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Review Article
Use of Cereals and Egg Products in Extruded Foods: A Review

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Abstract
The aim of this paper was to review the use of cereal flours and egg in the production of extruded foods. This review paper focused on literature that has to do with extruded products containing raw materials of animal origin especially egg. Some researchers have attributed some benefits to egg such as being a perfect food, having some antioxidant properties, most globally accepted and cheapest animal protein. This puts egg in a good stead to be used as protein source and researchers have used them as ingredients in product formulation. Extrusion cooking has been extensively used in the production of snacks, pet treats, breakfast cereals and sometimes beverages and instant powders. Most extruded foods are cereal based, containing either wheat, maize, rice or other cereals, legumes, tubers and even by products from fruits and vegetable processing such as apple pomace. Over the years extruded products have been known to be starch based. This could be as a result of the viscoelasticity of starch which results in expansion of the extrudate. Extrusion is basically a low moisture cooking process. As the moisture content increases, the tendency of product expansion decreases. There is a conscious demand by consumers for a lightweight and more nutritious product preferably containing protein sources which can also be used to combat malnutrition especially among school age children. Few researchers have harnessed these benefits, therefore, it is recommended that the use of egg as protein source in extrusion cooking needs to be further exploited.

Key words: Extrusion, snacks, breakfast, protein, texturization

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INTRODUCTION

Food extrusion is a processing method which involves some physical and chemical changes in the raw materials, it involves different unit operations in one process such as mixing, shaping, forming, puffing and cooking in some cases depending on the desired end product. The extrusion temperature depends on the desired end product (it could be cold or hot). A very good example of cold extrusion is seen in pasta production while an example of hot extrusion is seen in snack production. Extrusion is basically a low moisture cooking process. As the moisture content increases, the tendency of product expansion decreases[1]. During extrusion, the different processes such as mixing and cooking take place in the barrel. The high temperature and pressure in the barrel melts the feed. The exit point of the extrudate from the extruder is the die, which is usually small[2]. At the die, there is sudden pressure drop which leads to water evaporation so that the extrudate exits forcefully leading to an expanded product[3]. However, the level of expansion depends on the ingredients and extrusion conditions. Extrusion cooking is conventionally a high temperature short time process which solubilizes fibre, inactivates enzymes and antinutrients, increases digestibility by about ten times of starch and proteins[4]. In most cases of extrusion cooking, the microstructure of the extrudate is different from that of the raw materials. Most researchers have not investigated extrudate microstructure[5]. Food extrusion is a multifaceted cooking process which results in light weight and pleasant products. Extrusion cooking is mostly used for grain processing and results in change in texture[6]. Most extruded foods are cereal-based. Cereal is the commonest grown staple food crop which is generally accepted by all age ranges. Grains, especially cereal and legume are the main source of protein and common staple foods in developing countries[7]. Cereal contains starch and starch have a tendency of expansion on extrusion cooking due to its viscoelastic property. However, these starch-based snacks is no longer trending among consumers. There is a conscious demand by consumers for a lightweight and more nutritious product preferably containing protein sources which can also be used to combat malnutrition[8] especially among school age children[9]. One of the benefits of extrusion is the production of protein-rich cereal based snack products[10]. Egg, fish, meat and milk are first class (complete) protein sources of animal origin and some researchers have used them as ingredients in product formulation. Complete proteins are from animal sources[11] and have the essential amino acids which are in similar proportion to those found in human tissues, muscles and organs. Plant sources of protein have also been used such as chick pea, soybean, faba bean and Bambara groundnut[12]. Some researchers have attributed some benefits to egg such as being a perfect food, having some antioxidant properties[13,14], most globally accepted and cheapest animal protein. This puts egg in a good stead to be used as protein source and few researchers have harnessed these benefits. The use of egg as protein source in extrusion cooking needs to be further exploited. Nwadi and Okonkwo[15] in a doctoral research used whole wheat flour and chicken egg to produce extruded products which were acceptable based on sensory scores. Eggs from different poultry species are consumed daily by humans with chicken eggs being the most consumed. Other poultry species are becoming popular in different parts of the world. Japanese quail egg and meat is referred to as specialty products in Europe and America. Ostrich eggs are a delicacy in South Africa while in Asian countries it is duck eggs. Guinea fowl and pheasant eggs are also being exploited. In recent times, due to globalization, consumers often demand lightweight products which is low in calorie yet balanced to a large extent in nutrient composition especially proteins and micronutrients. The aim of this paper was to review the use of cereal flours and egg in the production of extruded foods.

