The Significance of Whole Grain Teff for Improving Nutrition: From Injera to Ready to Eat Porridge by Using Extrusion Cooking Technology

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Abstract

Teff (EragrostisTef) is a fascinating grain, ancient, minute in size, packed with nutrition and used for centuries as the principal ingredient of the Ethiopian population diet. The micro- and macronutrients level of teff grainis apparently higher than that of barley, wheat and sorghum and the amino acid composition comparable to that of egg protein, except for its lower lysine content. In Ethiopia, it has been using as a staple food by making flat bread called Injera. Teff can be diversified from its current provision of Injera to other forms like instant porridge to improve the nutritional quality and it may play a significant role in food security and agriculture in Ethiopia. Compositing of teff with cowpea will help to lower the cost and will compensate the lower lysine content of teff. Extrusion technology, which combines several unit operations including mixing, high temperature short time (HTST) cooking, kneading, shearing and forming is a suitable technology with lower processing cost used to prepare highly nutritive ready to eat food products. In addition it can help to retain maximum available lysine, can either depolymerise the starch or form resistant starch which resulted in high and low glycemic index (GI) starchy food respectively by adjusting the extrusion conditions.

Introduction

Protein energy malnutrition is a major problem in many developing countries which affects infants during transitional phase of weaning (Sanda 2010). Nutritional requirement in developing countries is remained questionable for long-time. The prevalence of nutritional disorders, both under and over nutrition in developing countries is becoming a risk to a wide number of diseases and health disorders as well as premature mortality (Caterson 2002). Under-nutrition, for example protein energy malnutrition (PEM) can be characterized by the number of stunted children and adults whereas over nutrition can be characterized by the prevalence of chronic diseases such as diabetes and obesity (Caterson 2002). Symonds, Mendez, Meltzer, Koletzko and Godfrey (2013) reported that nutritional disorder which results stunting and/or obesity are known negatively affect woman's productivity and is associated with the excess death of mothers and children. Even though, compositing of cereals and legumes is a good complementary food, a suitable technology should be used to enhance the nutritional quality if possible and to produce high and/or low glycaemic complementary food in order to limit the problem of PEM and/or diabetic disease.

Extrusion technology, which combines several unit operations including mixing, high temperature short time (HTST) cooking, kneading, shearing and forming has been reported as a suitable technology to prepare highly nutritive food products (Cheftel, 1986).

It has a lower processing costs and higher productivity than other cooking and forming processes (Moscicki and Zuilichem, 2011). In addition it can retain maximum available lysine and has minimum browning index by adjusting the extrusion conditions (Iwe, Zuilichem, Stolp and Ngoddy 2004). Variation of screw speeds and die diameters also can either depolymerise the starch or form resistant starch and resulted in high and low glycaemic index (GI) starch respectively (Liu, Halley and Gilbert 2010). For instance, Cheftel 1985 reported that optimum extrusion cooking condition (Tm= 125-165°C, % H2O = 10-20, RPM = 80-150 and F = 300g per min) helps to improve protein digestibility and starch digestibility. On the other hand, extrusion cooking with mild temperature and high moisture content (90-140°C and 20-50% moisture) has been reported to have the potential to increase the level of resistant starch (Stojceska, Ainsworth, Plunket and Ibanoglu 2010). These could be either by the formation of amylose-lipid complex or by the formation of retrograded starch during subsequent cooling. Beyond the processing technology, the complementary grains should be a good source of nutrients and economically affordable and accessible for developing countries. For this reason teff and cowpea have chosen. This is because of Ethiopian indigenous grain, teff(*EragrostisTef*), has been shown that the micro- and macronutrients level is apparently higher than that of barley, wheat and sorghum (Melak and Mengesha, 1996). On the other hand, cowpeas (*Vignaunguiculata (L) Walp*) are widely available in developing countries and are inexpensive sources of protein, lysine and carbohydrate (Khattab, Arntfield & Nyachoti, 2009). The seed coat also contains pectin substances and some minerals **(**Longe 1980).

