased with increase in levels of added hemp powder. The extrudates blended with hemp powder had a lower water absorption index than the control (extruded rice without hemp). The extruded rice/whole hemp had more total phenolics and flavonoids and had a better scavenging effect on DPPH radicals than extruded rice/defatted hemp. The highest potential to inhibit β-carotene oxidation was found in extruded rice/40% whole hemp. Increasing amounts of hemp powder resulted in lower equilibrium moisture content of energy bars. The energy bar made with extruded rice/20% whole hemp was preferred for colour, taste and overall acceptability.

Elisa *et al.*, (2012) studied the cellular architecture and its relationship with mechanical properties in expanded extrudates containing apple pomace. Different levels of pomace (0–28%) and in-barrel processing moisture (17.5–25%) resulted in extrudates with a
wide range of microstructures (average cell size 0.05–3.43 mm, wall thickness 0.12–0.34 mm and void fraction 0.53–0.76).

*Saeleaw et al., (2012)* examined the effect of extrusion conditions on mechanical-sound and sensory evaluation of rye expanded snack. The extrudates were produced according to different conditions of barrel temperature (150\(^\circ\)C and 190\(^\circ\)C) and feed moisture content (12% and 16%) using a 2×2 factorial design. A combined mechanical and acoustic method was employed using a texture analyzer in combination with the acoustic envelope detector (AED), to describe the influence of extrusion parameters on the properties of extrudates. With increasing extrusion cooking temperature, number of force and number of sound peaks were increased but maximum force was decreased. Moreover, the thickness of the cell wall decreased with increasing extrusion cooking temperature. All these trends were reversed with increasing feed moisture content. The barrel temperature was dependent on the feed moisture content. The principle component analysis (PCA) showed a positive correlation between the sensory parameters, hardness and sound intensity of crunchiness and the instrumental parameters (force area, mean force, maximum force) and negative correlations between the number of sound peaks, number of force peaks and crunchiness.

*Wang and Ryu, (2013)* analysed the physical properties of extruded corn grits with corn fibre by CO\(_2\) injection. Corn grits and corn fibre mixed at different ratios (0/100, 15/85 and 30/70) were extruded at different melt temperature (90, 105 and 120\(^\circ\)C) using extrusion with and without CO\(_2\) injection. Increasing melt temperature also significantly improved physical properties of extrudates in both non-CO\(_2\) and CO\(_2\) injection (200 mL/min) extrusion process. The injection of CO\(_2\) in the extrusion process showed similar effect on physical properties of extrudates at the lower melt temperature (90 and 105\(^\circ\)C); whereas it exhibited opposite trend at higher melt temperature (120\(^\circ\)C). At the lower melt temperature, the surface
of extrudates with the CO₂ injection was smoother and had lower fracturability, whereas the cross sectional microstructure was more uniform. The addition of corn resulted in the formation of non-uniform and more broken cross-sectional microstructure.

Liang et al., (2013) reported the development of protein rich extruded products from soy protein isolate and corn flour blends using a twin screw extruder. The physical properties of the extruded product were evaluated and related to process variables: soy protein isolate (SPI) (32.2-66.6 g protein/100 dry matter), feed moisture (31.6-48.4 g/100 g)and process temperature (126.4-193.6 °C). A central composite rotatable design (CCRD), and response surface methodology was used to evaluate the significance of independent and interaction effects of extrusion process variables on the product’s various physical properties. The independent variables had significant (p≤ 0.05) effects on physical properties of extrudates. Higher SPI and feed moisture contents increased the breaking stress and bulk density, but decreased the expansion ratio, water solubility index, and rehydration rate. In addition, the higher SPI content decreased the colour value, L whereas higher feed moisture content increased it. The increase in temperatures increased breaking stress, expansion ratio, rehydration rate and L value, but decreased the bulk density and water solubility index.