Egg and egg products: Most people consume the egg of the chicken, *Gallus domesticus*. There exist about two hundred (200) breeds of chickens which have been developed worldwide. Poultry production is the most popular of all the different livestock. Egg products are eggs which have been processed and packaged into a more convenient form. Some examples of egg products include dried/liquid/frozen albumen, yolk or whole egg. These egg products are used in food industries. The functional and physical performance of eggs can be improved through the use of carbohydrates, gum, starch, salt and sugar[16,17]. Some functional properties of egg include leavening, thickening, binding, coating, emulsifying, crystallization and moisture control. The leavening property of egg is seen in baked products such as bread and cake. The emulsifying property of egg is seen in mayonnaise and salad dressing[18,19]. Egg powder can be incorporated into baby foods[20]. Food manufacturers especially in the bakery industry use these egg products because of its integral nature in the production of a large number of products. Egg has been described as a multi-tasking ingredient due to the peculiar characteristics of the egg white and egg yolk. Egg proteins play a vital role in the coagulation of many cooked foods. Most bakers use egg as a base ingredient due to its nature of being the least variable of all ingredients[21]. Egg is a complete protein source. It delivers essential nutrients to the body such as essential amino acids, vitamins and minerals which are highly bioavailable[22]. Among dietary proteins, egg is one of the cheapest, bioavailable and most socially acceptable in the globe[23]. Kumbár *et al*.[24] classified egg as nature's original functional food. Egg products are often incorporated into processed food products[25]. Larsen[26] described egg as a near perfect food due to its nutrient composition. Egg is mostly used in its dried form in baked products such as biscuits and other processed foods due to microbial instability[27], easier handling and storage conditions. Most of the eggs produced globally are sold as shell eggs[28]. Manufacture of egg powder started in the late 1980s as a result of increase in demand for a more stable and portable product[9] and egg in this form can easily be incorporated as ingredient in extruded foods. Sharif *et al*.[9] declared egg a perfect food and stated that researchers have proven egg to be therapeutic and prevents chronic and contagious diseases. The low water activity is a desirable characteristic. Egg is a protein food, most of the proteins found in egg is in the egg white, however other nutrients such as fats and oils also cholesterol are contained in the yolk. The special components found in egg such as omega 3 depends on the nutrition of the laying hen. A very good example is the vitamin content of egg, the vitamin content of egg depends largely on the nutrition of the laying hen[29].

