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Development of Extruded Senegalese Infant Formula from Mixtures of Pearl Millet and Grain Legumes

Maty Diop[1, 2*], Mamadou Salif Sow[2], Eliasse Diémé[1, 2], Cheikh Ndiaye[2], Mohamed Lamine Gaye[1], Djibril Traoré[2]

[1]*Université Cheikh Anta Diop de Dakar, Faculté des Sciences et Techniques, Département de Chimie, BP 5005, Dakar, Sénégal*

[2]*Institut de Technologie Alimentaire: laboratoire de Chimie, laboratoire de microbiologie, laboratoire de mycotoxine, atelier céréales et légumineuses, BP 2765, Dakar, Sénégal*

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***Corresponding author:** *Maty Diop, Université Cheikh Anta Diop de Dakar, Faculté des Sciences et Techniques, Département de Chimie, BP 5005, Dakar, Sénégal; E-mail: maty0889@live.fr*

Abstract

Instant compound flours were developed from local Senegalese plants, using a single-screw extruder (Technochem brand) previously designed for soybean processing. Adapting the parameters of the equipment to our local cereals (sorghum, millet, and maize), legumes and oleaginous plants was the first technical step performed. We modified the parameters of the extruder and then carried out several tests to determine the best blend obtained from several combinations of co-extruded raw materials that led to compound flour (70% millet, 15% peanut, and 15% cowpea) of high nutritional value. Prior to this step, analyses were run on each compound of the blend to determine their selected macro (moisture, ash, acidity, protein and lipid) and micro composition (iron, magnesium, and zinc). For a good result, the extruder parameters were set at a frequency of 48.2 Hz and a temperature of 280°F. Three shear rings of 1.47 mm of diameter each, followed by a bigger one (1.59 mm), were respectively inserted along the end of the screw; the rotational speed of the screw was set at 900 rpm and total liquid content was 30%. The final instant flour obtained was composed of 13.99% protein, 9.37% fat, 4.10% moisture, 1.64% ash and 0.08% acidity. The flour was split in four different batches and each was flavored with one of four powders (mango, papaya, baobab fruit or carrot). On a hedonic scale from 1 to 9, the results of the organoleptic tests performed by 21 trained panelists showed that all four samples received a score higher than 5 in all three categories (taste, color, and texture). However, taste wise papaya flavor received a better score followed by mango, carrot and baobab fruit flour. In conclusion, changing the parameters of the extruder helped obtain a well-accepted instant blend from local plants when local fruits were used to enhance flavors.

Keywords: Extrusion; instant meals; local products; hydrothermal processes; millet; cooker-extruder setup;

Introduction

Extrusion cooking is a process of transformation and development of a product from raw biopolymeric dough like material (raw, damp, expansive, protein or starchy based material) that uses a die in order to produce finished products via a high-temperature, short-time process. Food materials (cereals and legumes) are usually heated and the starch fractions are gelatinized while the proteins fractions are denatured during a cooking operation by a combination of pressure, temperature, mechanical shear and forming/shaping causing a molecular transformation, breakdown, alignment and chemical reactions of the food components. The process significantly reduces the number of micro-organisms, inactive enzymes and antinutrient factors. Beneficial changes of bioavailability as well as the nutrient content may take place during the extrusion because of antinutrient inactivation and increased digestibility of biopolymers [1, 2]. According to [3], and reported by [4], extrusion technology is essential to add value to cereal grain- and legume-based materials. They define it as a powerful processing operation combining several unit operations like mixing, heating, kneading, shearing, shaping and forming. According to [5], extrusion is also a tight control of many successive and related variables such as the composition of food, the particle size of the feed materials, feeding speed, and temperature of the food, temperatures of the different units, speed of the screw, the screw configuration and dies geometry [6]. Reported that hot extrusion is food processing at high temperature for a short time (HTST) which generally reduces microbial contamination, inactive enzymes and facilitates the removal of anti-nutritional factors. After processing by extrusion, the product dries with low moisture content (low water activity) and does not need to be refrigerated for preservation.