Beyond the processing technology, the complementary grains should be a good source of nutrients and easily accessible for developing countries. For this reason teff and cowpea have been chosen. This is because of Teff (EragrostisTef) is a fascinating grain, ancient, minute in size, packed with nutritionand used for centuries as the principal ingredient of the Ethiopian population diet (Stallknecht, Kenneth, Gilbertson, andEckhoff, 1993).It has been proven that the micro- and macronutrients level of grain teff is apparently higher than that of barley, wheat and sorghum (Melak and Mengesha, 1996). The amino acid composition of grain teff is reported to be comparable to that of egg protein, except for its lower lysine content (Gamboa and Ekris, 2008).Even though, teff is a rich source of nutrients and essential amino acids, it is also relatively an expensive grain when compared to wheat, barley and sorghum in Ethiopia. In Ethiopia, it has been using as a staple food by making like pan cake called "*Injera*". However, nowadays teff is used as different products like pasta and macaroni at the commercial level but not as extruded ready to eat porridge (Gamboa*et, al.*, 2008).

The paper will explore how teff can be diversified from its current provision of Injera to other forms like instant porridge to improve the nutritional quality in terms of protein digestibility and starch digestibility and how it may play a significant role in food security and agriculture in Ethiopia. Teff as source of varied nutritional products from injera to different food values will be discussed. In addition, the use extrusion cooking with different conditions to produce a low and high GI instant teff and cowpea composite ready-to-eat porridge will help to tackle the problems of diabetes and PEM respectively.

Literature Review

This review examines the effect of dual burden in developing countries and protein and energy requirements to help overcome this problem. Nutritional aspects and effect of traditional processing methods on the protein quality and energy density are discussed. An outlook of extrusion cooking technology and its effect on the nutritional quality of porridge is also given.

Dual burden in developing countries

The dual burden in developing countries leads to nutritional disorder and affects human productivity. The prevalence of nutritional disorder in developing countries becoming a risk of a wide number of diseases and health disorders as well as premature mortality (Caterson 2002). The prevalence of protein energy malnutrition and over nutrition becomes unbalanced because of the socioeconomic difference in developing countries (Ebot 2010). This unbalancing of nutrient resulted in the occurrence of under-nutrition and over-nutrition in different socioeconomic groups (WHO 1995).An estimated of 3 million children has died at the age of 4 weeks in 2011 and more than 98 % of neonatal deaths occurred in low-income and middle-income countries (UNICEF, WHO, World Bank, and UN Population Division). These early death could be associated with the poor parental growth and development. Symonds*et al.* (2013) reported that nutritional disorder which results stunting and/or obesity are known negatively affect woman's productivity and is associated with the excess death of mothers and children. The 2013 hunger map of the world food program shows, from the world above 35% of undernourished population are found in Ethiopia, Eritrea, Mozambique, Burundi, Malawi, Zambia and Swaziland. On the other hand, globalization and lifestyle changes resulted in a remarkable risk of diabetes in particular in developing countries (Guariguata, Whiting, Hambleton, Beagley, Linnenkamp and Shaw 2013).

Compositing of cereals and legumes

Amino acid complementation between cereal and oilseed (or legume) usually results in high protein efficiency ratio (PER) close to that of casein. It is sometimes desirable to supplement the extruded flours with free lysine or methionine (together with vitamins and minerals) (Cheftel 1986).The nutritional quality of cereal grains is limited due to their lower contents of protein, fat, minerals and vitamins when compared to animal foods (Yigzaw, Gorton, Akalu and Solomon 2001). On the other hand, it is well known that grain legumes are higher in protein quality and quantity than cereals. Due to the fact that, amino acid composition of both legumes and cereals exhibits deficiencies of some essential amino acids for the human diet, they are complementary (Yigzaw et al., 2001) and resulted in higher protein quality than does either alone.

Complementary feeding means giving other foods in addition to the usual feeding system and for children when an infant is 6 months old breast milk will no longer be enough to fulfill the nutritional requirements WHO, http://www.who.int/nutrition/topics/complementary_feeding/en.)

Complementary foods are needed to fill the calorie, protein and micronutrient gap between the total nutritional needs of the child and the amount provided by breast milk. In addition complementary feeding helps to control chronic diseases which are caused by obesity if the complementary food prepared to address a specific nutritional need.

Even though, compositing of cereals and legumes is a common practice at house hold level in developing countries, the way of compositing and processing method is different than that of commercially available complementary products. For example, as shown in fig1, in Ethiopia they have been using cereals and legumes to make their daily food. On the other hand, limited cereal and legume types are well known for compositing as a complementary food product in developing countries. For instance, teff is not a well-known grain outside of Ethiopia and it is not widely used in other products except making flat bread ("Injera"). On the other hand, cowpea is not considered as an edible grain by humans and was not used as a food material until recent years.