Potter et al., (2013) used fruit powders in extruded snacks suitable for Children’s diets. The study investigated the interactions between fruit powders, extrusion process and physical properties and nutritional qualities of the resulting product. Five different samples were extruded using the same process conditions including a solid feed rate of 20 kg/h, moisture of 13% and barrel temperatures of 80 and 120 °C. Nutritional properties (soluble and insoluble fibre and total antioxidant content) and physical properties (bulk density, lateral expansion, and hardness) were evaluated. The addition of fruit powder showed significant (P < 0.05) effect on expansion and density of the extrudates. Both soluble and insoluble fibre
increased substantially after extrusion process while antioxidant levels significantly (P < 0.05) decreased. The resulting products had an improved nutritional profile compared with other extruded snack products being low in fat and sugar and a good source of fibre.

2.5 Microstructural studies on snacks

The microstructural study of the extruded snack foods by various researchers has helped to develop an understanding about different microstructural changes in the extrudates by the application of scanning electron microscopy, which is one of the novel technique used for the microstructural study.

Ryu et al., (1993) used a scanning electron microscope to observe cell structure orientation of wheat flour extrudates produced with different compositions, and reported that the type of emulsifiers and the addition of sucrose and shortening powder significantly influenced structural parameters.

Tan et al., (1997) characterized cellular structure of puffed corn meal extrudates using SEM images, measuring the run length (number of pixels at 0 gray scale, i.e., distance along a void), and from these, calculated average run length and standard deviation, variance, and third moment of run lengths, and reported that most of these parameters were good indications of directly measured cell size and uniformity.

Chewangkul et al., (2001) investigated the use of Confocal Laser Scanning Microscopy (CLSM) to study changes in microstructure throughout the process of instant noodle production. Multiple staining of acridine orange, fluorolink Cy- 3 and sulforhodamine was applied in order to differentiate protein, starch and lipid, respectively, in the same image. Scanning Electron Microscopy (SEM) was also conducted, complementarily, to contribute stereoscopic images. The microscopic data obtained from triple-labelled samples examined
by CLSM were found to correspond to the stereoscopic SEM micrographs. Morphological changes and microstructural arrangement of starch granules and protein matrix, and the presence of lipids were found to respond to different regimes of process; addition of water, inputs of mechanical force and heat and introduction of frying. Thus, triple staining, via CLSM, could be regarded as a potential tool for monitoring microstructural differences resulting from varied processing conditions.

**Choi and Philips, (2004)** studied the cellular structure of peanut-based extruded snack products using scanning electron microscopy. Mixture of partially defatted peanut flour fat and rice flour was extruded to produce indirectly, puffed extrudates using a co rotating twin-screw extruder. Extrudates were dried to obtain half-products of 11-12% moisture content, and the half-products were expanded by deep-fat frying. The effects of three levels of peanut flour (30, 40, and 50%), screw speed (200, 300, and 400rpm) and feed rate (4, 5, and 6kg/h) were studied by characterizing the cellular structure of expanded snack products using Scanning Electron Microscopy (SEM). Average cell size (mm$^2$) and the number of cells per unit area (cm$^2$) were determined from the interior cross-section area of snack products. Those parameters were influenced mainly by the level of peanut flour followed by screw speed and feed rate. Increasing peanut flour from 40 to 50% produced less puffed final products resulting in small cell size compared to snacks of 30 - 40% peanut flour. The maximum cell size was produced in the snack products extruded with peanut flour of 30 - 40% at screw speed of 250 - 330 rpm and feed rate of 4.7 - 5.7kg/h.

**Rzedzicki and Blaszczak, (2005)** analyzed the impact of microstructure in modelling physical properties of cereal extrudates. The effect of an extruder used, of the concentration of oat bran, of the moisture content of raw material, and of the barrel temperature profile on the course of the process and physical properties of the extrudates was investigated. The
study indicated that at the oat bran concentration of up to 20%, the extrudate demonstrated cellular structure, low density and exceptionally high expansion. With oat bran concentration reaching 20-30%, the cellular structure of the extrudate disappeared, but compactness was retained. Higher proportions of oat bran (over 30%) excluded the cellular structure of the extrudates which takes the form of crumble. Subsequent increase in oat bran concentration, over 60%, leads to a product of more loose structure with semolina-like microstructure. However, wide ranges of raw material moisture content and process temperature enabled obtaining a compact product with the oat bran concentration over 30%.

