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A REVIEW

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Application of extrusion cooking technology in food industry

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SUMMARY :

Snack foods are being considered integral part of human food habits and they become more relevant if targeted to satisfy the need. The promising feature of the technology is that the final product can be tailored as per nutrition requirement by changing the feed material composition. The concern of the present time to prepare such food products which can be aid in control prevailing diseases like heat problems, diabetics, blood pressure etc. extrusion cooking is a feasible technique to manufacture expanded products and has been the objects of studies to enhance the nutrition and functional properties of extrudates for the development of various product. Extrusion cooking results in starch gelatinization, denaturation of proteins, inactivation of many native enzymes and antinutritional factors, reduction of microbial counts and improvements in digestibility and biological value of proteins. Extruded product can be categorized for a particular application depending on their functional properties such as water absorption and water solubility indexes, expansion ratio, bulk density and viscosity of the dough.

KEY WORDS : Application, Extrusion, Cooking technology, Food industry

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Extrusion cooking is a relatively recent form of food processing. Forcing material through a hole is the process of extrusion. It involves compressing and working a material to form a semisolid mass under a variety of controlled conditions and then forcing it, at a predetermined rate, to pass through a hole. The origins of extrusion are in the metallurgical industry, where in 1797 a piston driven device was used to produce seamless lead pipes. The current understanding of extrusion technology and the developments in machine design are largely due to research carried out by the plastics industry. Extrusion technology was first applied to food materials in the mid-1800s, when chopped meat was stuffed into casings using a piston type extruder. Extrusion cooking process is high temperature short time process in which moist, soft grain is fed into extruder where desired temperature and pressure are obtained over a required period of residence time (Altan *et al.*, 2008; Deshpande and Poshadri, 2011 and Iwe, 1998). As result, screw kneads material into a semi-solid, plasticized mass. If the food is heated above 100^{0}C the process is known as extrusion cooking or hot extrusion. Generally external heat for cooking of the product is not supplied and it is achieved through shear and friction in the extruder. Extrusion cooking is used worldwide for the production of expanded snack food foods, modified starches ready-to-eat (RTE) cereals, pasta and pet foods (Deshpande and Poshadri, 2011). This technology has many distinct advantages like energy efficient, lack of process effluent and versatility with respect to ingredients selection and shapes and textures of the products that can be produced. It is used for processing of starch and proteinaceous material. Therefore, extrusion cooking is believed to be an important food processing technique for preparation of nutritious food.

Cold extrusion, in which the temperature of the food remains at ambient is used to mix and shape food such as pasta and meat products. Low pressure extrusion, at temperatures below 100^{0}C, is used to produce for examples, fish pastes, surimi and pet foods.

There are a variety of available extruders that have been designed for different applications. For food, particularly RTE cereals the two commonly utilized extruder consist of a single screw or twin screws that revolve in an enclosed barrel. The turning of the screw serves many functions, including mixing raw material, pressurizing product mass and moving product along the length of the barrel to be extruded through a die. The advantages with the use of extruders is higher productivity, low operating cost, versatile to use and energy efficient than the other processes cooking process.

Grains used for extrusion and its composition :

Cereal flours and other starchy materials are widely used as raw materials in the production of many extruded products. The ingredients used in extrusion are predominantly dry powdered materials, with the most commonly used being maize, rice and wheat flours. In addition to starch-based products, a range of protein-rich products can be manufactured by extrusion using raw materials such as soya or sunflower, beans, field bean and isolated cereal proteins. Accordingly, many of the studies relating to cereal extrusion focus on changes occurring in the starch component of the product under varying extrusion conditions and the resulting effects on its physical, chemical and organoleptic properties. The type of extruder, feed moisture, feed rate, barrel temperature, screw speed, screw profile and die size are all important in developing the characteristics of the extruded product.

Maize (*Zea mays* L.) also known as corn, is one of the world's most versatile food grain. It contains 355 Kcal energy with 9.08 per cent protein, 3.88 per cent fat, 0.03 per cent ash, 76.80 per cent carbohydrates, vitamins and amino acids (Santosa *et al*., 2008).

Santosa *et al.* (2008) developed the extrudates from maize of different varity and at four moisture levels (0,5,10 and 15%). He observed that all the corn varieties could be processed using extrusion technology. Addition of 5 per cent moisture resulted better quality extrudates compared to other concentration.

