CAFEi2012-108

GLUTEN-FREE EXTRUDED PRODUCTS: A REVIEW

Paykary M.[1], Karim R.[2], Aghazadeh M.[1], Kazemi M.[1]

[1]Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Malaysia.
[2] Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Malaysia.
E-mail: rosaz@food.upm.edu.my

ABSTRACT

Although, gluten is one of the most important components in cereal technology, due to the claim that almost 0.05% of the current world population has allergy to gluten (celiac patients), there is a growing necessity to increase the choices of gluten free products. Extruder as a versatile and highly efficient instrument for thermal and mechanical processing has a widespread application in food production. Also because of its versatility, it is a high efficient instrument in food industries. While there is a new approach to prepare gluten free products, the varieties of them are not comparable to the needs of demanded people. This review discusses on production of gluten free food products using extruder. High starch, high protein, and high fiber gluten free food products and their physical, chemical, rheological and sensory properties were compared to that of gluten based material. Different kinds of seed flour and their starches (rice, pigeon pea, buckwheat, soy bean, kidney bean, amaranth, cassava, oat, sorghum, and quinoa) have been used as improving agents. The effect of extrusion at appropriate conditions (type of extruder, barrel temperatures, screw speeds, die-nozzle rate, and feed rate), with or without addition of other ingredients on the physical and chemicalcharacteristicsof the new products were discussed. In many cases, improvers were significantly ($p<0.05$) useful to retain the gluten benefits in the final products that were developed, even were able to act exactly as gluten in material matrix.

Keywords: *celiac, extrusion, coeliac, cereal product, gluten-free*

INTRODUCTION

Celiac Disease (CD) is one of the most important issues in food technology. This food intolerance is specially evidencein places where the use of wheat is common[1]. Table 1shows the prevalence of CD observed in different countries by means of serological population screening. Today the prevalence of CD seems to occur in 1:200 or more of the population [2, 1]. Figure 1 shows the ratios of CD in different levels. Unfortunately, many people are suffering fromCD, a type of genetic disorder resulting in gluten intolerance. CD is a genetically determined condition in which certain grain proteins cause an autoimmune response that damages the lining of the small intestine, causing blunting of the villi and malabsorption of nutrients. Gluten is the general term for the proteins that have been found to be toxic in those with CD - specifically the storage proteins (prolamins) in wheat (gliadin), rye (secalin) and barley (hordein) [3].

Table1: Prevalence of CD observed in different countries by means of serological population screening [2, 3]

Geographic area	Prevalence on screening data
Hungary	1:85
Estonia	1:88
Finland	1:99
United Kingdom	1:100
United States	1:111
Ireland	1:122
Switzerland	1:132
Portugal	1:134
Italy	1:184
Sweden	1:190
Netherlands	1:198
Norway	1:250
Spain	1:389
Denmark	1:394
Croatia	1:500
Germany	1:500