Figure 1: Ethiopian traditional compositing method (Ethiotube.com)
The righting in this Photo in Amharic says "let us eat lunch."

Teff (*EragrostisTef*)

Teff (*EragrostisTef*) is a fascinating grain; ancient, minute in size, packed with nutrition and used for centuries as the principal ingredient of the Ethiopian population diet (Stallknecht, Kenneth, Gilbertson and Eckhoff, 1993). It has been shown that the micro- and macronutrients level of grain teff is apparently higher, as shown in table 1, than that of barley, wheat and sorghum (Melak and Mengesha, 1996).

The amino acid composition of grain teff is reported to be comparable to that of egg protein, except for its lower lysine content (Gamboa and Ekris, 2008). Even though teff is a rich source of nutrients and essential amino acids, it is also a relatively expensive grain when compared to wheat, barley and sorghum in Ethiopia. In Ethiopia, it has been using as a staple food by making flat bread and complement with legumes and vegetables as shown in fig1. However, nowadays teff is used in different products at the commercial level but not as an extruded complementary food product with a composite of legumes (Gamboaand Ekris, 2008).

Table 1. Average chemical composition and physical properties of teff grain

Parameter	Mean ±SD*
Moisture content/% db	11.83±0.07
Protein (N×6.25)/%	10.73±0.06
Ash/%	2.93±0.08
Fat/%	3.07±0.03
Carbohydrate**/%	71.44±0.09
Thousand grain weight (TGW)/g	0.33±0.01
Length/mm	1.08±0.107
Width/mm	0.63±0.109

Note: * Standard deviation; ** Calculated by difference.

Cowpeas (*Vignaunguiculata (L) Walp*)

Among food legumes cowpeas (*Vignaunguiculata (L) Walp*) are widely available in developing countries and are inexpensive sources of protein, 20 to 40 g/100 g on dry matter and moderately high in carbohydrate content (Khattab, *et al.* 2009). Cowpea seed also contains the essential amino acid lysine (7 g lysine/ 100 g protein) (USDA, http://www.nal.usda.gov/fnic/foodcomp/search).The seed coat also contains pectic substances with sugar compositions of: rhamnose, arabinose, xylose, mannose and glucose **(**Longe 1980).

It is also cheaper in cost than teff and as the result it can lower the cost of the composite to make it more economically affordable source of nutrients.

Structure and chemical composition of cowpea

Cowpeas (*Vigna unguiculata* (L.) Walp) are a multi-purpose legume and they can improve soil fertility, are easy to establish, have high nutritive value and high palatability (Bruce 2008). Cowpeas are made up of three main parts: the cotyledon, the hilum and the seed coat (Mwangwela

2006) as illustrated in Figure 2. They are a dicotyledonous, and the cotyledons form the major part of the seed. Each cotyledon contains parenchyma cells (60 to 100 µm) with reserve materials in the form of elliptical starch granules (11 to 20 µm). These are embedded in a proteinaceous matrix containing protein bodies (3 to 6 µm) (Singh 1991). The parenchymatous cells of the cowpea cotyledon are bound by a cell wall and middle lamella. Vascular bundles containing a large number of closely packed cells are scattered throughout the cotyledon (Sefa-Dedeh and Stanley, 1979a, b).The cowpea seed coat contains pectic substances with sugar compositions of: rhamnose, arabinose, xylose, mannose and glucose **(**Longe 1980). They also contain 20.1 to 28% crude protein (Giami, 2005).

Table 2. Chemical composition of raw cowpea seed (Longe, 1980)

Composition	**Percentage %**	**Sugars**	**Percentage %**
moisture	10.4	Glucose	0.2
Crude protein	28.0	Fructose	0.4
Fat extract	1.9	Sucrose	1.6
Ash	3.8	Raffinose	0.7
Crude fibre	3.1	Stachyose	2.7
starch	40.6	Verbascoe	3.6

Of the protein present, 95% is found in the cotyledon and only 4% and 3% in the seed coat and embryo respectively (Duranti and Gius 1997). In addition, legume cotyledons are composed of four storage protein fractions: albumins, globulins, glutelins and prolamins, which can be grouped according to their solubilities in different media (Freitas, Teixeira and Ferreira, 2004). Due to cowpeas being seeds, most of the proteins present are storage proteins, i.e. globulins, which later on supply amino acids in order to aid the growth of the developing plant (Freitas *et al*., 2004). This fraction is the major seed protein component, and it is mostly affected by thermal processing and is responsible for the overall digestibility of cowpeas (Freitas *et al*., 2004).