One of the main objectives of the extrusion technology is to increase the variety of foods available through the production of a wide range of products with different shapes, textures, colors, and tastes. For example, in Africa, several studies have been conducted to develop and produce extruded products from indigenous materials (Filli et al., 2014). This is the case of [7], determined the residence time of the soy/sweet potato mixture using a single-screw extruder [8]. Studied the available lysine content and browning index after cooking extrusion of the soy/sweet potato mixture. In another study, [9] reported the extrusion on the bioavailability of vitamins and minerals in adults' rats fed raw and extruded African breadfruit (Treculia africana Decne) mixtures [10].determined the effects of system parameters and product property responses during extrusion of Fura composed of millet/soy mixture [11]. Reported a study with a single-screw extruder on the expansion ratio of extruded water Yam (Discorea alata) starches. Oluwole, 2013 reported a study on the assessment of microbial changes and nutritional qualities of extruded white Yam (Discorea rotundata) and bamabara groundnut (Vigna Subterranean) blends, etc.

In developing countries where food products are primarily made of cereals and legumes, extrusion technology remains the process that can play an important role in achieving food and nutrition security objectives due to its complementarity in terms of protein fortification and good response to the technology. Extrusion technology can be used for the development of instant food products produced from traditional grains (cereals and legumes) grown in Africa. However, traditional staples of African extraction are usually made from these single cereals (millets, sorghum, corn, rice, fonio, etc.) which serve as the primary meals. But these cereals have the disadvantage of being deficient in the essential amino acid lysine which predisposes them to yielding products of acceptable protein content. There is, however, a practical technological solution of blending them with the grain legumes that are abundant in lysine. Though the legumes are inadequate in sulphur-containing amino acids, the cereal grains are adequate in sulphur-containing amino acids; therefore, they complement each other appropriately at suitable ratios. Many scientists have reported that blending of cereals with grain legumes at an appropriate ration can yield a product with the needed amino acids profile that is suitable for human nutrition [12, 13].

In Senegal, 14 brands of infant flours are currently found in the market but two out of the 14 only are produced locally and both are not pre-cooked [14]. The Institute of Food Technology (ITA, Dakar, Senegal, 2012) has received a single-screw extruder (Technochem International Inc., USA) designed initially for the transformation of soybean grain. Therefore, the main objective of this study is to set up the single-screw extruder for the processing of our local cereals. At the same time, we have developed through extrusion technology infant instant meals from these cereals, leguminous and oleaginous that can be used for malnutrition and food insecurity purposes.

Material and Methods

Samples

For the study, we need Souna millet, peanuts, cowpea (as cereal and legumes). We also need mango, papaya, baobab and carrot powders to flavor the instant infant meals we will obtain. Thereby, Souna millet is used as the main cereal base (70%), to which is added peanut (15%) and cowpea (15%). Mango, papaya, baobab and carrot powders (5% of each) were added to millet-peanut-cowpea flour for sensory testing.

Proximate chemical composition of raw materials for setting up the extruder

Moisture of the millet, groundnuts and cowpea is determined by gravimetric (Memmert oven) at 105° C over 4 hours. The protein content in millet, groundnuts and cowpea was determined by the method of Kejldahl (Distiller KjelFlex K-360; mineralizing Kjel Digester K-449). Total sugars contained in the millet, groundnuts and cowpeas have been determined by the Luff-Schoorl method (volumetric dosage). The lipids in millet, groundnuts and cowpea have been extracted in Soxhlet (Gerhardt, Soxtherm extractor).

Aflatoxins founded

Aflatoxins in peanut seeds were measured by high performance liquid chromatography HPLC (EN 14123 method).

Extrusion cooking processing

The single-screw mini-extruder is a Technochem model with electric motor 7.5 HP and two variable frequency drive (one for 230V and the other for 380V). All of our experiments were performed at with 230V. The screw was placed vertically in relation to the electric motor. It was composed of two small feed-screws and three double-flight screws. A shear bushing was placed in front of the two feed-screws and in front of each double-flight screw. A bullet with washer was placed in front of the last shear bushing and the whole screw was blocked by a bullet with washer.