**Sung and stone, (2005)** studied the microstructure of pasta and starch pasta to evaluate the changes in the surface and internal structure of pasta and “starch pasta” made from various flours and wheat starch before and after cooking. Cooked “starch pasta” revealed a honeycomb-like internal structure similar to cooked pasta when viewed by scanning electron microscopy (SEM). The honeycomb-like structure of cooked pasta was formed mainly due to the coagulated protein embedded in the gelatinized starch. Swelling of cooked pasta was observed mainly due to the hydration and coagulation of protein rather than due to gelatinization of starch. The diameter of cooked starch pasta does not increase as much as that of cooked pasta without starch. A fibrillar protein network of high cooking quality pasta was enveloped in a gelatinized starch, whereas low cooking quality products contained more diffuse gelatinized starch in a less extensive protein framework.

**Wojtowicz, (2005)** studied the addition of some functional ingredients to common wheat flour and its effect on the quality parameters and the microstructure of the extrusion-cooked precooked pasta products. The microstructure was characterised by SEM microscopy technique at different magnifications. The processing parameters (screw rpm and moisture content of raw materials) established some physical properties and the microstructure of the
pasta products processed on a modified single screw extrusion-cooker. The addition of functional components like salt, egg powder, di-sodium orthophosphate, methylcellulose and ascorbic acid had a strong effect on the surface microstructure and the interior structure of products as well as dried precooked pasta quality. The best results associated with the uniform and compact structure of pasta products and excellent quality was obtained, when processed a flour mixture enriched with a methylcellulose additive at 80–100 rpm and at 80–95°C temperature range.

**Baixauli et al., (2007)** examined the effect of the use of an automatic dosing unit on the rheological, microstructural and textural properties of an aerated batter for preparing a bakery product. Two cases were studied: in one the batter was dosed manually into the paper cups and in the other the batter was dosed automatically into the paper cups. The flow properties of the batter dosed by the two methods showed significant differences in the consistency index, although there was no difference in the flow index. The microstructure of the two batters was analyzed by cryo-scanning electron microscopy (cryo-SEM). Observation of the batters’ microstructure revealed many changes that could be related to the dosing step.

**Nath et al., (2007)** reported the application of high-temperature short time (HTST) air puffing and found to be very useful process for production of potato–soy ready-to-eat snack food as it ideally produced highly porous and light texture. The process parameters considered were puffing temperature (185–255°C) and puffing time (20–60 s) with constant initial moisture content of 36.74% and air velocity of 3.99 m/s for potato–soy blend with varying soy flour content from 5% to 25% using response surface methodology with central composite rotatable design (CCRD). The optimum product in terms of maximum expansion ratio (3.69), minimum hardness (2754.3 g) and maximum overall acceptability (7.3) were obtained with 10.31% soy flour blend in potato flour at the process conditions of puffing
temperature (230.06°C) and puffing time (25.46 s). Microstructural changes were evaluated at different stages (with an interval of 5s) of HTST puffing for product obtained under optimum processing conditions. The maximum expanded porous structures with larger cracks and smaller pits were recorded in the SEM micrographs at 20 s of HTST air puffing.

Ozkoc et al., (2009) studied the effect of gums on macro and micro-structure of breads baked in different ovens. The different ovens included infrared (IR)-microwave combination and conventional. The gums used were xanthan, guar, k-carrageenan and xanthan-guar blend. The gums were added to the formulation at 0.5% concentration. Results of Image analysis demonstrated that xanthan-guar gum blend addition improved bread quality with increasing pore area fractions. It was seen that about 75% of the pores of control breads baked in infrared-microwave combination oven and about 63% of the pores of control breads baked in conventional oven had diameters of above 1000 mm. According to SEM analysis, pores in control breads baked in conventional oven were found to be smaller, and had spherical, oval-like shape as compared to the ones baked in IR-microwave combination oven. Moreover, more homogeneous closed cell structure was observed for conventionally baked control breads. The pores of breads, baked in IR-microwave combination oven were close to each other which resulted in coalescence of the gas cells to form channels and the pores were no longer spherical. The starch granules in conventionally baked breads were more distorted and seen as a continuous sheet of gelatinized starch. On the other hand, granular residues and continuous starch structure was observed together in IR-microwave combination heating.