Sharma *et al.* (2002) conducted an investigation on five improved genotypes of maize namely Paras, Prabhat, PAC 776, Bio 9637 and Prakash. The grains were analyzed for chemical components and it was reported that moisture content ranged from 8.21 to 8.85 per cent in all the varieties. Prakash and PAC 776 varieties showed the higher percentage of moisture (8.85 and 8.79%, respectively). It was also reported that varieties Paras and Prakash were rated superior for characters such as protein (10.23 and 9.80%), fat (4.45 and 5.00%) and tryptophan (0.72 and 0.70% of protein). Bio 9637 and Prabhat were promising for carbohydrate (77.33 and 77.74%), minerals (1.40% in both varieties) and energy values (358 and 356 Kcal).

Bhattacharya and Prakash (1994) prepared extruded from rice and chick pea (*Cicer arietinum* L.) flours, containing 20 per cent moisture, 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). 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.

Bhattacharyya *et al.* (1993) used rice and chickpea flours blends in the ratios of 100:0, 90:10, 70:30, 50:50, 30:70 and 10:90 and tempered, blended mixtures with water to a moisture content of 15 per cent and extruded with a single screw. On increasing the proportion of chickpea in the blends, the diametric expansion (DE) and water holding capacity (WHC) decreased, while peak shear force (PSF) and bulk density (BD) increased.

A rice and green gram (*Vigna radiata* L.) blend (1:1, dry basis) was extruded by Bhattacharya *et al.* (1993) using a co-rotating twin-screw extruder with a barrel diameter of 3 mm. The effects of barrel temperature (100–175 °C) and screw speed (100–400 rpm) on the extrusion system parameters (torque and specific mechanical energy) and extrudate characteristics (expansion ratio, density and maximum shear stress) were studied. The response functions (torque, specific mechanical energy, expansion ratio, extrudate density and maximum shear stress) were related ($r \geq 0{\cdot}870, p \leq 0{\cdot}01$) to the process variables (screw speed and temperature) by second-order polynomials. The torque during extrusion was highest at the highest temperature levels. The specific mechanical energy linearly increased with screw speed. The maximum breaking (shear) stress of the product was highly sensitive to the levels of the extrusion variables and varied up to 25-fold. High barrel temperature combined with a low screw speed is suitable for obtaining an expanded product.

Borhade *et al.* (1983) mentioned that horse gram and moth bean seeds contained 23.6 per cent and 21.9 per cent protein (N x 6.25), respectively. Both the legumes are rich sources of iron. The iron contents in horse gram and moth beans were 11.0 and 9.6 mg/100 g, respectively. NaCl at 10 per cent (w/v) and Na_2CO_3 at 0.5 per cent (w/v) were found to be effective in extracting 89 per cent and 80 per cent of moth bean and horse gram proteins from defatted flour. The minimum solubility of horse gram proteins from defatted flour was at pH 4.0 whereas, proteins from moth bean exhibited minimum solubility at pH 4.5. The water and oil absorption, and foaming capacities in case of horse gram and moth bean flours were 2.0 g/g and 2.2 g/g, 23.0 per cent and 2.0 g/g, 1.6 g/g, 27.6 per cent, respectively.

Mishra *et al.* (2006) studied the antioxidant activity of Garcinia indica (kokam) is an Indian spice. They observed that the antioxidant activity of aqueous and boiled extracts corresponding to their use in cooking and home remedies, besides the commercial kokam syrup. The assays employed are ORAC, FRAP, ABTS and the ability to inhibit lipid peroxidation in rat liver mitochondria. Kokam syrup and the two aqueous extracts had significant antioxidant effects in the above assays. They have high ORAC values (29.3, 24.5 and 20.3), higher than those reported for other spices, fruits and vegetables. The high antioxidant activity of kokam adds one more positive attribute to its known medicinal properties and hence, its use in cooking, home-remedies and as a soft drink may be promoted.

Varalakshmi *et al.* (2010) reported that Garcinia is a large genus of polygamous trees or shrubs, distributed in the tropical Asia and Africa and is a rich source of bioactive molecules including xanthones, flavonoids, benzophenones, lactones and phenolic acids. In the present study, an attempt was made to evaluate the antimicrobial properties of *Garcinia indica* on certain microbes and cytotoxic properties of *Garcinia indica* on Balb/c 3T3 mouse fibroblasts. *Garcinia indica* fruit rind extract showed inhibitory effect on cultured 3T3 mouse fibroblasts. The cell concentration decreased with increasing concentration of the extract. The *G. indica* extract has both antifungal and antibacterial properties and has a potential for use as a biopreservative in food applications and therapeutic agent in cancer treatment.

