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Extrusion processing of agri-horti and dairy products: A review

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Abstract
Extrusion processing is a versatile process used for producing kind of food products. Raw material ideal for extrusion processing are ingredients rich in starch and protein. In extrusion processing, properties of extrudates change due to thermo-mechanical operation in which moisture, pressure, temperature and mechanical shear are applied to starchy and proteinous raw material. Other ingredients such as cereals, pulses and byproduct of the grain milling, protein rich components, dietary fibres, fruit and vegetables' extract, and dairy ingredients could be incorporated into extrudates for enhancing the nutritional properties of the product as well as for producing variety of food products. Fortification of these ingredients not only changes the nutritional profile but also alter the functional properties of the final extruded product. In this paper, effect of incorporation of these ingredients on the final characteristics of the extrudates has been reviewed.

Keywords: extrusion, food processing, fruits, vegetables, cereals, pulses

Introduction

Extrusion processing in food is defined as a thermo-mechanical processing in which moistened, expansible starchy cereal and proteinous raw materials mainly are cooked under high pressure, temperature and mechanical shear (Miladinovic and Zimonja, 2010) [30]. The raw mixture cooks and transforms its physicochemical properties quickly by the heat generated by combined effect of viscous extrudate dissipation and shearing effect (Thymi *et al*., 2005) [51]. Combination of processes such as conveying, compounding, deformation, segregation, change of temperature, shaping, flavor generation, encapsulation, and sterilization take place when a raw material passes through an extruder (Rao and Thejaswini, 2015) [38].

In extrusion, a set of mixed ingredients at a particular rheological status are forced through an opening in a perforated die with a design specific to the food which is cut to a predetermined size by blades. The whole set up used for these combined processes is called an extruder which is composed of five components: (i) the feeding system; (ii) the pre-conditioning system; (iii) the screw or worm; (iv) the die; (v) the barrel and (vi) the cutting mechanism. The final product's properties vary with the configuration of screw, barrel and die (Riaz, 2000) [39].

Extruders are categorized, on the basis of the method of operation and method of construction, into two categories each; cold extruders and extruder-cookers and single- and twin-screw extruders respectively. Cold extrusion is used to produce those types of confectionary where temperature of the food remains at ambient, cause minimal losses (Fellow, 2000) [18] such as pasta, pastry dough etc. In extrusion cooking (or hot extrusion), food is heated above 100ºC which is an HTST process used to produce expanded products like ready to eat snack food, texturised vegetable protein, breakfast cereal, pet food, dried soup etc.

Extrusion cooking brings many changes in the structure of the extrudates and modifies the properties like improving the solubility, swelling power, water hydration viscosity and water holding capacity, increasing the soluble fiber content of fibrous materials such as plant cell-wall rich materials, bran and hulls of various cereals and legumes (Ralet *et al*., 1990., Ralet *et al*., 1993a, 1993b., Gourgue *et al*., 1994., Hwang *et al*., 1998., Gaosong and Vasanthan, 2000., Rouilly *et al*., 2006). The extruded products also improve sensorial characteristics, digestibility (Singh *et al*., 2010) [73, 72, 33, 36, 28, 46, 80] and nutrients bioavailability (Gu *et al*., 2008) [19] compared to conventional food, thus it has been used to meet the dietary requirements of particular groups (such as children, anemic, malnourished and diabetic, obesity and other related diseases) of the population. The extrusion process appeals the food industries also due, economical advantages, high productivity, low operating costs, energy efficiency and shorter cooking times. Extrudate mainly consists of starchy or, proteinous raw material; for example rice flour or, corn starch. Extruded snacks made with only one type of cereal does not meet the requirement of nutritional value (Rampersad *et al*., 2003) [37] being relatively lower in nutrients such as dietary fibres, vitamins, and minerals (Pastor- Cavada *et al*. 2011) [36]. So, many inclusions such as incorporation of other cereal, pulses, fruits and vegetables, dairy products etc. have been made for making them multi-nutrient food product, for example, inclusion of dietary fiber and nutrients such as lycopene (Stojceska *et al*., 2010, Dehghan-Shoar *et al*., 2010) [47, 13]. Studies have been also conducted to identify the impact of inclusion of such ingredients on functional properties of extruded/pasta product.