Zarzyck et al., (2010) applied oat whole-meal and protein components as modifiers of extrudates microstructure. The application of oat whole-meal (5, 10 and 15%) as a modifier of the structure of corn-oat extrudates was studied. Material for comparison, constituting a point of reference, was oat bran. Additional structure modifiers applied were
whole powdered milk, at the rate of 1%, and everlasting pea wholemeal in the amount of 10%. Results showed that oat whole-meal can be successfully applied as a modifier of the structure of extrudates, replacing more expensive oat bran. The extrudates produced were characterized by microstructure very similar to that of extrudates with a content of oat bran. The extrudates had the characteristic ‘honeycomb’ pore structure. Over the whole range of process parameters applied, total liquefaction of raw material was observed, even at 15% content of oat whole-mealin the blends. Change in the moisture content of the material blends and in the process temperature had a notable effect on the microstructure of the products, causing changes in the thickness of walls of air pockets and in their dimensions. No deterioration of extrudate microstructure was observed following the application of the additional modifiers – whole powdered milk and everlasting pea whole meal.

Wang et al., (2010) studied the effect of vacuum and microwave freeze drying on microstructure and quality of potato slices. Potato slices, immersed in 0.5% CaCl₂ solution for 10 min were examined using light microscopy for their microstructure in frozen state before drying, during the sublimation drying stage, in the desorption drying stage and in the final dried form. Additionally, the final dried product was also tested for vitamin C content, colour, starch content, texture and sugar content. Experiments were carried out using conventional vacuum freeze dryer as well as a microwave freeze dryer. Results for both un-blanchéd and blanched potato tissues, crystal growth during sublimation drying stage was observed to cause structural damage to the cell walls. Blanched tissue suffered more damage during the freezing process. Interestingly, microwave freeze drying yielded product similar in quality to that obtained in vacuum freeze drying with conductive heating.

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

Zhen et al., (2011) investigated the thermal processing effects on the functional properties and microstructure of lentil, chickpea, and pea flours. The existence of anti-nutritional components and the length of time required for preparation have, however, limited their frequency of use compared to recommended intake levels. Anti-nutritional components in pulses can be largely removed by heat treatment. Additionally pre-treatment of pulses with heat and processing of seeds into flour could further enhance their use by decreasing processing and preparation times. In this study, trypsin inhibitor activity, functional
properties, and microstructural characteristics of flours prepared from different varieties of lentil, chickpea, and pea as affected by roasting and boiling were evaluated. Both thermal treatments resulted in significant reduction (p≤0.05) in trypsin inhibitor activity ranging from −95.6 to −37.8%. Scanning electron microscopy (SEM) results showed that the roasted pulse flours had similar microstructure (i.e., starch granule and protein matrix structure) to the raw samples. For the pre-boiled flours, amorphous flakes were observed by SEM with no presence of intact starch granules. This is likely due to gelatinization of starch during cooking. Interestingly, flours treated by boiling exhibited significantly higher (p≤0.05) fat binding capacity, water holding capacity, and gelling capacity, while protein solubility was significantly reduced compared to the raw and roasted pulse flours. Overall, thermal treatments either had no impact or impacted to different extents the emulsifying and foaming properties of the flours. The results suggested that thermally-treated pulse flours may have very good potential to be used as value-added food ingredients for food applications due to their improved nutritional value and, in some instances, superior functionality.