Cereals: Most plant-based foods in the globe contain cereal as the major ingredient[30]. This makes cereals the most important among the food crops[31,32]. The most commonly used cereal grains include wheat, rice and maize[33]. Wheat contains more proteins than maize and rice. Cereal flours are used most times as ingredients in extruded foods[34]. Román *et al*.[35] reported that wheat and rice are the most commonly used cereal flours in developed countries as gluten and non-gluten flours respectively. In a study, Ding et al.[36] reported that under the same extrusion conditions, extrudate from wheat was the hardest while from maize expanded more and finally from rice was the most crisp. Breakfast cereals and snacks have cereal as a major ingredient and are mostly produced through extrusion. Quatela *et al*.[37] defined breakfast cereal as a minimally processed grain-based food product which could be dried or rolled or processed by cooking, flaking or puffing. Eggs are commonly consumed at breakfast[38] mostly in the boiled or fried form. Use of cereal for breakfast have been in use for many years[39]. Healthy breakfast cereals are produced from whole grains[40]. Breakfast cereals are usually expanded through extrusion cooking which makes it crisp and easy to use, this has increased the popularity of extruded breakfast cereals[41]. Breakfast cereals are commonly produced from wheat, other cereal grains include rice, barley, maize and sorghum. Extrusion technology is mostly applied in production of pasta products, baby foods, texturized foods, breakfast cereals and snacks[42-45]. Extrusion have also been widely used in the production of functional foods[46,47]. Extrusion cooking creates room for different ingredients to be combined into a single product. Chemical and structural changes take place during extrusion cooking[48]. Athar *et al*.[49] reported that extrusion cooking technology was invented in the 1940s for snack food manufacture. Extrusion cooking is now being preferred to conventional cooking due to some textural properties such as high expansion ratio and more crunchiness[47]. Altan *et al*.[50] and Masatcioglu *et al*.[51] produced an expanded snack from barley grits and barley flour. Extrudates have been produced from wheat flour[52-55]. Extrudates have been produced from maize (corn) flour[56-59]. Extrudates have been produced from rice flour[60-63]. Most snacks are cereal-based. Some methods have been used to expand snacks such as extrusion, baking, frying and microwave[64]. Snack can also be made to be rich in nutrient depending on the preferences of the producer and/or consumer as the case may be. Snacks can be classified based on the ingredients or method of processing such as frying and extrusion. In classifying snacks based on processing methods, we have first, second and third generation snacks. Most snacks which are simply extruded and is ready for consumption, fall into the second generation snacks[65]. Extrusion cooking processes have been used to produce more healthy snacks as it gives room to addition of different ingredients which will eventually be mixed to give a homogeneous finished product with high nutrient benefit[66]. The snack industry is presently focusing on producing snacks which is healthier, such as one containing lesser quantity of sodium, fat and sugar[67]. Snacks without nutritional benefit is regarded as junk and eating of such snacks is unhealthy as it can lead to heart diseases, abnormally high blood pressure and excessive body fat[68-70]. Larson *et al*.[71] recommended eating of different healthy foods and snacks rich in nutrient. Inclusion of egg into these cereal based extruded foods will produce snacks rich in nutrients.

Extrudates containing animal sources of protein: Addition of protein sources to ingredients for extrusion will deliver a more nutritionally balanced product. Some researchers have added animal protein sources such as egg proteins so as to enhance the nutritive value of the extrudate (Table 1). Singh *et al*.[72] produced extrudate from wheat flour and milk 30% or egg 10% proteins and reported that lower temperatures and higher moisture content favors protein food extrusion. The extrusion cooking was between 110 and 125°C at moisture content of 19 and 23.5% and 13.75 and 16% for egg and milk proteins respectively. Choudhury and Gautam[73]

Table 1: Extrudates containing animal sources of protein

Raw materials	References
Wheat flour and milk (30%) or egg (10%) proteins	Singh *et al.*[72]
Fish muscle and rice flour	Choudhury and Gautam[73]
Corn, chickpea and bovine lung	Santiago *et al.*[74]
Lamb and corn starch	Rhee *et al.*[75]
Whey protein concentrate and rice flour	Teba *et al.*[76]
Rice flour, fish powder, menhaden oil and vitamin E	Pansawat *et al.*[77]
Wheat flour, egg whites, milk powder, oat flour, corn starch and cauliflower	Stojceska *et al.*[78]
Snack product using egg yolk and egg yolk fractions (plasma and granules), locust bean gum and carrageenan	Valverde *et al.*[79]
Wheat semolina and fresh egg	Zardetto and Rosa[81]
Wheat gluten, wheat starch and egg white protein powder	Peng *et al.*[80]

produced extrudate from fish muscle and rice flour and reported that fish protein incorporation into the rice flour decreased expansion index and increased hardness of the extrudate. Santiago *et al.*[74] produced extrudate from corn, chickpea and bovine lung, Rhee *et al.*[75] produced extrudate from lamb and corn starch, Teba *et al.*[76] from whey protein concentrate and rice flour, Pansawat *et al.*[77] from some ingredients including rice flour and fish powder all of which were nutritious and had high protein contents. Different researchers have used egg in the production of different extruded products. Stojceska *et al.*[78] produced an extrudate from many ingredients including wheat flour, egg whites, corn starch and cauliflower and reported that cauliflower addition significantly increased the protein level of the product. Valverde *et al.*[79] developed a new snack product using egg yolk. Peng *et al.*[80] used egg white protein to improve the textural properties of textured wheat gluten.