Effect of Cereals and Millets on Quality of Extruded Products

Cereals are ideal raw material for extruded snacks because of their starchy nature. When starchy cereal flour passes through a die, it is subjected to a combination of temperature, moisture, shear, and pressure due to which the starch gets gelatinized and dextrinized. Upon exiting the die, the material faces the surrounding which is at a lower pressure and temperature, thus causing a rapid structural expansion as the water in the product vaporizes (Alvarez-Martinez *et al*., 1988) [7]. In general, corn and rice flour are used as a raw material for producing extruded snacks but various other cereals also contribute many physicochemical and textural changes to the extruded products. These cereals are not only rich in complex carbohydrates but also with various minerals and vitamins like niacin, iron, riboflavin and thiamine. Apart, cereal grains contain different phytochemical profiles than fruits and vegetables (Liu, 2007) [29]. Many researchers have proved that adding cereals and their byproducts in extruded food make it more nutritional and also more palatable.

Sorghum is a rich source of starch (70%) and protein (18%., with significant share of two amino acids: lysine and tryptophan), and fat (about 5%), vitamins (mainly groups B), minerals, especially magnesium, calcium and iron. Breakfast Cereal (BFC) containing white sorghum significantly showed higher starch, resistant starch and In-vitro protein digestibility than that with red sorghum and whole grain oat without compromising the sensory properties and thus, it has the potential to be used in breakfast cereal industry (Mkandawire *et al*., 2015) [31]. However, starch digestibility of sorghum based extrudate is also affected by pre-extrusion grain sizes (Al-Rabadia *et al*., 2011) [4].

Different blend composition of wheat semolina and pearl millet flour (100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80, 10:90, 0:100) was used for pasta preparation and effect of level of pearl millet flour in the blend on functional properties of pasta was studied and It was concluded that pasta cannot be prepared from 100% pearl millet flour (Jalgaonkar and Jha, 2016) [22] as with increase in the level of pearl millet flour in the blend, increased protein, ash and cooking loss of pasta whereas hardness, cohesiveness, springiness, gumminess and chewiness showed decreasing trend. Pasta made with blend of wheat semolina and pearl millet flour with the ratio of 70:30 showed maximum acceptability in terms of desirable quality characteristics such as cooking loss (<8%), protein content (>10%), ash content (<0.7%), colour and texture (Jalgaonkar and Jha, 2016) [22].

Inclusion of hull-less barley, Barley β -glucan and Bacillus coagulans GBI-30, has been included in the polyphenol rich durum wheat flour to produce functional pasta rich in proteins and phenolic acids and it was found that the produced pasta had better cooking performance (Fares *et al*., 2015) [17]. β-glucan and bioactive phytochemicals are also found in oats. Commercial Oat-based breakfast cereals available in the market were examined by Ryan *et al*. (2011) [42] to analyse and compare the polyphenol content and total antioxidant capacity and it was found that the these breakfast cereals were significant source of polyphenols and antioxidants. Corn fibre can also be used for reduction of loss of total phenolic content in the extruded corn grits (Wang *et al.,* 2013) [55].

Fibre and minerals rich ingredients like oat and teff flour were compared with wheat flour (control) for the preparation of fresh egg pasta and it was concluded that nutritional value of spaghetti can be increased by taking oat as a raw material without compromising with the palatability, while teff pasta was found to be less acceptable with reference to sensory quality (Hager *et al.,* 2013) [20]. The predicted glycaemic index **'**GI' was lower for teff and oat, followed by wheat pasta.

The addition of pseudocereals has also been found to improve the functional properties of extrudates (Alencar and de Carvalho Oliveira, 2019) [3]. Pseudocereals rich in carbohydrate and protein, are gluten-free and are not from the grass family (Gramineae). A few examples are amaranth, quinoa, kaniwa and buckwheat. Cardenas-Hernandez *et al*., 2016) [11] has studied the functional properties of pasta with amaranth ingredients (amaranth seed flour (AF) and dried amaranth leaves (DAL)) and reported that the product showed high protein, crude fiber, and ash contents. DAL added pasta had higher contents of iron, zinc, magnesium and potassium compared to that of control pasta and also had the higher antioxidant capacity values after cooking. The results demonstrated that addition of amaranth ingredients in pasta decreased the cooking time, increased cooking loss, and decreased luminosity values than that of semolina control pasta.