Wojtowicz and Mościcki, (2011) studied the effect of wheat bran addition and screw speed on microstructure and textural characteristics of common wheat precooked pasta-like products. Precooked pasta-like products were processed on a single screw extrusion-cooker with L: D=16:1, shaped on the circular open die. Screw speed during the extrusion-cooking ranged from 60 to 120 rpm. Wheat bran was added in the amount from 5 to 25% of common wheat flour mass. The microstructure showed unmodified bran fractions at low screw speed, in turn higher rpm disrupted wheat bran cell walls. Hardness of dry pasta-like products, evaluated with the cutting test, diminished with higher bran content in the recipe and was increasing with rpm applied. The firmness of hydrated products also decreased with increasing bran addition.
Ramirez et al., (2011) carried out the microstructure analysis on pre-treated apple slices and its effect on water release during air drying. Microstructural studies have played an important role in the comprehensive understanding of some food phenomena that occur during drying processes. The effect of four pre-treatments (immersion in boiling water, vacuum impregnation, freezing/thawing, and uni-axial compression) was studied on apple microstructure characterized by cell cavities size parameter and how the changes induced by these pre-treatments can affect the water loss rate during air drying. The quantitative structure analysis showed that freezing/thawing and compression pre-treatments caused more damage on the apple structure, yielding larger cell cavities in comparison to vacuum impregnation and immersion in boiling water and control. The results revealed that disruption of the cell walls can be considered as a factor that affects the drying rate.

Medina et al., (2011) investigated the physical properties and microstructural changes during soaking of individual corn and quinoa breakfast flakes. The maximum rupture force (RF) of 2 types of breakfast flaked products (BFP)—corn flakes (CF) and quinoa flakes (QF)—were measured directly while immersing in milk with 2% of fat content (milk 2%) or distilled water for different periods of time between 5 and 300s. Under similar soaking conditions, QF presented higher RF values than CF. Soaked flakes were freeze-dried and their cross section and surface was examined by scanning electron microscopy. Three consecutive periods (fast, gradual, and slow reduction of RF) were associated with changes in the microstructure of flakes. These changes were more pronounced in distilled water than in milk 2%, probably because the fat and other solids in milk set deposited on the flakes’ surface hindering liquid infiltration. Structural and textural modifications were primarily ascribed to the plasticizing effect of water that softened the carbohydrate/protein matrix, inducing partial collapse of the porous structure and eventually disintegration of the whole piece through deep cracks.
Elisa et al., (2012) analyzed the impact of different hydration regimens on texture, microstructure and digestibility in fiber-added extruded products. Blends containing 0, 17, 22, and 28% pomace were hydrated to 17.2% by adding water either into the pre-conditioner (P), the extruder (E) or dividing half in each (PE). Increasing the opportunity for hydration (P > PE > E) promoted more complete starch gelatinization at all pomace levels. Apple pomace promoted milder extrusion conditions, resulting in less starch gelatinization and solubilisation, poor expansion and reduced starch digestibility. Digestible starch was inversely correlated to cell wall thickness/cell size ratio \((r = 0.91)\), which increased with pomace addition.

Air cell structures of expanded corn extrudates have been studied by Barett & Pelag, (1992) who reported that structures are affected by extrusion conditions. The correlation of density, expansion and cell size with the fat infusibility into the extrudates was studied by Barett & Ross, (1990). Data from microstructural studies of extrudates can be used to gain an understanding of what happens inside the extrudates under different conditions.

2.6 Effect of frying on snacks

The process of frying reported by the researchers is one of the best techniques to improve the organoleptic as well textural properties of the extruded snack foods. The frying is therefore carried out as one of the unit operations for the development of extruded snack food.

Frying is a complex unit operation that is widely used in the food industry. During the process, food is immersed in an oil bath at a temperature above the boiling point of water. This results in counter flow of water vapour (bubbles) and oil at the surface of the product (Bouchonet et al., 2003). Oil uptake is one of the most important quality parameters of fried food, but this is incompatible with recent consumer trends towards healthier food and low fat
products (Bouchon and Pyle, 2004). The consumption of oil and saturated fat in particular is related to significant health problems, including coronary heart disease, cancer, diabetes, and hypertension (Saguy and Dana, 2003). Other undesirable effects derived from the high temperatures involved in the frying process and exposure to oxygen are the degradation of important nutritional compounds and the generation of toxic molecules in the foodstuff or the frying oil itself (Fillion and Henry, 1998). This information has raised a red flag regarding human consumption of fried food. As a result, healthy, low fat snack products have acquired a new level of importance in the snack industry (Moreira et al., 1999). However, even health-conscious consumers are unwilling to sacrifice organoleptic properties, and intense full-flavour snacks continue to play an important role in the salty snack market (Mariscal & Bouchon, 2008).