Extrusion cooking :

Singh *et al*. (2007) reviewed the nutritional aspects of food extrusion. Mild extrusion conditions (high moisture content, low residence time, low temperature) improve the nutritional quality, while high extrusion temperatures (200^0C), low moisture contents (<15%) and improper formulation (e.g. presence of high-reactive sugars) can impair nutritional quality adversely.

Bisharat *et al.* (2013) studied that effect of extrusion conditions on the structural properties of corn extrudates enriched with dehydrated vegetables. It was observed that the extrudates obtained using a twin-screw extruder, operated at different conditions, including screw speed (150 rpm, 200 rpm, 250 rpm) and extrusion temperature (140 °C, 160 °C, 180 °C). The moisture content of the raw mixture was regulated in three levels (14%,16.5%, 19%), whereas, the concentration of the added ingredient was adjusted to 4 per cent, 7 per cent and 10 per cent for broccoli and to 4 per cent, 6 per cent and 8 per cent for olive paste. It was concluded that the products with 14 per cent moisture content and 4 per cent material concentration that were extruded at the highest screw speeds (250 rpm) presented the highest degree of expansion.

Sun *et al.* (2006) studied that the effect of extrusion cooking of barley, peas and a mixture (4:1) of potato starch and wheat bran. Extrusion cooking increased the proportion of rapidly digestible starch (RDS), and reduced the proportion of slowly digestible starch (SDS) and resistant starch (RS). He concludes that extrusion processing had a major impact on the site and extent of nutrient absorption in the gut of pigs, but that the influence was strongly dependent on the botanical origin of the carbohydrate source.

Lazou *et al*. (2007) studied the effect of extrusion conditions, including feed rate (2.52–6.84 kg/h), feed moisture content (13–19% w. b.), screw speed (150 – 250 rpm) and extrusion temperature (150–230°C) on structural properties of corn-legume based extrudates. Porosity of extrudates was found to increase with temperature and residence time and to decrease with feed moisture content and corn to legume ratio. Screw speed did not affect extrudates properties. Comparatively, the usage of white bean in mixtures for the production of snacks, led to a product with higher porosity than those with other legumes.

Functional properties of flour and extrudetes :

Jyothi *et al.* (2009) studied the physical and functional properties of arrowroot starch extrudates. Different levels of feed moisture (12%, 14% and 16%) and extrusion temperatures (140, 150, 160, 170, 180 and 190 °C) were used for extrusion. The expansion ratio of the extrudates ranged from 3.22 to 6.09. The water absorption index (6.52 to 8.85 g gel/g dry sample), water solubility index (15.92% to 41.31%) and oil absorption index (0.50 to 1.70 g/g) were higher for the extrudates in comparison to native starch (1.81 g gel/g dry sample, 1.16% and 0.60 g/g, respectively). Hardness and toughness were more for the samples extruded at higher feed moisture and lower extrusion temperature, whereas, snap force and energy were higher at lower feed moisture and temperature. Extrusion cooking of arrowroot starch resulted in products with very good expansion, colour, and lower digestibility, which can be exploited for its potential use as a snack food.

Adeleke and Odedeji (2010) studied the functional properties of wheat and sweet potato flour blends. They studied the functional properties and gives the procedures for determination of swelling powder, viscosity determination, pH determination, water absorption capacity, fat absorption capacity, foaming capacity and foaming stability, bulk density. The results showed that the swelling power for wheat flour was 12.75 per cent which was greater than that of sweet potato flour of 5.73 per cent, wheat flour recorded the highest foaming capacity of 4.12 per cent while sweet potato flour had 1.28 per cent, The pH values for other blends ranged between 5.40 and 5.70 as more and more sweet potato flour was added to wheat flour the pH value was tending toward slight acidity, bulk density value for wheat flour was 7.47 g/cm^3 while sweet potato flour recorded 6.83 g/cm$^{3.}$

Parameters affecting extrusion :

Filli *et al.* (2010) studied the effects of extrusion conditions, feed composition percentage moisture (wb) and screw speed (rpm) on the water absorption index (WAI); water solubility index (WSI) and viscosity from millet/soybean flour mixtures. They reported that, the optimal combination of feed composition (17.7% soybean), feed moisture (27.3% wb) and screw speed (161 rpm) resulted in optimal WAI of 4.6 g water per g sample. The optimal combination of feed composition (14.77% soybean), feed moisture (15.23%) and screw speed 220 rpm resulted in optimal WSI of 6.15 per cent.