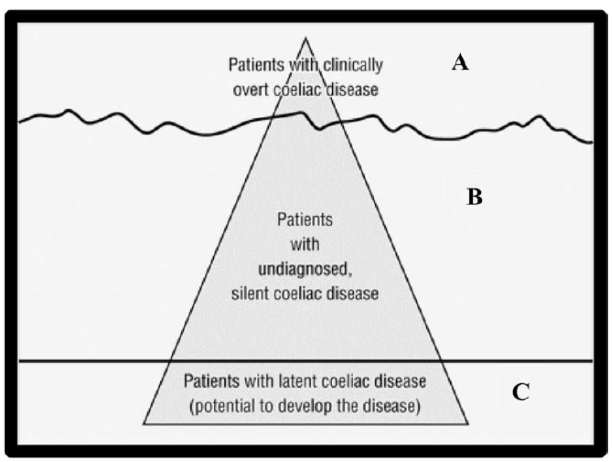

Fig.1: Iceberg model depicting prevalence of CD. Source: Raymond et al., 2006

Extrusion-cooking has become a well-established industrial technology, with a number of food and feed applications. The extruder is viewed as a continuous chemical reactor processing biopolymers and food mixes at high temperatures (up to 250°C) for relatively short residence times (usually 1-2 min), at high pressures (up to 25 mPa), under high shear forces, and in most cases, at relatively low water contents (below 30 %). Extrusion-cooking is not a single unit operation. Its specificity and wide range of applications, as compared with other thermal or HTST processes, depend on (1) the number of mechanical and thermal processing steps that can take place along the screw(s) and barrel, and (2) the high shear and pressure exerted on low moisture food mixes. Extruder geometry, process conditions and food mix composition interplay to bring about various physical, chemical and nutritional modifications of the food constituents. Reducing sugars can be formed from starch or oligosaccharides under severe extrusion conditions [4].

Based on the above explanation, this review discusses on the production of gluten free extruded products which are suitable for CD people.

Pasta

Pasta is an inexpensive and essential staple food in many different cultures usually made from wheat [5], which is consumed in most countries across the world. Traditionally, pasta is made by mixing durum wheat flour and water. Durum wheat flour has been proven to deliver the highest pasta quality, which is attributed to the gluten that is present in wheat. Gluten is a structural protein that gives pasta cooking stability and firmness or “bite” (*al dente*). Gluten is composed of glutenin, which gives dough elasticity, and gliadin, which is responsible for making the dough extensible [6]. Extrusion-cooking causes starch gelatinization followed by retrogradation, forming a rigid starch network and improving the cooking quality of the product.

Typical gluten-free (GF) foodstuffs which are based on rice and maize usually have a comparatively low content of quality proteins, and are low in fiber, calcium, and iron. GF products also have a high fat and calorie content, to compensate for the decreased sensorial acceptability. Recently, there has been significant study on gluten-free products involving a diverse approach which included the use of starches, hydrocolloids, dairy products, gums and other non-gluten proteins, prebiotics and combinations thereof, as alternative to gluten, to improve the structure, mouth feel, acceptability and shelf-life of GF products [7].

Rice is one of the few cereal products that do not contain gluten. However, the absence of gluten poses problems in the structure and cooking quality of rice pasta[8]. When rice flour is used as the only ingredient for pasta production, it requires additives or particular processing techniques to modify in a suitable way the properties of macromolecular components (starch and proteins) that are relevant to the structure of the final product [9]. Due to the absence of gluten, rice is recommended as safe for people affected by celiac disease and it is commonly used to produce gluten-free (GF) products, alone or in combination with other no-gluten cereals and/or additives[10, 11].

Non-wheat pasta like rice or corn pasta can be made by means of extrusion cooking. Extrusion cooking is an efficient practice by which cooking and forming processes can be carried out simultaneously. When compared to other cooking methods; extrusion offers several advantages, the control of degree of cooking and the maintenance of reasonable nutritional value, among them. The effects of extrusion parameters on the characteristics of a pasta-like product have been investigated. Increasing moisture content of the dough decreased the brightness, bulk density, cooking loss and stickiness, but increased the cooking time and firmness. Raising the barrel temperature increased the cooking time, firmness and stickiness, but decreased the brightness, bulk density and cooking loss in non-wheat pasta. Similarly, increasing the screw speed decreased the brightness and bulk density, increased cooking time, firmness, stickiness and also cooking loss[12].

The addition of waxy starch or tapioca starch resulted in rice pasta with an increase in hardness and stickiness, whereas the addition of common corn, Hylon V, or Hylon VII resulted in rice pasta with a decrease in hardness, stickiness, and adhesiveness. The addition of starch significantly changes the color, pasting, cooking and texture properties of rice pasta, and these changes are governed by the type of starch incorporated into the rice pasta. Gluten-free rice pasta can be prepared with properties similar to the semolina pasta by incorporating starches[8]. Although starch retrogradation is considered a negative phenomenon in baking, it could positively affect the quality of extruded products as pasta[13, 10].