The millet and cowpea were cleaned and calibrated by using a vibro-sieve, which has three compartments separated by two sieves. Each sieve holds seeds of the same size. The sizes of opening of the sieves used were 1.5 mm (upper sieve) and 1 mm (lower sieve) for millet and 4.75 mm (upper sieve) and 2.80 mm (lower sieve) for cowpea. After cleaning and calibration, the envelopes and part of the germ of millet and cowpea were removed with a Nuhull type huller. It should be noted that before being shelled, the cowpea was first cleaned with water, boiled at room temperature and dried on racks. Originally, the cooker-extruder was designed for the processing of soybeans; therefore, it was important to homogonize our raw material mixture prior to extrusion. The millet was crushed without sieve; the cowpea was crushed with a sieve of 3mm thick; and the peanut seeds were crushed with a 5mm sieve.

Table 1: Cooking extrusion formulations		
Formulations	**Ingrédients**	**Ratio**
Formulation 1	Millet: Peanuts: Cowpea	70:15:15
Formulation 2	Millet: Peanuts	70:30:00
Formulation 3	Millet: Peanuts	60:40:00
Formulation 4	Cowpea: Peanuts	60:40:00

Table 2: Hydration of 5 Kg mixtures				
Formulations	**Desired final liquid content (%)**	**Blend moisture (%)**	**Total water required to reach final liquid content (L)**	**Hence water to be add (ml)**
Formulation 1	30	18,43	1,75	830
Formulation 2	30	24,78	1,61	370
Formulation 3	30	28,96	1,52	70
Formulation 4	30	28,66	1,53	100

Total Water Required= (Desired Final Liquid Content × Initial Solid Content)/ (1 - Desired Final Liquid Content)

Water to be Added = Total Water Required – Initial Liquid Content

Initial Liquid Content = Initial Mass of Blend * Blend Moisture

Initial Solid Content = Initial Mass of Blend – Initial Liquid Content

Table 3: First extrusion conditions					
Formulations	**Treatment**	**Desired moisture (%)**	**Frequency (Hz)**	**Screw speed (rpm)**	**Ring size (mm)**
Formulation 1	1	30	48.2	900	4*(1.47)
	2	30	48.2	750	4*(1.47)
	3	30	48.2	600	4*(1.47)
	4	40	48.2	600	4*(1.47)
Formulation 2	1	30	48.2	900	4*(1.47)
	2	30	48.2	600	4*(1.47)
Formulation 3	1	30	48.2	900	4*(1.47)
Formulation 4	1	30	48.2	900	4*(1.47)

Table 4: Formulations 3 and Formulation 1 tested again					
Formulations	**Treatment**	**Desired moisture (%)**	**Frequency (Hz)**	**Screw speed (rpm)**	**Ring size (mm)**
Formulation 3	1 (trial 2)	30	48.2	900	4*(1.47)
Formulation 1	4 (trial 2)	40	48.2	900	4*(1.47)
	1(trial 2)	30	48.2	900	4*(1.47)
	5	35	48.2	900	4*(1.47)
	5 (trial 2)	35	48.2	900	4*(1.47)
	4 (trial 3)	40	48.2	900	4*(1.47)
	6	37.5	48.2	900	4*(1.47)
	7	30	48.2	900	3*(1.47);1*(1.59)

In the single-screw extruder, mixtures to treat are introduced into the screw-sheath by the feeding hopper. The screw swallows the material and progresses it along the machine to the end where the extruded product comes out through the small die. The expulsion of the extruded product is due to the axial thrust of the material, caused by the reaction of pressure during transport. The thermometer makes it possible to raise the cooking temperature of the product. This heat is generated both by transfer to the contact of the product with the inner lining of the sheath and the mechanical shear exercised by the screw. The extruded product obtained is dried in order to reduce the moisture content. The extruded instant food product (flour) is obtained by grinding the dry extruded product with a mobile hammer mill. It is divided into two parts - one is instant unenriched flour and other being flour enriched with milk powder and sugar.