Zardetto and Rosa[81] produced extrudate from wheat semolina and fresh egg. Egg is useful in food processing due to its functional properties such as emulsifying, foaming and coagulation[82]. Whole egg or its powder could be added to raw material for extrusion owing to its high nutrient content especially of proteins. Eggs are used in human diet as a result of their nutritive value. In developing countries, egg happens to be the cheapest source of animal protein available to the general populace. In a review, Alamprese[83] listed the minimum egg content and admissible types of eggs for egg pasta in different countries (Table 2).

Extrusion of protein foods: Cereals contain a large quantity of starch. Starchy foods expand more during extrusion cooking compared to protein foods. This is because starch is more viscoelastic than proteins. From literature, a starch content of 60-70% d.b. results in directly expanded product. Product expansion results in product crispiness. Most of the chemical reactions which occur during extrusion is poorly understood[45]. Many researchers showed that the expansion index of extrudate depend on starch gelatinization. However, excessive starch degradation negatively affects expansion index. The structure and conformation of protein macromolecules negatively affects expansion index. Protein reduces expansion index because it acts as diluent and therefore affects the distribution of water in the food matrix[84]. Increasing the protein content of food while decreasing the starch content results in a firmer textured product. Extrudates with high protein content compared with starch content have a greater tendency of breaking[85]. Both starch and proteins are modified during extrusion based on the processing conditions which have been used. Starch and protein properties play a vital role in determining the appropriate texture of extrudates[55]. Addition of proteins to extruded starch-based snacks results in tough crusts which does not expand. However, prior denaturation of the proteins results in a better matrix[86]. Hood-Niefer and Tyler[87] reported that in pea flour and starch extrusion, as protein content increased, expansion index decreased, while bulk density, particle density, porosity, hardness and available lysine increased. Lysine is a very sensitive amino acid and harsh processing conditions such as amino acid extrusion greatly reduces its concentration in food. In cereals, lysine is a limiting amino acid[10]. During extrusion, there is starch fragmentation and lysine is often lost through maillard reaction. The rate of lysine loss during extrusion is higher at low moisture content. Gremmel and Paschke[88] reported that when proteins are heated, physico-chemical changes take place in their structure. As a result of these physico-chemical changes such as denaturation and texturization of proteins[89], the functional properties of the product also changes Hagenimana *et al.*[90]. Some physico-chemical properties which may be affected by heat include solubility and composition[91]. Uysal *et al.*[92] reported that increase in heat treatment changes protein composition and decreases its solubility. Proteins have a globular structure which is destroyed by extrusion cooking[93]. During the extrusion of pea protein isolate, Beck *et al.*[94] reported that expansion of the protein network during low moisture extrusion increased protein aggregation which may have

Table 2: Minimum egg content and admissible types of eggs for egg pasta in different countries