Addition of amaranth flour in the production of amaranth-enriched rice-based pasta had been proven toimprove the textural properties of the product[9]. The presence of this lysine rich high-protein flourcould rearranges their organization or their interaction with other components of the systems at various stages in the process to ensure interactions among proteins or between proteins and other pasta components.

Mastromatteo et al. had reported on the optimization of non-conventional gluten-free fresh and dry pasta formulation based on quinoa, maize and defatted soy. They found that dough samples with high content of maize had the higher value of elongation and shear viscosity and then increased dough firmness. The pre-gelatinised maize content also affected the rheological properties by increasing the dough firmness[14].

In another study by Sepielli, et al., addition of inulin at 5 and 7.5% in pasta resulted in higher values of elongation and shear viscosity with respect to the other samples, therefore a higher firmness. Sensory analysis showed that all dry samples had a positive score of overall quality; in particular, the sample with 5% of inulin showed the highest score because of the highest resistance to breakage[15].

Gluten-free products generally are not enriched and frequently are made from refined flour or starch. Such products have been found to provide lower amounts of total dietary fibre than their fortified gluten-containing counterparts. The materials were added at the level of 30% into the gluten-free balanced formulation (control) made from rice flour, potato starch, corn starch, milk powder and soya flour. The results clearly show that extrusion technology has the potential to increase the levels of total dietary fibre in gluten-free products made from vegetables, fruits and gluten-free cereals[16].

Snacks

Extrusion is a suitable process for producing snack foods for patients suffering from coeliac disease as far as starch is the main component providing the desirable expanded structure in the final product. Cereal grains are generally used as the basic raw materials in extruded snack foods. Nutritious GF snack foods can be prepared by incorporation of cereal flours, legumes, milk powder, soya flour, vegetables, and fruits into the formulation [17].

Nyombaire had reported on the production of puffed snacks from raw ground red kidney beans (*Phaseolus vulgaris* L.) using a laboratory co-rotating twin-screw extruder (Model JS30A, Qitong Chemical Industry Equipment Co, Ltd., Yantai, Shandong, China), with a screw diameter of 30 mm and barrel L/D of 14 (diameter-to-length ratio). The die was a square thick plate with 7mm diameter circular hole. The effect of barrel temperature (BT, 120 °C/105 °C or 130 °C/115 °C), screw speed (SS, 118 rpm,184 rpm, or 253 rpm), feed rate (FR, 80 g/min or 120 g/min), and moisture content (MC, 25 g/100 g or 36 g/100 g) on the characteristics of the final product were monitored. These include expansion ratio (ER), bulk density (BD), water absorption index (WAI) and water solubility index (WSI). Expansion takes place when material under the given heat treatment is forced through an extruder die; water vaporizes and the resulting simultaneous vapor flash-off expands the starch content, producing a porous, sponge-like structure in the extruded product. Extrudate's degree of expansion is closely linked to the size, number and distribution of air cells within the material. Among all the extrusion variables studied, only feed rate at 80 g/min had a significant impact on expansion ratio (ER). Moisture content, screw speed, and product temperature did not significantly affect the ER. Bulk density (BD) of extruded products is closely related to ER. There was significant difference in BD based on the moisture content; BD was generally higher for extrusion at 36% of moisture content. Barrel temperature and screw speed showed no clear trends and had minimal effect on BD of bean extrudates; whereas, feed rate at higher BT-2 (130 °C/115 °C) showed some significant differences in BD of extruded samples.

Feed rate, moisture content, and screw speed did not significantly affect water absorption index (WAI). Although, there was no significant difference, the WAI mostly increased with increasing feed rate and increasing moisture content. Increasing screw speed did not have a significant impact on WAI. For most extruded samples, an increase in barrel temperature from 120 °C/105°C to 130°C/115°C resulted in increased WAI; however, this increase was not always significant. Temperature-dependent increases in WAI can be attributed due to higher proportion of gelatinized starch in the extrudates [18].