Sectional expansion index (SEI), stiffness, water absorption index (WAI) and water solubility index (WSI) also gets affected by pseudo-cereals inclusion in corn-based extruded snacks (Diaz *et al*., 2015) [15]. SEI reduced by increasing the content of amaranth and kaniwa while with the addition of quinoa, SEI increased upto 35% of quinoa addition after which SEI decreased. The stiffness property also varies differently for different pseudocereals; increasing contents of amaranth and kaniwa reduce the stiffness while increasing contents of quinoa increased the stiffness. However, quinoa addition has minor effects on stiffness in lesser concentration and for further addition of quinoa, stiffness increases. WAI also reduce by increasing the pseudocereal concentration in extrudate as pseudocereal flour being high fibrous in nature reduce the extent of carbohydrates hydrolysis, encourage the formation of amylose-lipid and amylose-protein complexes and thus reduce WAI (Brennan *et al*., 2008., Diaz *et al*., 2013) [10, 16]. Though, extrudates having higher contents of quinoa had stable WAI but the pore size reduced significantly. The increasing contents of amaranth, quinoa and kaniwa reduce WSI of extrudate (Diaz *et al*., 2015). Diaz *et al*. (2013) [15, 16] had also observed that corn based snacks were less crunchy, less crispy and less adhesive than the control sample without addition of these cereals.

Effect of Byproduct of Grain Milling Industry Such as Bran on Quality of Extruded Products

Byproducts of grain milling industry such as bran, well-heeled with dietary fibre, have the capability to lower down blood cholesterol levels and keep heart diseases at distance. Many researchers have incorporated bran to enhance the nutritional and physical quality of extruded food and pasta. Robin *et al.* (2011) [40] studied the effect of level of bran addition in wheat flour on starch deformation. Higher level of bran led to increase starch solubility and free water content, and a decrease in melt temperatures and starch glass transition temperature of up to -260 °C.

Corn bran can increase the xanthophyll content of the wheat flour noodles (Baek *et al.,* 2014) [8]. Maize bran can be incorporated in the formulation for breakfast cereal to enhance their antioxidant capacity (Holguín-Acuña *et al.,* 2008) [21]. Water absorption capacity can be increased by adding corn bran in the formulation whereas the ER is negatively affected by corn bran (Baek *et al.,* 2014) [8]. Bran amount on the quality such as (i) texture, (ii) structure, and (iii) rehydration properties of extruded cereals was analysed by tomography and magnetic resonance imaging (Chassagne-Bercesa *et al.,* 2011) [12] and it has been found that adding bran increase the fiber content which in turn increase the hardness and decrease the crispness of extruded cereals. Bran inclusion also decrease the expansion and thus the cell size and the porosity of extruded cereals decreases while the thickness of cell wall from all around increases, in agreement with the increase of maximum hardness observed.

Size of the bran also affect on macrostructural properties (Alam *et al.* 2016) [1]. They compared properties of extrudates containing two different sizes of rye bran in the mixture of rye endosperm flour and corn starch and found that fine bran addition effectively improved macrostructural properties as compared to coarse bran through increasing expansion by 3.3-11.7% and piece density by 3.8-10.5%. Size of rye bran also influences the crispiness of extrudates in inverse way (Alam *et al.,* 2016) [2].

In General, one compromise with the structural, textural and sensory properties in extruded products when incorporating cereal bran for getting higher dietary fiber. Researchers worked on increasing the sensorial characteristics of extruded product by treating bran in different ways. Nikinmaa *et al.* (2017) [33] studied for making superior structural and textural extrudate by fermenting the bran with dextran producing *Weissella confusa* and found that extruded cereal foam with *Weissella confusa* fermented bran had similar radial expansion and higher crispiness index than that of the control extrudate (made with pure rye endosperm flour). Sibakov *et al.* (2015) [45] has also treated bran in four ways (untreated, ultra-fine ground, enzymatically hydrolysed and hot water-extracted solubles and residue) and added them into the defatted endosperm oat flour to produce extruded snacks. They investigated the impact of these treatments on the chemical, textural and structural properties of extrudates and concluded that the water-soluble (WS) and water-insoluble (WIS) Oat Bran Concentrate (OBC) fractions had significant differences in their chemical compositions; WS-OBC had higher β- glucan and TDF contents and lower protein and starch contents compared to WIS-OBC.