Country		Minimum egg contents	Admissible types of eggs
Austria	Egg pasta	90 g whole egg kg^{-1} flour (or 32 g yolk)	Whole egg, physically
	Special egg pasta	180 g whole egg kg^{-1} flour (or 64 g yolk)	Nonperishable ready-made
	Home-made egg pasta	270 g whole egg kg^{-1} flour (or 96 g yolk)	Preserved eggs, also quick-frozen
Belgium		50 g yolk kg^{-1} pasta (or the equivalent amount of whole egg)	Whole egg and egg yolk, also dried
France		140 g whole egg kg^{-1} flour (or the equivalent amount of yolk)	Whole egg and egg yolk, also dried
Germany	Egg pasta	100 g whole egg kg^{-1} flour (or the equivalent amount white or yolk or combination)	
	Home-made egg pasta	200 g whole egg kg^{-1} flour (or the equivalent amount of white or yolk or combination)	Whole egg, egg yolk, egg white, of also quick-frozen or dried
	High egg content egg pasta	300 g whole egg kg^{-1} flour (or the equivalent amount of white or yolk or combination)	
Greece		Two whole eggs kg^{-1} pasta	Whole egg, either fresh or pre-served concentrated, powdered)
Italy		200 g whole egg kg^{-1} flour	Fresh eggs or liquid egg products
Portugal	Egg pasta	Five fresh eggs kg^{-1} pasta	Fresh eggs
	Pasta with eggs	Two eggs kg^{-1} pasta	Fresh or quick-frozen eggs or egg powder
Spain		150 g whole egg kg^{-1} flour (or 65 g yolk)	Whole egg or yolk
United Kingdom		160 g whole egg kg^{-1} flour (3.7% dried egg solids)	
United States		5.5% of the total solids must derive from solids of egg or egg yolk	

Alamprese[83]

been formed by some sheets and helical structures as identified by Fourier transform infrared spectroscopy. Sodium dodecyl sulfate polyacrylamide gel electrophoresis suggested that the protein's vicilin and convicilin were not altered except for the legumin which led to decrease in protein solubility[94]. Osen *et al.*[95] attributed the insolubility in legumin to disulphide crosslinking. Gremmel and Paschke[88] further reported that heat treatment reduces some allergenic properties of egg which makes consumption more convenient. Singh *et al.*[72] reported that low temperature and high moisture during extrusion cooking, is most favorable for production of protein products. When extrusion is done at a high moisture content at a very low temperature and very short residence time, there is a higher retention of amino acids. On the contrary, extrusion cooking at 200°C and above and moisture content of 15% or lower have adverse effects on the nutritional quality of foods. However, Pérez *et al.*[96] reported that moisture content of 14% and temperature of 170°C was the best for extrusion of maize and soybean mixture (88/12). Generally, the nutritional quality of protein is adversely affected by extrusion cooking[97]. In the past, protein extrudate is not used for direct consumption but rather made available in powdered form to be used as a functional food mostly as an ingredient for some other food product. The detailed structural (mostly microstructural) changes which take place during extrusion cooking have not been adequately documented. Product characteristics and digestive behavior can be affected by this structural change. During extrusion, proteins unfold and cross-linking also occurs. The changes in the structure of proteins is dependent on heat and shear. Protein-protein interaction and water distribution affect expansion properties[5,94]. Osen *et al.*[95] reported that fibrous meat analogues was produced from pea protein isolates extruded at high moisture content. However, texture can be controlled through extrusion temperature. It was reported that at less than 120°C the samples had soft texture which was dough-like while at temperatures above, it appeared fibrous. Yu *et al.*[98] produced extrudate from some ingredients including corn, soy flour and soy protein isolate (SPI) at process temperatures of between 126.4-193.6°C and moisture content of between 31.6-48.4 g/100 g and reported that increase in SPI, moisture content and temperature resulted in decreased water solubility index and expansion ratio but increase in breaking stress. Higher SPI and moisture content resulted in increased bulk density while higher temperatures decreased it. Silva *et al.*[99] produced extrudate from corn and carioca bean flour and reported that an increase in the moisture and carioca bean flour content resulted in decreased sectional and volumetric expansion index but increased bulk density. The degree of expansion in extruded food products depends on characteristics of the air cells in the material such as its size, number and distribution. As the extrudate forcefully exit the die of the extruder, the water contained in it vaporizes resulting in product expansion[100]. Sumargo *et al.*[101] produced extrudate from brown rice and pinto bean flour and reported that Increase in bean flour and moisture content resulted in decreased expansion index and increase in bulk density and hardness in the extrudate. Sharif *et al*.[9] produced extrudate from some ingredients including rice and soy flour and reported that increase in soy protein decreased expansion index but increased bulk density. Ravindran *et al*.[102] produced an extruded pea and rice flour-based snack (70:30) fortified with guar, locust bean and fenugreek gums at different levels and reported that the different gums resulted in a well expanded product. Natabirwa *et al*.[103] extruded Roba1 variety of beans and reported that increase in moisture content at low temperature decreased expansion ratio. Chickpea contains about 24.4% protein, Meng *et al*.[104] extruded chickpea flour and reported that high barrel temperature favored expansion ratio, however, when the increase got to a critical level of approximately 168°C the expansion ratio declined. Lentil contain between 20-30 g/100 g of proteins[105]. Rathod and Annapure[84] produced extrudate from lentil flour and reported that extrusion cooking improves protein digestibility by up to 89% compared with other traditional heat processing methods, also the best method to reduce antinutrients in lentils by above 97% without the protein content being altered. Pinto *et al*.[97] extruded bovine lung powder and reported that under drastic extrusion conditions, the nutritional quality of proteins is adversely affected as a result of attempt on adequate texturization.