The water solubility index (WSI) is a parameter that indicates the total degradation undergone by starch granules; that is, it is the integration of the effects of gelatinization, dextrinization, and the consequent solubilization of starch. Increasing feed rate significantly increased WSI of bean extrudates. The increased WSI under high feed rate was probably due to fully developed flow along the die which also increases starch and/or fiber degradation during extrusion cooking. Extruded product properties depend mostly on the molecular transformations, for example, disruption of starch granules, depolymerization of amylose and amylopectin; these transformations are generated in the various parts of the extruder by pressure, shearing and residence time[18].

Ibanoglu uses theWerner and Pfleiderer Continua 37 co-rotating twin-screw extruder (Stuttgart, Germany) for production of a nutritious snack food from rice, maize and chickpea flours with the addition of several types of herbs. The temperature of the extruder barrel and the moisture of the feed material were kept constant at 110°C and 13.5% db, respectively, without external injected water. The screw speed and feed rate were expressed in table 2 as independent process variables. The result showed that feed rate and screw speed both had an effect on the firmness of the product at 95% confidence interval (CI). The interaction between the two factors was also found to be significant. Firmness decreases as the feed rate increases, making the penetration of the probe in the texture analyser easier as indicated by a lower peak force. On the other hand, firmness increases as the screw speed increases, especially at higher feed rates, indicating the interaction of the two factors. The effect of screw speed on lateral expansion was significant whereas, the quadratic effect of feed rate was found to be significant on the lateral expansion (95% CI). There was no interaction between the two extrusion variables. Lateral expansion increases as screw speed increases. Responsible for this, the material requiring more shear for a better developed dough, resulting in better expansion. The results for color showed that the changes in the L, a and b values during extrusion were not significant at 95% CI[17].

In another product, the ingredients used for the preparation of gluten-free for extrusion products were 50% rice flour, 12.5% milk powder, 12.5% potato starch, 12.5% corn starch and 12.5% soya flour. Rice flour was replaced with dry cranberry, beetroots, apple, carrot and Teff flour at a level of 30%. Extrusion trials were performed with a Werner and Pfleiderer Continua 37 co-rotating twin-screw extruder (Stuttgart, Germany). The barrel diameter and L/D ratio were 37 mm and 27:1, respectively. A screw configuration that was a standard design for processing cereals and flour-based products was used. This screw profile was made up of conveying self-wiping elements, except for a section consisting of short reverse and forwarding elements to improve mixing and apply shear to the material being extruded while restricting flow and building up pressure. The extruder was fitted with a circular die with a diameter of 4 mm. A twin-screw volumetric feeder (Rospen, Gloucestershire, UK) was used for feeding the dry mixture to the extruder. The independent processing variables included moisture content (%), feed rate (kg/h) die geometry (mm), screw speed (rpm), temperature profile (°C) and screw configuration. The dependent variables included die pressure (psi), material temperature and torque. The process conditions were set as follows: feed rate 15–25 kg/h, water feed of 12%, screw speed between 200 and 350 rpm; the barrel temperatures were 80 °C at feed entry and 80–150 °C at die exit. Pressure, material temperature and torque were monitored during extrusion runs. As the result, large variations in WAI, WSI, bulk density and hardness were found in all the extrudates obtained from different process conditions. WAI increased in cranberry and carrot but decreased in apple with increasing barrel temperature. WSI increased in apple with increase of barrel temperature and increased in carrot with increasing screw speed. Increasing barrel temperature lowered bulk density in carrot and hardness of the control sample. Lateral expansion decreased most in samples containing apple, cranberry, carrot and beetroot, under all process conditions, while Teff samples were similar to the control. Barrel temperature increase significantly lowered the LE in Teff [16].