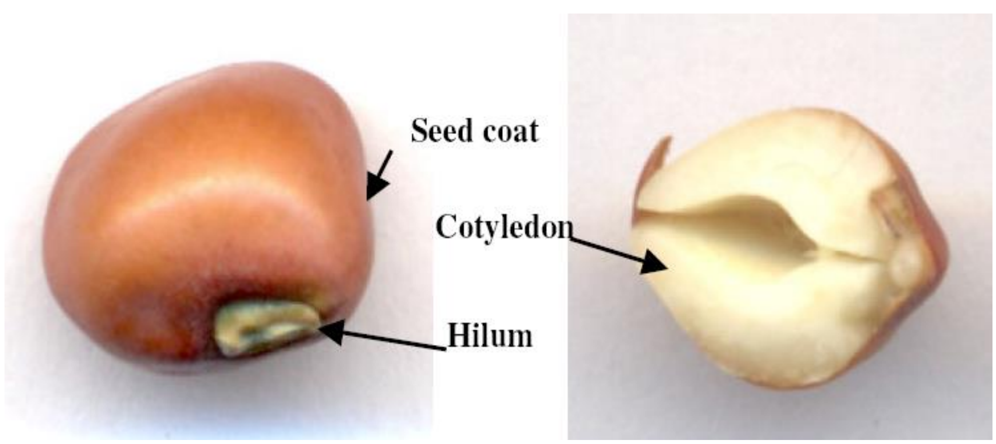

Figure 2. Morphology of the cowpea seed showing seed coat, hilum and Cotyledon **(**Mwangwela, 2006)

Challenging problems of traditional cooking methods

Deterioration of nutritional quality, owing to hightemperature, is a challenging problem in most traditional cooking methods (Singh, Gamlath and Wakeling2007). Besides taking of long time to process traditional porridges, the effect of high temperature on the nutritional quality is problematic. It is well known that, teff processing to make flat bread, has to be fermented prior to cooking. Even though, fermentation of cereals helps to improve the nutritive value such as availability of proteins and amino acid profile, could decrease certain antinutritional factors like phytates, and protease inhibitors (Yigzaw*et al.,* 2001), it can also decrease the GI (Melak and Mengesha 1996). Mostly, protein nutritional quality is affected by traditional processing method of legumes.This because of the storage condition of legumes leads to the development of hard-to-cook defect and takes long time for cooking (Khattab*et al.,* 2009).

Effect of traditional processing on protein quality

Most food proteins are denatured when exposed to moderate heat treatments (60–90°C, 1 h or less) (Damodaran, 1996). Extensive denaturation of proteins often results insolublization, which can impair those functional properties that are dependent on solubility (Duranti and Gius, 1997). Thermal denaturation of monomeric globular proteins is mostly reversible. For example, when many monomeric enzymes are heated above their denaturation temperatures, or even briefly held at 100°C, and then are immediately cooled to room temperature, they fully regain their activities (Lapanje, 1978). However, (Ahren and Klibanov, 1985) reported that, thermal denaturation can become irreversible when the protein is heated at 90–100°C for a prolonged period even at neutral pH. When a protein solution is gradually heated above a critical temperature; it undergoes a sharp transition from the native state to the denatured state. Damodaran (1996) reported that, the mechanism of temperature-induced denaturation is highly complex and involves primarily destabilization of the major non covalent interactions and the essential amino acid lysine is no longer biologically available.

It has been reported that, the reduction of protein digestibility is primarily because of poor absorption of ketosamine (Amadori product) or aldosamine (Heyns product) (which could be formed by the reaction of amino lysine with carbonyl derivative) in the intestine (Damodaran, 1996). In addition, Mwangwela (2006) reported that, dicarbonyl compounds formed during the browning process participate in cross-linking of proteins resulting in reduced protein solubility.Furthermore, cowpea protein has tyrosine which could be oxidized to form dityrosyl cross links during thermal processing (Duranti and Gius, 1997). Formation of dityrosyl cross links have also been reported in other forms of processing such as irradiation. However (Duranti and Gius, 1997) observed that, under severe heat treatment, isopeptide cross links would possibly be formed, especially in foods of high protein and low carbohydrate content.