Effect of Protein Rich Foods on Quality of Extruded Products

Proteinous raw materials can be used as extrudate or, can be incorporated in starchy flour to make protein rich ready to eat (RTE) breakfast cereals, pasta, bread substitutes and pet foods. When undergo through extruder, protein texturized by denaturation, dissociation, thermal degradation, fractionation, and alignment of polymer chains; texturized soy protein is most popular proteinous extruded product available in the market. Beside this, many other protein rich raw materials like whey protein, legumes, peanut protein products, wheat proteins, soy protein etc. have been used in extrusion. Proteinous raw material in extrusion is used to produce meat like product which can be used for partial or, full replacement of meat.

Legumes are well known as protein rich sources. Fortifying legumes in any food can enhance its protein quality. When Bengal gram added in the rice flour extrudate and the properties were evaluated, it was found that protein of Bengal gram inhibits the expansion of extrudate thus increase the density of the same (Nithya *et al.,* 2016) [60]. Relation between expansion and protein was also described by Seth and Rajamanickam, 2012 [86], Shannon *et al.,* 2010 [88] and Rinaldi *et al.,* 2006 [77]. It was also found that Bengal gram inclusion does not have much effect on WAI but it does affect the WSI in negative way. When properties of the extrudate was evaluated by incorporating pigeon pea in the barnyard millet flour, it was found that both bulk density and sectional expansion index increase by increase in proportion of the pea flour (Chakraborty *et al.,* 2011) [18]. WAI and crispiness reported to reduce by the inclusion of the same. Corn pasta fortified with quinoa and broad bean., a type of legume when evaluated for proximate and nutritional analysis, it was found that bean enhanced the protein content of the extrudates but due to lower protein content of quinoa, overall protein richness of the extrudate was lower (Giménez *et al.,* 2016) [30]. Protein true digestibility was also reduced with addition of these two flours.

Wojtowicz and Moscicki (2014) [105] incorporated different types of legumes (white bean, split yellow pea and lentil) in different ratio and observed their effect on pasta extrudate properties such as specific mechanical energy (SME), ER, water holding capacity (WHC), cooking losses, water absorption index (WAI), water solubility index (WSI), the hardness, color of dry pasta products and quality attributes of ready to eat reconstituted pasta, like hydration time, firmness, chewiness, color and sensory characteristics. They concluded that highest protein content was in pasta fortified with lentil. Inclusions of legume also enhance the fibre content of pasta which in turn increases the energy consumption. Cooking time was reduced by legume inclusions which also increased the water holding capacity of pasta.

Soybean is a well known source of protein. Types of soy flour available in the market are: soy flour, made from toasted soybeans; soy protein concentrate (SPC) and isolate made from defatted soy flakes (containing 70 g and 90 g protein per 100 g respectively); textured soy protein, obtained from both textured soy flour and textured soy concentrate (Baiano *et al.,* 2011) [28]. A lot of studies have been done for inclusion of soy flour in extrudate. When added in wheat flour to make puffed extruded product through single screw extruder in varying ratio, it was seen that flow rate of extrudate through the extruder reduces as soy flour added to the blend (Zasypkin and Lee, 1998) [108]. Expansion ratio has also been affected by soy flour inclusion; the effect is in negative manner. Increasing level of soy flour in the extrudate decrease the starch gelatinization, which in turn thicken the pore wall and thus producing heavy product with significantly increased hardness and decreased crispiness (Liu *et al.,* 2000, Li *et al.,* 2005, Normell *et al,* 2009, Adrian *et al.,* 2008, and Kumar *et al.,* 2015) [52, 51, 61, 1, 32]. Soy protein inclusion also affects the dough rheological indices (Baiano *et al.,* 2011) [28] and increases the tenacity - extensibility ratio, and cooking time and may cause dough weakening in spaghetti making.

When physical properties of protein rich extruded product made with blends of corn flour and soy protein isolates was evaluated, it was found that as the soy protein isolate content increase in the product, breaking stress and bulk density also increase but decrease the ER, WAI, WSI, rehydration rate and L value (Yu *et al.,* 2013, Sun *et al.,* 2002, Filli *et al.,* 2012, Kumar *et al.,* 2015) [55, 97, 27, 32]. Decrease in water absorption index may be due to decrease in starch content with increase in soy level. Specific mechanical energy also gets affected by SPC fortification (De Mesa *et al.,* 2009) [14]. SPC found to reduce Specific mechanical energy. SPC inclusion also depress the cell size and thicken the cell wall when seen through X-ray micrographs. The cell size decreased and cell walls thickened with the addition of SPC which in-turn increase the no. of cells in the micro-structure of the extruded snacks. The reason behind this effect may be foaming action of proteins, which led to greater number of nucleation sites for water vapor Physical properties like hardness and crispiness of expanded product get affected also.