Behaviour of proteins during extrusion cooking: Many researchers have reported that proteins is sensitive to heat and shear, proteins have a globular structure which is destroyed by extrusion cooking. Extrusion results in denaturation and texturization of proteins which affects physico-chemical properties such as solubility and composition. Disulphide crosslinking leads to insolubility of the protein. Extrusion cooking improves protein digestibility by up to 89% and reduces antinutrients by above 97% without altering the protein content in lentils. Lower temperatures and higher moisture content favors protein food extrusion and results in higher retention of amino acids. Low moisture extrusion increases protein aggregation. In the extrusion cooking of Roba1 variety of beans, increase in moisture content at low temperature decreased expansion ratio. During extrusion cooking, expansion index of extrudate depend on starch gelatinization however, excessive starch degradation reduces expansion ratio. During extrusion cooking, high barrel temperature favored chickpea flour expansion ratio, however, when the increase got to a critical level of approximately 168°C the expansion ratio declined. Chickpea flour contains 24.4% protein. Addition of proteins to extruded starch-based snacks results in tough crusts which does not expand. Protein-protein interaction and water distribution affect expansion properties. Fortification with guar, locust bean and fenugreek gums at different levels results in a well expanded product. Increasing the protein content of food while decreasing the starch content results in a firmer textured product. At temperatures less than 120°C extrudates had soft texture which was dough-like while at temperatures above, it appeared fibrous. Extrudates with high protein content compared with starch content have a greater tendency of breaking. Protein reduces expansion index because it acts as diluent and therefore affects the distribution of water in the food matrix. However, prior denaturation of the proteins results in a better matrix. Drastic extrusion conditions with the aim of adequate texturization negatively affects protein nutritional quality. In the past, protein extrudate is not used for direct consumption but rather made available in powdered form to be used as a functional food mostly as an ingredient for some other food product. The chemical reactions which occur during extrusion cooking have not all been fully understood. Also, the detailed structural (mostly microstructural) changes which take place during extrusion cooking have not been adequately documented. Further research on the effect of extrusion on proteins would be useful for the food industry.

CONCLUSION

This review has shown that among extruded foods available there are more of starch-based extrudates such as grains, roots and tubers. During extrusion cooking, a starch material is necessary so as to ensure expansion of the snack and cereal contains starch. Cereals have been extensively used in extruded food products. Almost every extruded food contains cereals in full or in part. This makes cereal a very important staple food. Cereal based extruded product containing a suitable quantity of egg is better compared with one containing only cereal in terms of nutritive value. Eggs are used in human diet due to their nutritive value. Since most extruded foods are starch-based, addition of eggs will go a long way to enhance the nutritive value of the extrudates. Egg is also the cheapest, most globally accepted and most available source of animal protein and a very healthy food which increases the nutritive value of any food in which it is an ingredient. Egg should therefore, be added to every extruded food product. Use of egg in extruded foods needs to be further exploited due to the fact that egg is a good protein source, contains antioxidants and have many nutritional benefits, this makes egg an important ingredient requiring attention in the extrusion industry. Also, consumers now opt for more nutritious products due to health issues.

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