Cross linking of protein due to thermal traditional processing of porridge

Several food proteins contain both intra- and intermolecular cross-links, such as disulfide bonds in globular proteins, desmosine, and isodesmosine; and di- and trityrosine-type cross-links (Damodaran, 1996). Processing of food proteins, especially at alkaline pH, also includes crosslink formation (Damodaran, 1996; Duranti and Gius, 1997). Since traditional porridge could be cooked with the addition of milk, alkaline pH condition may favour for the cross-linking of protein. Such unnatural covalent bonds between polypeptide chains reduce digestibility and biological availability of essential amino acids that are involved in, or near, the cross-link (Damodaran, 1996). Among the various processing -induced chemical changes in proteins, the Maillard reaction (non-enzymatic browning) has the greatest impact on its sensory and nutritional properties (Duranti and Gius, 1997). The Maillard reaction refers to a complex set of reactions initiated by reaction between amines and carbonyl compounds at elevated temperature (Friedman, 1996). The Maillard reaction alters protein nutritional value, and some of the products may be toxic, but probably are not hazardous at concentrations encountered in foods (Damodaran, 1996).

Unfortunately, the amino group of lysine is the major source of primary amines in proteins (Duranti and Gius, 1997) and cowpea is relatively rich source of lysine. At high temperature processing, it is frequently involved in the carbonyl-amine reaction, and it typically suffers a major loss in bioavailability when this reaction occurs (Damodaran, 1996). In this case, the complementary porridge contains cowpea, and cowpea contains lysine as an essential amino acid, the loss could occur during thermal processing at high temperature for longer cooking time due to maillard reaction. Damodaran (1996) reported that, the extent of Lys loss depends on the stage of the browning reaction. Lysine involved in the early stages of browning and these early derivatives are hydrolyzed to lysine and sugar in the acidic conditions of the stomach (Damodaran, 1996).

Amino acids racemization

Racemization is the process by which L-amino acids are changed to D-amino acid and occurs in proteins that are thermally processed at 150 to 250°C (Hayase, Kato and Fujimaki, 1975). Liardon and Hurrell (1983) found that thermal processing of proteins at alkaline pH, as is done to prepare texturized foods, invariably leads to partial racemization of L-amino acid residues to D-amino acids. Acid hydrolysis of proteins also causes some racemization of amino acids (Fay, Richli and Liardon, 1991). The mechanism at alkaline pH involves initial abstraction of the proton from the α-carbon atom by a hydroxyl ion. The rate of racemization is also dependent on hydroxyl ion concentration, but is independent of protein concentration (Damodaran 1996). Racemization of amino acid residues causes a reduction in protein digestibility becausethe peptide bonds involving D-amino acid residues are less efficiently hydrolyzed by gastric and pancreatic proteases (Hayase*et al.*, 1975). This leads to loss of essential amino acids that have racemizedand impair the nutritional value of the protein (Liardon and Hurrell 1983). D-Amino acids are also less efficiently absorbed through intestinal mucosa cells, and even if absorbed, they cannot be utilized in in vivo protein synthesis (Hayase*et al*., 1975).Moreover, some D-amino acids, such as D-proline, have been found to be neuro-toxic in chickens (Cherkin, Davis and Garman 1978). In addition to racemization and b-elimination reactions, heating of proteins at alkaline pH destroys several amino acid residues, such as Arg, Ser, Thr, and Lys. Arg decomposes to ornithine (Damodaran 1996).