The rheological properties of the expanded product may be affected due to the dilution effect of soya on starch, influencing the extent of starch gelatinization (Sibel and Fahrettin, 2008) [91]. Reduction in cooking time is due to the competition of soy proteins and starch for water which also reduce the change in length to the length of dry spaghetti ration without affecting ratio of increase in weight or, diameter to the weight or, diameter of dry spaghetti. When soy flour mixed in potato flour in different proportion to make ready-to-eat snack food, physical properties like expansion ratio, hardness, and overall acceptability found to be affected (Nath *et al.,* 2008) [57]. Fortification of soy protein in the form of soy protein concentrate and defatted soy flour in sweet potato flour to make pasta was also studied and it was concluded that these proteins reduce the stickiness, firmness, cohesiveness and springiness of the pasta and at the same time increase the cooking loss. β-carotene content of pasta decrease as the protein source content increase (Limroongreungrat and Huang, 2007) [48]. Soy flour inclusion decreased the ER in quadratic term and increased the hardness in linear term.

Lobato *et al.* (2011) [49] added soy flour in a mixture of corn starch and oat bran to prepare functional puffed ingredient; corn starch was added in the minimum amount just to give structure to the product. They concluded that inclusion of oat bran and soy flour has negative impact on radial expansion. Same result has been found by other researcher as described above. Incorporation of defatted soy flour in rice flour to prepare extrudates was optimized by Garg *et al.* (2010) [29] and they concluded that, volumetric expansion index, specific length crispiness, and hardness of extrudate are highest for 18-20 % of soy flour. Soy protein also interacts with other protein like semolina protein present in the pasta extrudate and form large polymers (Lamacchia *et al*., 2010) [28]. Soya protein isolate (SPI) is the most refined form of soya bean proteins can also be used for enhancing the protein content of puffed product. This incorporation also increase the fat content of extrudate in increasing order, carbohydrate content is in decreasing order while ash content increases (Bhatt *et al.,* 2016) [11]. When come to the textural and physical parameters, length increase significantly whereas there is no significant difference in diameters. ER increases with increase in SPI thus decreasing the bulk density resulting in lighter, crisper final product. But when SPI added with other nutrient such as lycopene, their effect on extrudate is different, with increase in incorporation of lycopene and SPI content, Expansion index decreases. SPI cause reduced hardness and does not have much effect on colour (Bhatt *et al.,* 2016) [11].

Some crops are rarely used in staple food due to their low quality and lower protein content such as sorghum which is a popular crop in semi-arid regions as having drought tolerance property. Protein sources can be incorporated in this cereal's flour to make them protein rich. Devi *et al.* (2013) [21] developed sorghum based extrudate by making them protein rich by fortifying different sources of protein—whey protein isolate, defatted soy flour, and mixed legume flour. They concluded that expansion ratio of snacks decreases with increase in content of protein source. Among these three sources, incorporation of defatted soy flour results in lowest expansion compared to incorporation of other sources. Crushing force and crispness work both decreased with incorporation of protein sources.

Effect of Fruits on Quality of Extruded Products

Fruits, being rich in vitamins and minerals, are growing throughout the world with great interest. More than 675 million metric tons of fruit are produced globally (source: www.statista.com) each year and India is the second largest producer of the fruits producing about 81.285 million tonnes contributing 12.6% of the total world production of fruits (Source: APEDA Website, 2016) [9] because of the wide range of climate and physio-geographical conditions which ensures availability of most kind of fruits and vegetables.

Many studies have put in evidence that fruits and vegetables are important components of a healthy and balanced diet, whether they are consumed in the main meal or as a snack. They are a source of vitamins, minerals, and fibers, of a certain amount of energy (mainly in the form of sugars), are also a source of phytochemicals, which are potentially beneficial for our health. Every fruit have unique nutritional properties like carrot pomace is a good source of crude protein, crude fibre, iron, calcium, b-carotene and dietary fibre, cauliflower described as sources of fibre and antioxidants, yam is an excellent source of dietary energy and rich in minerals like phosphorous, potassium, manganese and vitamins, spinach is found as a good source of vitamin A, iron and other micronutrients and cabbage is enriched with vitamin B_1 and minerals like Ca, Mg and phosphorous. Mushroom has high content of vitamin B_2, B_5 and phosphorous (Turksoy & Ozkaya, 2011). Likewise, others fruits and vegetables have high composition of vitamins and minerals mainly.