The effect of Teff flour in extruded puffed product was discussed in another study. Tef (*Eragrostis tef [Zucc.] Trotter*) is a unique durable crop grown over a wide range of environmental conditions and has been utilized as food and supplements for majority of the human diet. It is as nutritious as major staple cereals like wheat, rice, oats and barley and even better in some aspects, containing more calcium, zinc, iron and potassium and being high in dietary fiber. The grain is too small, with average length and width of 1.20 and 0.75 mm respectively. This results in a better nutrition provision and higher fiber content. The extruder conditions are mentioned in Table 2.

Table 2: The ingredients and extruder conditions for production of gluten free extruded snacks

Basic ingredients	Type of extruder	Moisturec ontent(%)	Barrel temperatures (□C)	Screw speeds (rpm)	Feed rate (g/min)	Reference
Light red kidney beans (Phaseolus vulgaris L.)	co-rotating twin-screw extruder	25-36 (wb)	120 /105 130 /115	118, 184, 232	80, 120	[18]
Rice, Maize, Chiekpea	co-rotating twin-screw extruder	13-15 (db)	110	220-340	367-433	[17]
Rice flour, Milk powder, Ptato starch, Corn starch, Soy flour, Cran berry, Beetroot, Apple, Carrot, Teff flour	co-rotating twin-screw extruder		80-150	200-350	250-417	[16]
White and red tef (*Eragrostis tef* [Zucc.] Trotter) flour	co-rotating twin-screw extruder	17-26 (wb)	70/ 110-150	100-140	150	[19]

The WAI and WSI of extrudates from both cultivars significantly ($p<0.05$) are affected by the barrel temperature, feed moisture content and screw speed.WSI increased significantly ($p<0.05$) from 0.024 to 0.028 and 0.026 to 0.033 for white and red Teff extrudates, respectively as barrel temperature was increased from 110 to 150°C. However,

WSI increased from 0.0238 to 0.0279 for white Teff and 0.023 to 0.0316 for red Teff as the moisture content was reduced from 26 to 17%. Changes in WSI as screw speed increased from 100 to 140 rpm were not statistically significant. The increase in WSI therefore shows a macromolecular degradation with the intensity of extrusion condition. Large amount of soluble materials are released at high extrusion temperature, high screw speed and low feed moisture content. Increased screw speed induces a sharp increase of mechanical energy resulting in a harsh mechanical disruption of starch molecules[19].

The radial expansion of extruded products from red and white Teff flour were significantly ($p<0.05$) affected by the combination of feed moisture content, barrel temperature, and screw speed (Table 2). Samples extruded at 130°C barrel temperature at 17% feed moisture content and at 100 rpm screw speed (treatment 12) had the greatest radial expansion ratio of 2.44 and 2.14 for red and white Teff respectively, compared to the rest of the conditions. Extrusion using high barrel temperature (150 °C) at the same feed moisture and screw speed levels resulted in extrudates with significantly higher ($p < 0.05$) expansion ratio as compared to those processed at barrel temperatures of 130 and 110 °C). Low feed moisture at the same barrel temperature and screw speed also showed a significantly higher ($p<0.01$) radial expansion of extrudates for both types of Teff flours[19].

For most treatments an increase in screw speed from 100 to 140 rpm significantly ($p<0.05$) increased the radial expansion.In contrast to this finding, increasing screw speed increased the axial expansion at the expense of radial puffing, which is attributed to less resistance of the die due to lower die pressure observed at high screw speed. The higher specific length of extrudates at 110 °C barrel temperature and 100 rpm screw speed (treatment 1 and 3) appeared with minimum radial expansion. Extruding at150 °C barrel temperature and 17% feed moisture showed a relatively higher radial as well as higher axial expansion, thus a maximum volumetric expansion[19].

In general, when barrel temperature was 110 °C and the feed moisture content was 26 to21%, an increase in screw speed from 100 to 140 rpm significantly ($p<0.05$) reduced the specific length but not for higher extrusion temperatures and lower feed moisture contents.