Extrusion cooking technology

Among high temperature short time (HTST) processing technologies, extrusion cooking technologycombines several unit operationssuch as HTST cooking, kneading, shearing, forming and capable of performing tasks under high pressure(Moscicki, 2011). It has been reported as a suitable technology to prepare nutritionally balanced or enriched (weaning foods, meat replacers, animal feeds and dietetic foods) (Cheftel, 1986). This is advantageous to limit unwanted denaturation effects on, for example, proteins, amino acids, vitamins, starches and enzymes (Moscicki, 2011).The growing popularity of extrusion-cooking in the global agri-food industry, caused mainly by its functional advantage, led many indigenous manufacturers to implement it on an industrial scale, based on the local raw materials (Moscicki, 2011). It can be implemented with relatively low effort, does not require excessive capital investment, the equipment is user-friendly and offers a chance to use raw materials which have not previously displayed great economic importance (e.g., faba bean) or have even been considered as waste (Moscicki, 2011).In the extrusion cooking, temperature, mixing mechanism, moisture content and residence time distribution are mainly responsible for a certain physical state of the extrudate and quality parameters of final product such as texture are often dependant on the viscosity (Moscicki, 2011). Furthermore it has the ability to retain the macro- and micronutrients of the extrudate. In the next sections the effect of extrusion cooking on the macro- and micronutrients will be discussed.

Effect of extrusion on macronutrients with a specific reference to protein and starch

Extrusion cooking has a negative or positive effect on the macronutrients of the finished product depending on the extrusion condition and the food material to be processed. Singh *et al*. (2007) reported that effects of extrusion cooking on nutritional quality are vague. In addition, it has been reported that an extrusion-cooker is a process reactor (Van Zuilichem1992).

These means the designer has created the prerequisites with the presence of a certain screw lay-out, the use of mixing elements, the clearances in the gaps, the installed motor power and barrel heating and cooking capacity, to control a food and feed reaction (Moscicki 2011).Proper use of these factors allow to stimulate transformation of processed materials due to heating, for example, the denaturation of proteins in the presence of water and the rupture of starches, both affected by the combined effects of heat and mechanical shear (Moscicki 2011) .The intense mechanical shear during extrusion cooking is able to break the covalent bonds in biopolymers, and the deep structural disorder and mixing facilitate modification of functional properties of food ingredients and/or texturizing them (Asp and Bjorck, 1989; Riaz, 2001). Furthermore, Singh *et al.,* (2007) reported that nutritionally balanced extruded product could be obtained through carful control of process parameters. In the next sections the effect of extrusion on protein and starch will be discussed.

Effect of extrusion on protein quality of the final product

Protein nutritional value is dependent on the quantity, digestibility and availability of essential amino acids (Singh *et al.*2006). According to FAO/WHO/UNU (1985), protein digestibility is the main determinant of protein quality. Lysine is the limiting amino acid in all cereals and the essential amino acids isoleucine, threonine and tryptophan may also be present in inadequate quantities (Dahlin and Lorenz 1992).Traditionally, protein quality has been improved in cereal grains by amino acid supplementation, introduction of new, greater protein varieties or development of low-cost food blends complementary in amino acid profile. Now a day, different conventional and novel food processing technologies are applying to improve the protein quality of food products. Among processing technologies, extrusion cooking has been reported to increase the protein quality of the extruded product depending on the extrusion condition and food material to be processed (Cheftel, 1986; Fapojuwo*et al.*, 1987; Mouki 2013). It is probably a result of denaturation of protein and inactivation of enzyme inhibitors present in the food material to be extruded. This is because of most protein undergo structural unfolding and/or aggregation when subjected to moist heat or shear (Cheftel, 1986). In addition, Dahlin and Lorenz (1992) reported that, heating may benefit protein digestibility by translation the protein more susceptible to hydrolysis due to structural changes, destruction of anti-enzymatic factors or decrease lipid-protein and starch-protein complexes. Fapojuwo, *et al.*(1987) observed that temperature is the key extrusion variable that influence protein in vitro digestibility of sorghum. In addition, Singh *et al*. (2007) reported that, among process variables, the feed ratio has the maximum effect on protein digestibility followed by barrel temperature.

On the other hand, increased screw speed may have increased the protein digestibility of extruded corn-gluten, because the increase in shear forces in the extruder denatures the proteins more easily, thus facilitating enzyme hydrolysis (Bhattacharya &Hanna, 1985). Generally all processing variables have different effects in protein digestibility. The destruction of trypsin inhibitors facilitate by increasing extrusion temperature and moisture content (Bjorck and Asp, 1983). Low moisture high temperature extrusion processing has been reported in decrease protein quality mainly due to lysine losses via maillard reaction (Bjorck and Asp, 1983). Dahlin and Lorenz (1992) observed that the in-vitro protein digestibility has been influenced by the interaction between extrusion temperature and feed moisture content during cereal processing.