Deep-fat frying is a process of cooking foods by immersing them in edible oils and fats at elevated temperatures to induce fast dehydration. One of the most important quality changes during the process is the amount of oil retained inside the product, which is incompatible with current health trends. Several studies have shown that oil is mainly retained in the crust region (Aguilera and Gloria, 1997; Bouchon et al., 2001; Keller et al., 1986; Pedreschi et al., 1999), which mostly penetrates during the post-frying cooling period (Bouchon et al., 2001, 2003; Mellema, 2003; Moreira et al., 1997; Ufheil and Escher, 1996). Research has demonstrated that during frying the vigorous escape of water vapor and related inner pressure precludes oil migration into the crust and therefore, oil penetration is limited during most of the immersion period. As a result, oil absorption would be essentially a surface-related phenomenon, which is determined by the equilibrium between surface drainage and suction during post-frying cooling (Bouchon et al., 2003)
Deep-fat frying is one of the oldest and most common unit operations used in the preparation of processed foods, and is especially suited to develop snacks with unique flavours and textures. It can be defined as a process for cooking foods, by immersing them in edible oil, at a temperature above the boiling point of water, usually between 160 and 190°C, under atmospheric conditions (Farkas, 1996). The process involves simultaneous heat and mass transfer, which cause significant microstructural changes to both the surface and the body of the product. Heat transferred from the oil into the food causes protein denaturation, starch gelatinisation, water vaporisation, crust formation and colour development, which are typical phenomena of the combined effects of multiple-order chemical reactions (Singh, 1995). Mass transfer is characterised by the loss of water from the food as water vapour and the movement of oil into the food (Dobraszczyk et al., 2006). It is not clearly understood how oil uptake takes place, but there is some experimental evidence showing that water loss and oil absorption are asynchronous phenomena. It has been proposed that, during frying, the vigorous escape of water vapour would generate a barrier to prevent oil migration into the porous structure and, as a consequence, oil absorption would be limited during most of the immersion period. As a result, oil uptake would be essentially a surface-related phenomenon resulting from the competition between drainage and suction into the porous crust once the product is removed from the oil and begins to cool (Moreira et al., 1997; Ufheil and Escher, 1996).

Crispness of the crust formed during deep-fat frying of battered products is a key driving factor for consumer preference. During deep frying of these products a significant amount of oil is absorbed in the crust and is considered a detrimental aspect related to health concerns. In practice, main achievements directed to reduce the oil content of this type of products go together with a larger retention of moisture of the fried crust and therefore lower crispness. Therefore, current trends seek how to decrease oil content of deep fried foods.
Garayo and Moreira, 2002; Meyers and Conklin, 1990; Priya et al., 1996; Sanz et al., 2004; Beirendonck, 2001) without detrimental effect on crispness (Martín et al., 2010). In this way, healthier snacks can be prepared while preserving texture.

Deep fried products form an important group of food products consumed worldwide. Products are fried directly in hot fat or are first battered and breaded and subsequently fried. These products should be crispy as such or should have a crispy/crunchy crust and a much softer and moister interior. This crispy/crunchy character is an important sensory characteristic on which consumers base their appreciation. The difference between crispness and crunchiness is not well established. In general crispness is characterised by brittle fracture at a low fracture force and distinguishable fracture events (Luyten et al., 2004).