The moisture content of fresh extrudate was significantly affected ($p<0.05$) by feed moisture content followed by barrel temperature whereas screw speed has no a significant effect. Extrusion at 150°C barrel temperature gave extruded products, which showed higher expansion and retained the lowest moisture after puffing for the same feed moisture content. High moisture contents were associated with less expanded extrudates and required additional energy input to remove the water.

Bulk density was significantly ($p<0.05$) influenced by extrusion variables used and their interaction. The results in Table 2 indicated that barrel temperature exhibited a predominant effect followed by feed moisture in reducing the bulk density evidenced by about 50% and30% relative decrease respectively in bulk density for the same other two variables. However, screw speed appeared to have slight effect on the bulk density. Tef flour extruded at barrel temperature of 150 °C, 17% feed moisture were significantly ($p<0.05$) less dense than extruded under the rest of the conditions. Density was reported to decrease with the increase in the extrusion temperature due to starch gelatinization.

Increased gelatinization increases the volume of extruded product, consequently bulk density decreases as observed in this work. At high temperature the vapor pressure of the free moisture is also greater which would cause an increased rate of moisture flashing and puffing up on exit from the die[20]. This could result in a decreased bulk density as well.

The bulk density values of tef flour are not as low as those of highly expanded cereal extrudates, for which the low moisture and high barrel temperature extrusion conditions lead to high mechanical energy dissipation and consequently high expansion.

For similar moisture content and screw speed levels, high barrel temperature resulted in a significantly reduced hardness ($p<0.05$) of the extruded products from both Teff varieties. In general, an increase in barrel temperature from 110 to 150°C and decrease in feed moisture content from 26 to 17 % at 140 rpm screw speed decreased compression force from over 200 to 64.16 N and to 60.83 N for white and red tef extrudates, respectively [19]
.

CONCLUSION

Incorporation of amaranth flour, starch, and other additives in rice pasta combined with extrusion-cooking improves the textural and nutritional quality of the final product without much dramatic worsening of cooking behavior. In this respect, introduction of the extrusion-cooking step prior to pasta-making is decisive, as pasta made from an extrusion-cooked mixture of rice flour and other additives had the best textural and nutritional characteristics.
The physicochemical changes occurring in the pasta-making process affect the properties of the final product, and involve both the starch and the protein fractions, and their mutual interactions.

Starch gelatinisation, during extrusion cooking, and its retrogradation after cooling, probably contribute to the formation of resistant starch, which leads to an increase in insoluble dietary fibre. Starch gelatinisation is a sequential process, which includes the diffusion of water into the starch granule, followed by water uptake by the amorphous region, hydration and radial swelling of the granules, loss of optical birefringence, uptake of heat, loss of crystalline order, uncoiling and dissociation of double helices in the crystalline regions and amylose leaching.

Under optimal conditions, extrusion technology is a suitable method for the preparation of gluten-free products with high levels of dietary fibre and protein. The increases of these components depend on the types of samples used as a source. The formation of gluten-free expanded products with high level of starch, fiber, or protein can be achieved by controlling extrusion conditions, such as temperatures, solid feed rate and screw speed combinations and the selection of appropriate raw ingredients.