Lysine retention ability of extrusion cooking

Depends on the extrusion condition, extrusion cooking either helps to retain the available lysine of the food product or decrease it through chemical reaction occurs during extrusion cooking. Overall decrease in apparent protein digestibility is reported as a responsible for the difference between lysine availability and lysine content (Cheftel, 1986). It has been reported that, high temperature low moisture (Tm ≥ 180˚C, and % moisture ≤ 15) extrusion processing leads to lysine loss and impairs nutritional quality due to maillard reaction (Cheftel, 1986). On the other hand, Iwe *et al.,* (2004), reported that feed composition, screw speed and die diameter have high effect on the retention of available lysine during extrusion cooking of soy-sweet potato mixture at constant temperature. It has been reported that the screw speed could contribute to lower the retention time of the feed mixture in the extruder (Iwe *et al*., 2004).

Effect of extrusion cooking on the physio-chemical characteristics of starch

Carbohydrates comprise more than 90% of the dry matter of plants (Bemiller and Whistler 1996). Starch is the predominant food reserve substance in plants and provides 70–80% of the calories consumed by human's worldwide (Bemiller and Whistler 1996). Starch is unique among carbohydrates because it occurs naturally as directly particles (granules) and chemical and physical characteristics and nutritional quality set it apart from all other carbohydrates. It is well known that cereals are rich source of starch. Undamaged starch granules are relatively dense, insoluble and hydrate only slightly in cold water. When starch granules heated in water they undergo disruption of molecular order within granules. Irreversible granular swelling, loss of birefringence and loss of crystallinity are the indication of starch gelatinization (Colonna, Doublier, Melcion, de Montredon, & Mercier, 1984a). Eventually, native starch is very viscous and when heated in the presence of water it limits the nutritional quality of the food product. High viscous food will be less energy dense food. This undesirable property of native starch could be overcome by using different processing technologies and/or by using chemical modification. Among the processing technologies, extrusion cooking has been reported is a bit unique because gelatinization occurs at much lower moisture levels (12–22%) than is necessary in other food operations (Guy, 2001). Viscosity increases during gelatinisation, and the nature of native starch gels are very sensitive to factors such as shearing, temperature, heating or cooling rate and in addition, the source of starch and the presence of other components (El-Khalek and Janssens 2010). Lui*et al.,* (2010) reported that starches undergo size dependent degradation during thermo-mechanical processing and it can change the physical properties of the resulting material.

In view of the fact that, starch composed of non-reducing ends of each branch and per whole there is a single reducing end group with three neighboring –OH groups, Lui*et al.,* (2010) reported that, in starch these end groups do not undergo reaction in extrusion. However, simple shear degradation of starch which results in decreasing of molecular weight and size is occurred during extrusion (Lui*et al*., 2010). Shear degradation is depends on the size distribution of amylose and amylopectine. Colonna*et al.,* (1984a) reported that amylose and amylopectine are partly hydrolysed to maltodextrins as a result of high shear extrusion of wheat starch (Tm = 180˚C, moisture = 11%, RPM =270).Furthermore, it has been suggested that starch constituents in cereal or legume flours may be more readily hydrolysed than in purified starches, these could be because of endogenous amylases are active during the initial extrusion steps (Cheftel, 1986).

Effect of extrusion on starch in vitro digestibility

According to the rate and extent of starch digestion in vitro, starch is generally classifies into rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistance starch (RS) (Englyst, Kingman and Cummings 1992). The RDS and SDS are digested in the small intestine whereas, RS is not digested in the upper gastrointestinal tract, but its microbial fermentation in the colon produces short-chain fatty acids that provide additional energy to the body (Englyst, Kingman, and Cummings, 1992; Zhang and Hamaker, 2009). RS starches has been divided into four groups: physically inaccessible starches (RS1), resistant starch granules (RS2), retrograded amylose (RS3) (Englyst*et al.*, 1992) and thermally or chemically modified starch (RS4) (Eerlingen and Delcour, 1995). The formation of viscosity and gel has been reported as a useful process for, delay in gastric emptying (Johansen, Knudsen, Sandstorm and Skjoth, 1996),possible reduction of absorption rates in the small intestine (Johnson and Gee, 1981), increased endogenous secretions (Low, 1989), proliferation of microorganisms in the lower digestive tract (Choct, 1997) and generally, increased gut viscosity decreases the rate of diffusion of substrates and digestive enzymes and hinders their effective interaction at the mucosal surface (El-Khalek and Janssens 2010).Extrusion condition with high moisture content and low temperature has been reported as a favor condition for the formation of resistant starch, specifically RS3 type (Stojceska *et al.*, 2010). Extrusion processing in the presence of lipid (formation of amylose-lipid complex) (Lin, Hsieh, and Huff, 1997), amylose to amylopectine ratio (Lui*et al*., 2010), feed moisture content and processing temperature (Stojceska *et al.*, 2010) and screw speed (Lin *et al.*, 2010) has been reported as conditions that are favour for the formation of RS3.