Nowadays, fruit processing is becoming very popular in India and adding these in any food product make them more delicious and nutrients viable. By inclusion of fruits and vegetables, one can increase the nutrient content of extruded snacks also. Apart from nutrition, fruits and vegetables also affect extrudate functional properties. Carrot pomace, rich in carotene and fibre, was incorporated in varying proportions in corn starch extrudate and properties such as ER, unit density, WSI, WAI, microstructure, and b-carotene content were analysed for understanding of fibres effect on extrusion and extrudates (Kaisangsri *et al.,* 2016) [26]. There was decreasing tendency of extrudate to expand with inclusion of carrot pomace. Carrot pomace along with cauliflower trimmings were included in composite flour comprising rice & defatted soybean flour to prepare extruded snack (Alam *et al.,* 2016) [1] and their impact on properties such as bulk density (BD), ER, WAI, hardness, and fiber content were analyzed. As observed by Kaisangsri *et al.* (2016) [26], ER decreases with addition of carrot pomace and cauliflower trimmings in the formulation, but the hardness, bulk density and fibre content increased. These inclusions also decreased the water absorption index and the best product was obtained with composite flour blends 15 percent of defatted soybean flour, carrot pomace powder and cauliflower trimmings powder in rice flour. Carrot pomace inclusion and substitution of durum wheat semolina with finger millet flour in different proportions were done to make pasta and the properties were evaluated and compared with semolina pasta (Gull *et al.,* 2015) [32]. Cooking loss and firmness decreased with the intensity of inclusion while weight gain increased. It was also concluded that it is possible to replace semolina with millet flour and carrot pomace in pasta with acceptable characteristics. When carrot pomace was fortified in rice flour along with pulse powder, the combined effect of carrot pomace and pulse powder on the physical properties such as lateral expansion, water absorption index and water solubility index was significant but on hardness, the effect was insignificant (Kumar *et al.,* 2010) [45].

Fruit pomace such as pineapple pomace can enhance fibre content as well as the microbiological quality of extruded product as concluded by Selani *et al.* (2014) [89]. The pine apple inclusion had very little effect on hardness, yellowness, water absorption, and bulk density but significant effect on expansion, and luminosity (negative effect) and therefore, pineapple can be added in extruded product without compromising with the sensory quality. Inclusion of apple pomace in the corn flour-based extruded snack formulation and the resulted effect was studied by O'Shea *et al. (*2013) [35]. With increase in concentration of apple pomace in the corn flour-based extruded snack formulation, radical expansion ratio decrease. Texture, acoustic properties, starch properties and moisture were also affected by apple pomace. This is attributed to the high fiber content present in apple pomace but beyond a certain limit, it began to have a negative impact on the responses due to its fiber hydrophilic properties to absorb excess water and damage aerated bubble structures (O'Shea *et al.,* 2013) [35].

Blackcurrent juice press which is rich in fibre, vitamin C and antioxidant was exploited with barley flour, oat flour or oat bran to prepare healthy snacks (Mäkilä *et al.,* 2014) [53]. Two methods was used for pressing., conventional enzymatic pressing (high content of fiber and seed oil) and novel non-enzymatic juice processing (high content of sugars, fruit acids and anthocyanins) and characteristics of snacks obtained from both the press residues were compared. Extrudate with novel non-enzymatic press residue extruded with barley or oat flour had higher expansion, higher contents of fructose, glucose and fruit acids while lower pH, hardness and density compared to enzymatic press residue and oat bran which make the snacks more apprehensive in terms of texture, appearance, and flavor.

Fruit waste such as milled orange peel grape seed and tomato pomace was extruded with durum flour, partially defatted hazelnut flour, and rice grit (Yagc and Gogus., 2008) [106] and physical and functional properties such as density, porosity, water absorption and water solubility indices were evaluated. The resulting product's properties behavior with respect to addition of fruit waste was lowering of bulk density and WSI, increasing porosity and unchanged WAI. In a study, tomato, in form of tomato skin powder and tomato paste, was incorporated into starchy flour such as rice flour, corn grits and wheat semolina extruded food (Dehghan-Shoar *et al*., 2010) [13] and it was observed that the characteristics of extrudate (with tomato) such as crispiness, expansion and density were lower whereas hardness was higher compared to that without tomato ingredient.