REFERENCES

[1] Gallagher, E. (2009). Gluten-Free Food Science and Technology: Wiley-Blackwell.
[2] Accomando, S. and F. Cataldo (2004) The global village of celiac disease. Digestive and Liver Disease. 36(7): p. 492-498.
[3] Gallaghera, E., T.R. Gormleya, and E.K. Arendtb (2004) Recent advances in the formulation of gluten-free cereal-based products. Trends in Food Science & Technology. 15 p. 143–152.
[4] Cheftel, J.C. (1986) Nutritional effects of extrusion-cooking. Food Chemistry. 20(4): p. 263-283.
[5] Shogren, R.L., G.A. Hareland, and Y.V. Wu (2006) Sensory Evaluation and Composition of Spaghetti Fortified with Soy Flour. Journal of Food Science. 71(6): p. S428-S432.
[6] Sissons, M.J., H.N. Soh, and M.A. Turner (2007) Role of gluten and its components in influencing durum wheat dough properties and spaghetti cooking quality. Journal of the Science of Food and Agriculture. 87(10): p. 1874-1885.
[7] Chillo, S., V. Civica, M. Iannetti, N. Suriano, M. Mastromatteo, and M.A. Del Nobile (2009) Properties of quinoa and oat spaghetti loaded with carboxymethylcellulose sodium salt and pregelatinized starch as structuring agents. Carbohydrate Polymers. 78(4): p. 932-937.
[8] Mertz, A.W. and Y.-J. Wang (2011) Properties of gluten-free pasta prepared from rice and different starches. DISCOVERY. 12: p. 67-73.
[9] Cabrera-Chávez, F., A.M. Calderón de la Barca, A.R. Islas-Rubio, A. Marti, M. Marengo, M.A. Pagani, F. Bonomi, and S. Iametti (2012) Molecular rearrangements in extrusion processes for the production of amaranth-enriched, gluten-free rice pasta. LWT - Food Science and Technology. 47(2): p. 421-426.
[10] Marti, A., M.A. Pagani, and K. Seetharaman (2011) Understanding starch organisation in gluten-free pasta from rice flour. Carbohydrate Polymers. 84(3): p. 1069-1074.
[11] Marti, A., K. Seetharaman, and M.A. Pagani (2010) Rice-based pasta: A comparison between conventional pasta-making and extrusion-cooking. Journal of Cereal Science. 52(3): p. 404-409.
[12] Wang, J., H. An, Z. Jin, Z. Xie, H. Zhuang, and J. Kim Emulsifiers and thickeners on extrusion-cooked instant rice product. Journal of Food Science and Technology. p. 1-12.
[13] ABDALLA, O.S., R.J. PEÑA, J.E. AUTRIQUE, and M.M. NACHIT (1993) Durum wheat breeding and quality improvement at CIMMYT Mexico. CIHEAM - Options Mediterraneennes. p. 133-141.
[14] Mastromatteo, M., S. Chillo, M. Iannetti, V. Civica, and M.A. Del Nobile (2011) Formulation optimisation of gluten-free functional spaghetti based on quinoa, maize and soy flours. International Journal of Food Science & Technology. 46(6): p. 1201-1208.
[15] Padalino, L., M. Mastromatteo, G. Sepielli, and M.A.D. Nobile (2011) Formulation Optimization of Gluten-Free Functional Spaghetti Based on Maize Flour and Oat Bran Enriched in b-Glucans. Materials. 4(12): p. 2119-2135.
[16] Stojceska, V., P. Ainsworth, A. Plunkett, and Ş. İbanoğlu (2010) The advantage of using extrusion processing for increasing dietary fibre level in gluten-free products. Food Chemistry. 121(1): p. 156-164.
[17] Ibanoglu, S., P. Ainsworth, E. Ayse Ozer, and A. Plunkett (2006) Physical and sensory evaluation of a nutritionally balanced gluten-free extruded snack. Journal of Food Engineering. 75(4): p. 469-472.
[18] Nyombaire, G., M. Siddiq, and K.D. Dolan (2011) Physico-chemical and sensory quality of extruded light red kidney bean (Phaseolus vulgaris L.) porridge. LWT - Food Science and Technology. 44(7): p. 1597-1602.
[19] Kebede, L., S. Worku, G. Bultosa, and S. Yetneberek1 (2010) Effect of extrusion operating conditions on the physical and sensory properties of tef (Eragrostis tef [Zucc.] Trotter) flour extrudates. EJAST. 1(1): p. 11.
[20] Harris, P.L., S.L. Cuppet, and K.W Lee (1988) A scanning electron microscope study of maize gluten meal and soy extrudate. Cereal Chemistry. 65(2): p. 228-232.