Blended extruded :

Altan *et al.* (2008a) studied twin screw extrusion of barley-grape pomace blends: Extrudate characteristics and determination of optimum processing condition. Grape pomace was mixed thoroughly with barley flour to the ratio of 0, 2, 6, 10, and 12.73 per cent (db). It was observed that, blends of 2 per cent grape pomace extruded at 160°C, 200 rpm and 10 per cent grape pomace extruded at 160°C, 150 rpm had higher preference levels for parameters of appearance, taste, texture off-odor and overall acceptability.

Altan *et al.* (2008b) studied evaluation of snack food from barley-tomato pomace blends by extrusion processing. Blends were prepared by mixing barley flour and tomato pomace in the ratios 100:0, 98:2, 94:6, 90:10, 87.27:12.73 on dry-to-dry weight basis.Sensory evaluation was carried out for appearance, taste, texture off-odor and overall acceptability. It was found that, extrudate with 2 per cent and 10 per cent tomato pomace extruded at 160°C, 200 rpm had higher preference levels for parameters of appearance, taste, texture off-odor and overall acceptability.

Bhattacharaya *et al.* (2005) studied the physico-chemical characteristics of extruded snacks from rice (*Oryza sativa* L.), corn (*Zea mays* L.) and taro (*Colocasia esculenta* L. Schott) by twin screw extrusion. The rice, corn and taro flours (100:10:9) were blended and extruded in co-rotating fully- intermeshing twin screw extruder (Model No P1, Kolkata) at barrel temperature 141, 150 and 159^{0}C, respectively and screw speed at 475 rpm while the feed rate was maintained at 28 g/min. Protein solubility, texture analysis, starch digestion and physical properties were analyzed. Results showed that flours extruded at 141^{0}C digested significantly slower than those extruded at 150 and 159^0 C. Also, increasing expansion, decreasing bulk density and decreasing breaking force with increasing barrel temperature. The protein solubility decreased after extrusion.

Byung-Kee *et al*. (2004) studied extrusion on regular and waxy barley flour for production of expanded cereals. He studied the physical properties and effect of extrusion parameters. Blend was extruded in laboratory single screw extruder. Result showed that, flour from break roll mill stream of both regular and waxy barley produced extrudate with higher expansion index (2.73-3.02), higher water absorption in lower flour from reduction roll mill stream.

Plahar *et al*. (2003) standardized extrusion cooking process for development of a high protein weaning food based on peanuts, maize and soybeans and evaluated the effects of blend formulation, extrusion temperature and feed moisture content on ease of extrusion and product quality characteristics. Results showed bulk density and hardness increased while expansion index decreased with increase in feed moisture content. For ease of extrusion and best product quality in terms of sensory attributes and cooking properties, the extrusion parameters were established for a blend formulation of 75 per cent maize, 10 per cent peanut and 15 per cent 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 per cent and extrusion temperature of 100^0C–105^0C.

Caravalho and Mitchell (2000) investigated the influence of added sucrose in maize grits and wheat flour on the degree of expansion and extent of starch conversion on extrusion processing. Replacing wheat flour by sucrose even at levels as high as 20 per cent of the flour weight had little effect.

Gutkoski and El-Dash (1999) studied the effects of initial moisture levels and extrusion temperatures on bulk density, water absorption and water solubility index, viscosity and colour of extruded oat products. The result showed that the water absorption index of extrudates were relatively low (4.16–6.35 g gel/g sample) but increased as the initial moisture of the raw material as well as the extrusion temperature was elevated. Products with lower values of L * (luminosity) and greater values of a* (red) and b* (yellow) were obtained at high moisture rates and at a 120^0 C extrusion temperature.

Faller *et al*. (1999) concluded that moisture content and extrusion conditions as well as soy protein type are directly related to sensory and physical characteristics. Information available to consumers either prior to or at the point of purchase may influence product selection.