Instead of pomace, fruit powder can also be added in the extruded product for enhancing their nutritional quality. Potter *et al.* (2013) [69] worked on incorporation of different types of fruit powder such as apple, banana, strawberry and tangerine in extruded snacks and their effect on characteristics of extrudate. They found that bulk density and hardness increases with fruit powder inclusion while lateral expansion reduced and final product had improved nutritional profile with increased levels of both insoluble and soluble fibre.

Yam (a type of edible tuber) when incorporated in corn-rice flour to develop extruded snack food (Seth *et al.,* 2013) [85], a significant position effect on WAI was observed where as there was very insignificant effect on WSI. Hardness increased considerably while the ER decreased.

In a study, grape marc powder was included in pasta making in varying proportion of 2.5, 5 and 7.5 % and their properties were evaluated (Sant'Anna *et al.,* 2014) [82]. The results show that the effect of grape marc powder addition on water absorption and cooking loss was insignificant while enhancing the nutritional quality such as total phenolic, condensed tannins, monomeric anthocyanin and compounds antioxidant capacity concentration but the sensory characteristics such as aroma, aftertaste, flavor and appearance was diminished. Texture of extrudate samples made from grape pomace-barley flour blends were also analyzed in terms of hardness, crispness, and brittleness by Altan *et al.* (2008) [6]. It was observed that increasing grape pomace level increased brittleness of samples, causes less crispy extrudate increase in peak force i.e. hardness of extrudates with respect to quadratic effect. It was also observed that increasing grape pomace level initially decreased SEI of extrudates up to 6% after that SEI increased slightly with respect to the quadratic effect of pomace level.

Honey is a sweet, viscous substance rich in sugar mainly fructose and glucose. It has high medicinal value and if included in food, it could enhance the quality. In a study, Juvvi *et al.,* 2012 [40] had worked on inclusion of honey in extruded expanded product made of rice and wheat flour and its effect. They observed that with increasing the honey proportion, bulk density ad WSI increased where as WAI and expansion reduced. Honey addition also affects the rheological characteristics of extrudates positively (Bobade *et al.,* 2017) [12]. When cooking quality was observed, it was found that honey cause delaying of gelatinization of starch and increased bulk density and decreased hardness and expansion. Nutritional parameters such as antioxidant activity, total phenolic content and total flavonoid content were increased with increased proportion of honey in extrudate (Kumar *et al.,* 2013) [46]. Conclusion of all the experiments was that the honey can be blended with starchy flour to make healthy extruded snacks.

Effect of Dairy Ingredients on Quality of Extruded Products

Though India is number one milk producing country in the world, its contribution to world trade is negligible. The gap can be bridged by value addition and product diversification. Today's consumers are increasingly seeking 'functional' foods for their health and well-being as means of nutritional intervention in disease prevention. Dairy products enriched with the health attributes of functional ingredients such as breakfast cereals would be safe and viewed as potential novel foods for health promotion. Whey, a by-product of cheese-making and casein manufacture in the dairy industry, accounts for about 20% (wt/wt) of total milk protein. Lactose makes up a high proportion (>75%) of the total whey solids. an excellent source of functional proteins, peptides, lipids, vitamins, minerals, and lactose (Qi *et al.,* 2010) [34].

When effect of adding whey protein on the water activity of extruded corn product was observed, it was found that whey protein negatively influenced water activity (Makowska *et al.,* 2014) [54]. Adding whey ingredients such as sweet whey solids (SWS) or whey protein concentrate (WPC) in extruded corn, potato and rice snacks cause reduction in SME value (Onwulata *et al.,* 2001). The expansion index and breaking strength of the extrudate also reduced significantly thus producing poor textured product. Upto 25% of addition, the effect was minimal beyond 25%, expansion index as well as water absorption indices reduced significantly which in turn affected the hardness of the product (Onwulata *et al.,* 1998, Onwulata *et al.,* 2001a, 2001b) [63, 64, 65]. In another study, milk protein such as whey protein concentrate or whey protein isolate along with wheat fibre were added in the corn-extrudates, it was found that fibre addition caused lowering of SME value but increasing the expansion and breaking strength of the extrudate (Onwulata *et al.,* 2001b) [65]. Thus it was concluded that textural properties of extruded products which were deteriorated by whey addition can be improved by incorporating fibres in it.