On the other hand, weaning food should have high glycemic index and low viscosity. This is because of the recommended dietary fibre intake of children older than 2 years of age in minimum should be age plus 5 g/d (William, 1995).

In addition, a safe range of dietary fiber intake for children is suggested to be between age plus 5 and age plus 10 g/d. Extrusion cooking at low temperature and low feed moisture has been reported to have complete starch gelatinization (Chinnaswamy and Hanna 1990). Furthermore, it has been reported that control of carbohydrates during extrusion is critical for product nutritional and sensory quality (Guy 2001). That means extrusion conditions and feed materials must be selected carefully to produce desired results. For example, a weaning food should be highly digestible, and snack for obese adults should contain little digestible material (Guy 2001).

Energy density of extrusion cooked product

Energy density of porridge is depends on the solid content. Extrusion porridge could be prepared by using 20 % solid as compared to traditionally prepared by thermal cooking that could be 9 % solid (Onyango, Henle, Hofmann and Bley, 2004). Bukusuba, Muranga, and Nampala (2008) reported that, the increase in solid content of extruded porridge is because of the depolimerization of amylopectn during extrusion cooking. The hydrolysis of amylose and amylopectine to dextrin results in the reduction of the viscosity and helps to increase the solid content of the extruded product.These indicate that, the viscosity of the extruded porridge will not be high because low molecular weight dextrins do not swell during reconstitution and it is desirable property of complementary food products. Precooked flours of reduced viscosity and increased solubility permit the preparation of weaning foods or gruels of higher concentration and calorie density as consumed (Harper & Jansen, 1985).

Conclusion

Complementation of cereals and legumes could be the best solution for the dual burden that developing countries are faced currently. Because of the teff grain high nutritional quality, it could be the best solution in order to solve PEM in African developing countries. In addition, now a day in developed countries, most people are becoming an allergy for gluten containing products and teff could be a solution to tackle the problem since teff is gluten free grain. Apart from complementing cereals and legumes, extrusion cooking has big advantage to create ready-to-eat porridges with different nutritional qualities as required to address nutritional needs. Even though, processing technology plays a big role, the selection of raw materials also to be prioritized to prepare any nutritious food products. Extrusion cooking of whole grain teff-cowpea composite at high temperature and low feed moisture content resulted in high glyceamic index ready to eat porridge because of the ability of extrusion cooking to complete gelatinization and depolymerization of starch granules. Due to the fact that GI and starch digestibility are directly related, depolymerization of starch helps to increase α-amylase susceptibility of starch granules. On the other hand, low barrel temperature and high feed moisture content resulted in a low GI ready to eat porridge. This is because of the high moisture content during extrusion, water acts as a plasticizer, and α-amylase susceptibility of the starch will be less due to the formation of retrograded starch.

In addition, since excess water reduces shear force during extrusion cooking, the contribution of shear force for the disruption of starch granules will be limited. Moreover, low feed moisture and high barrel temperature also helps to improve protein quality of the extrudate in terms of protein digestibility, protein digestibility corrected amino acid score, available lysine and essential amino acids availability. Even though, high temperature and low moisture known to induce maillard reaction, the short time cooking helps to prevent the occurrence of maillard reaction.

On the other hand, high feed moisture and low barrel temperature contributes for the low protein quality due to less denaturation of protein and the inability of inactivation of heat stable protein anti-nutritional factors. In conclusion, teff could help to tackle protein energy malnutrition and diabetes if a suitable cooking technology applied either to depolymerize or to form a resistant starch to produce high GI or low GI food product respectively.

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