Moyano and Pedreschi, (2006) studied the kinetics of oil uptake during frying of potato slices. Potato slices blanched in hot water (85°C, 3.5 min) and then dried until moisture content of ~ 60g/100 g (wet basis), were deep fried in sunflower oil at 120, 150 and 180°C. A control treatment consisted of unblanched potato slices without the pre-drying treatment (fresh samples). Two empirical kinetic models, a first order model and a proposed model were fitted (with linear time behaviour for short times, while time independent for long times). Oil uptake was high even for short frying times at the different temperatures tested suggesting that oil wetting is an important mechanism of oil uptake during frying. For control slices, oil uptake increased approximately by 32% as the frying temperature decreased from 180 to120°C at moisture contents ≤ 1 g water/g dry solid. No apparent effect of frying temperature in oil uptake was observed at moisture contents ≤0.5 g water/g dry solid in fried slices previously blanched and dried. The two kinetic models fitted properly the values of oil uptake during frying, with similar correlation coefficient, R².
Yagua and Moreira, (2011) studied the physical and thermal properties of potato chips during vacuum frying. Vacuum frying (1.33 kPa), with the aid of a de-oiling mechanism, was used to produce low-fat potato chips. The kinetics of oil absorption and oil distribution in the potato chips was studied so that effectiveness of the de-oiling system could be established. Non-linear regression was used to fit the experimental data to the models used to describe oil absorption in potato chips with time. Moisture content, oil content, microstructure, diameter and thickness expansion, bulk density, true density, and porosity of chips fried at different temperatures (120, 130, and 140°C) was performed to evaluate the effect of process temperature on the product. The convective heat transfer coefficient at the oil-chip interface was determined for the same temperature range. The final oil content of the potato chips was 0.072 ± 0.004, 0.062 ± 0.003, and 0.059 ± 0.003 g/g solid for frying temperatures of 120, 130, and 140°C, respectively. These values were lower (80–87% less) than those found in untreated potato chips, which indicated that the de-oiling mechanism is crucial in vacuum frying processing.

Saeleaw and Schleining, (2011) reported the effect of frying parameters on crispiness and sound emission of cassava crackers, which were produced by deep-fat frying in oil at 140, 150 and 160°C. Physical properties of cassava crackers were monitored at 5, 10 and 15s of the frying process. The results showed that with increasing frying time and temperature, the moisture content, the linear expansion, the number of force and sound peaks significantly increased while the density and mean of force peaks decreased. Further it could be seen that with higher temperature, the number of small size air cells increased. Moisture content, bulk density, maximum of sound peak, maximum force and mean force were found negatively correlated with linear expansion, number of sound peaks and number of force peaks.
Sothornvit, (2011) explained the edible coating and post-frying centrifuge effect on quality of vacuum-fried banana chips. Compared with regular vacuum-fried products (control samples), banana chips coated with either guar gum or xanthan gum solutions at 1.5% or centrifuged at a higher speed than standard conditions (from 140 to 280 rpm) reduced oil absorption by 25.22, 17.22 and 17.31%, respectively. Moreover, the combination of an edible coating and the higher centrifugation speed resulted in a greater reduction of oil absorption (33.71%) compared with control samples. Therefore, banana chips coated with an edible coating and produced using the higher speed during the oil centrifuge step in the vacuum-frying process maintained a good quality with low oil content, representing a healthier snack for consumers.

Parimala and Sudha, (2012) investigated the effect of hydrocolloids such as guar gum, Arabic gum, careegenin, locust bean gum, xanthan gum, hydroxyl propyl methyl cellulose (HPMC) and carboxymethyl cellulose (CMC) on the rheological, microscopic, mass transfer characteristics during frying and quality characteristics of puri. Hydrocolloids like CMC, Xanthan and HPMC increased the water absorption of puri dough, while it decreased in all other samples.. The dough development time and mixing tolerance index values increased, while dough stability did not get affected. On addition of hydrocolloid, there was a reduction in the pasting temperature, while the peak viscosity, hot paste viscosity and cold paste viscosity values increased. Hardness, cohesiveness and adhesiveness properties of the puri dough increased with the addition of hydrocolloids.

Bou et al., (2012) studied the quality assessment of frying fats and fried snacks during continuous deep-fat frying at different large-scale producers. Analytical parameters recorded in order to monitor oil degradation during continuous frying included viscosity, dielectric constant (DC), C18:2n 6/ C16:0 ratio, iodine value, acid value (AV), lipid UV absorption, p-
anisidine value (AnV), and polymer and diacylglycerol contents. Changes in DC, AV, lipid UV absorption, AnV and polymer content were useful to monitor frying oil quality. For all tested conditions, parameters that were most closely related to oxidation, such as AnV, lipid UV absorption, polymer content and DC, were the best complement/alternative to AV for routine quality control of frying oils during continuous deep-frying. Lipid extracts from fried snacks were also analyzed and the results were similar to those obtained for their counterpart frying oils. It was concluded that continuous deep-fat frying produces commercial fried snacks with a relatively uniform and high quality.