The effect extrusion process variables like feed moisture content, screw speed and die temperature on physical and textural properties like, bulk density, expansion ratio, hardness and moisture content of extrudate prepared from broken raw rice and mung bean flour were investigated by Jha and Prasad (1997). They summarized the results that expansion ratio of broken rice and mung bean extrudes varied from 2.2 and 3.46, bulk density varied from 65 to 150kg/m^3, hardness varied from 45 to 110 N and moisture content of extrudates varied from 6 to 12 per cent (wb). The extrudate food prepared in proportion of 70:30 at processing conditions of 170^0C die temperature, 170rpm screw speed and 12.6 per cent moisture content (wb) was found to be most acceptable product.

Priya *et al*. (1995) studied that in corn- starch – peanut flour based snacks, oil absorption by extrudates was only influenced by the type of peanut flour. Within the range of (per 1 kg batch) 0.30-0.34g/g added water, 0.16-0.20g/g non-fermented peanuts flour and /fermented peanut flour and extrusion temperatures of 125 to 150^oC, extrudates with a range of functional characteristics can be produced.

Kohda *et al*. (1989), studied the effect of moisture content and process temperature on the product properties and processing characteristics of cassava extrusion. Cassava flour was rehydrated to 10, 13, 16 and 19 per cent (wb) of moisture content. Result showed that a good appearance produced at process temperature 140-160^0C for feed moisture content of 13-16 per cent (wb). For all level of process temperature, the safe operation conducted for feed moisture content of 13-16 per cent (wb).

Nutritional and sensory properties of extruded product :

Deshpande and Poshadri (2011) studied the physical and sensory characteristics of extruded snacks prepared from foxtail millet based composite. Blends were prepared by mixing foxtail millet flour and other flours namely rice flour, chick pea flour, amaranth seed flour and cow pea flour in ratios 70:07:05:10:08, 60:05:05:20:10 and 50:10:05:30:05. Nutritional properties of the blends were analyzed and extrusion cooking was carried out in co-rotating twin screw extruder (Clextral BC 21, France). He reported that, composite flour in ratios 60:05:05:20:10 could be used to produce quality extrudates and acceptable sensory properties.

Murekatete *et al*. (2010) studied the characterization of Ready-to-Eat composite porridge flours made by soy-maize-sorghum- wheat. Two composite flour were formulated; sorghum-maize-soy 1 (SMS 1) and sorghum-maize-soy 2 (SMS 2). The SMS 1 was mixture of 45 per cent soybean, 25 per cent maize, 25 per cent sorghum and 5 per cent wheat flour while SMS 2 was a mixture of 25 per cent of soybean, 35 per cent of maize, 35 per cent sorghum and 5 per cent wheat flour. Results showed that, changes in proximate composition, minerals and amino acids content during HTST extrusion were significant in both flours while fatty acid did not change significantly.

Laike *et al*. (2010) studied the effect of extrusion variables including barrel temperature (110, 130 and 150°C), feed moisture content (17, 21 and 26 % wb) and screw speed (100 and 140 rpm) on the physical and sensory properties of an extruded product was investigated. The study showed significant differences ($p<0.05$) in hedonic rating for colour texture and overall acceptance between products as evaluated by the sensory panels. In general, extrusion variables induced significant changes in the product quality attributes evaluated.

Bhattacharya *et al*. (1993) studied the effect of the process variables; the feed ratio has the maximum effect on protein digestibility, followed by process temperature in the extrusion of fish–wheat flour blend. Tripling the ratio of fish to wheat increases the digestibility of the extrudates by 2–4 per cent. Increase in extrusion temperature (100–140^{0}C) enhances the degree of inactivation of protease inhibitors in wheat flour and consequently, the protein digestibility values are increased. Extrusion, even at 140^{0}C, does not have any adverse effect on protein digestibility, which might be attributed to the lesser residence time of food dough within the extruder.

Conclusion :

The proper selection and form in which these ingredients are used play critical role during the complex process of extrusion cooking. The extruder equipment and the wide range of process variable such as temperatures, pressure, shear, time etc also affect the final output. Significant changes take place in physical, physico-chemical, textural, biochemical, nutrition al profile of these ingredients and additives during the high temperature and short time process of extrusion cooking. Hence, it is quite complicated as to which of the identified / selected ingredients would fulfill the requirements of the final product. The review of past studies can, however, be used as the guidelines while undertaking development of newer formulated and functional foods.

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