For improving the nutritional quality of the extrudate, Brncic *et al*. (2009) [14] incorporated varying proportions of WPC in corn flour and evaluated the textural-mechanical properties of product. Extrudate diameter (de) and ER seemed to decrease with WPC addition while bulk density tended to decrease which resulted into reduction of hardness of the sample with WPC. Properties such as WAI raised and WSI lowered due to WPC fortification. WPC also tend to enhance the fat content apart from protein content of the corn-extrudate (Brnčić *et al.,* 2011) [14]. Mixture of WPC (four levels; 0%, 10%, 20%, and 30%), amylose and corn-starch was extruded with twin-screw extruder and the product's physical and functional properties were evaluated. With incorporation of WPC, radial expansion ratio and specific mechanical energy required were continuously increasing where as WSI first increased when WPC conc. in the blend was increased from 0 to 10%, beyond 10%, increasing the WPC conc. reduced the WSI drastically. Regarding WAI and shear strength, when WPC conc. increased from 1 to 10%, these parameters decreased while increasing the conc. beyond 10% increased the WAI and shear strength. In this study, interaction of amylase and WPC was also observed for above parameters (Matthey and Hanna, 1997). Effects of whey protein concentrate (proportion varied from 0.64–7.36 g/100 g rice), and feed moisture (5 levels varied from 16.64–23.36 g/100 g) on physicochemical characteristics of rice-extrudate was studied by Teba *et al*. (2017) [98]. The combined effect of WPC with moisture and WPC alone was observed and found that with higher level of WPC and moisture crystallinity of product enhanced; WPC alone seemed to reduce the retrogradation behaviour and increased the solubility of extrudate. Protein content was also found to improve in the WPC containing extrudates with retention of most of the polypeptides chains.

In another study, four sources of protein (egg albumen, rice bran protein concentrate, soy protein concentrate and whey protein) in rice pasta were compared (Phongthai *et al.,* 2017) [68] and among them WPC was found most effective in reduction of the cooking time of rice flour based pasta. WPC also found to maximize the water absorption compared to other protein source due to gel forming ability of animal protein. WPC addition has positive impact on product's texture. By protein coating on starch, the micro-structure of WPC enriched pasta was found to very homogenous and compact.

Conclusion

Extrusion processing can be called as a process which can enhance the properties such as textural, structural and nutritional properties of food. It mainly employs starchy and proteinous raw material which can make it a monotonous food producing process. But, its ability to allow incorporation and fortification of other ingredients such as cereals, pulses, tubers, fruits, vegetables, dairy ingredients etc. make it a versatile cooking process. These ingredients inclusion not only alter the nutritional profile of the extrudate but also affect the structural and textural properties.

Cereals other than rice and wheat when incorporated into extrudates enhance the nutritional quality of the food without much compromising with the sensory quality thus making it more consumers appealing. Pseudo cereals such as amaranth, quinoa, kaniwa which are gluten free in nature can also be added in the extruded product. But addition of these ingredients affects the properties, decrease the expansion while increasing hardness and WAI. Cereal mill's byproduct such as bran can also be fortified into cereal flour to produce extrudate. Bran inclusions not only enhance the fibre content of the product but also improve the mineral profile of the extrudates. Bran addition diminishes the sensorial acceptability of the product which can be improved by treating bran in different ways (fermented, ultra-fine ground, enzymatically hydrolyzed and hot water-extracted). Proteinous ray material such as Soy undergone through extrusion can act as replacement of meat, popular in market as texturized soy protein. Pulses can also improve the protein availability in extrudates. The inclusion may affect the textural characteristics. Even the interaction of two proteins present in extrudates affects the sensory quality of extruded food product. Fruits and vegetables, being rich in minerals and vitamins, can improve the nutritional profile of these foods while changing the properties also. Dairy ingredient, whey protein concentrate, is also a source of protein enrichment for the extruded product.

Raw materials used in extrudate determine the textural and sensory characteristics of the extrudates. Interaction of two or, more ingredients and their influence on the product's characteristics should be emphasized in future research. Pre-treatment of the raw material which can improve the quality of finished product can be studied in future. Extrusion has the potential to produce healthy, ready to eat food with appealing sensory characteristics.

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