Analysis of unenriched and enriched extruded instant flours

Moisture in the instant flours was determined by gravimetry (Memmert oven) at 105°C over four hours. Protein in the instant flours was determined by the method of Kejldahl (Distiller KjelFlex K-360; mineralizing Kjel Digester K-449). The lipids in the instant flours were extracted in Soxhlet (Gerhardt, Soxtherm extractor). The ashes of the instant flours rate were obtained by incineration (ThermoScientifique/Thermolyne Proofer) at 550°C during 4 hours. Instant flour acidity was determined by volumetric dosage according to the food manual analysis and common expertise (Raoul LECOQ, Tome I, and P.956).

Microbiological qualities of unenriched and enriched extruded instant flours

The following germs have been sought: yeast and mold (NF V08-059), total aerobic flora at 30°C (NF ISO 4833), fecal coliforms (NF V08-060), pathogenic staphylococci (NF EN ISO 6888-1), Clostridium sulfito-reducers (NF ISO 15213), Lactobacillus (NF ISO 15214), Listeria monocytogenes (NF EN ISO 11290-1), Cronobacter Sakazakii (Canadian 22964), salmonella (NF EN ISO 6579).

Sensory evaluation of four flours enriched respectively with bouy, mango, papaya and carrot powders

Twenty-one panelists have been designated at ITA to assess the taste, color and texture of the four porridges made of millet-groundnut-cowpea with 5% of bouy powder, carrot powder, mango powder or papaya powder on a 1-9 hedonic scale with 1 being « very bad » to 9 being « very good ». For the purposes of the sensory test, we add milk powder and sugar according to the following formulas:

Powdered milk=(Total weight of flour)/2

Sugar=(0.13 ×(Weight of flour+weight of powdered milk))/0.87

The data was processed by the EXCEL software.

Results and Discussion

Chemical composition of raw materials for setting up the cooker-extruder

Table 5 show composition of raw material and blends. These values have allowed us to determine by Excel content water, total fat and protein of the blend (70% mil - 15% peanut – 15% cowpea) which are respectively 8.88%, 9.55% and 13.75%. The content in the liquid (water and fat) is 18.43% (Table 2) is insufficient and should be at least 30% of total liquid to make the mixture pass in the cooker-extruder. Water to add depends on the amount of liquid in the mixture. Peanut seeds contain a total of 0.4 ppb (according to authorized standards) in aflatoxins B1, B2, G1, and G2. (Table 6)

Table 5: Proximate composition of raw material and blends

Samples	Water (%)	Proteins (%)	Fat (%)	Total sugar (%)
Millet	9.43	10.03	2.81	11.96
Peanuts	4.78	22.2	49.28	4.88
Cowpea	10.44	22.7	1.29	8.79
Formula 1				
M:P:C	8.88	13.75	9.55	10
Formula 2				
M:A	8	13.7	16.8	10
Formula 3				
M:A	7.6	14.9	21.4	9
Formula 4				
C:P	8.17	22.5	20.5	7

Aflatoxins

Table 6 show total aflatoxins in peanuts. Aflatoxins B1 (0.2 ppb) and B2 (0.2 ppb) ...

Table 6: Total Aflatoxins peanut seeds

Parameter	Peanuts
Aflatoxin B1 (ppb)	0.2
Aflatoxin B2 (ppb)	0.2
Aflatoxin G1 (ppb)	< 0.1
Aflatoxin G2 (ppb)	< 0.1
Total (ppb)	0.4

Parameters of the cooker-extruder

Three main parameters must be taken into account: humidity, size of the rings and speed of rotation of the screw. Also, for raw materials containing a lot of oil (peanut, soy), it is necessary that the mixture to be transformed has a restricted passage in the apparatus. For this, rings of large diameters are used; for low-fat raw materials, small rings are adequate. Finally, the precautions to be taken are: the cylinder must never touch the screw; the bullet should be tightened to the bottom with your hand then loosened at least three times. A screw is required to lock the bullet (clockwise). The cooker-extruder setup allowed to have fixed values such as frequency which is 48.2 Hz, the speed of rotation of the screw that rotates around 900 rpm, the sizes of the rings that are 3*(1.47mm) and 1*(1.59mm). Humidity should remain at 30% regardless of the amount of water to add, only the temperature changes. These new parameters of the machine made it possible to extrude local cereals from Senegal.

Table 7: First observations

Formulation	Treatment	Remarks
Formula 1	1	After adding water, the blend was put in a homogenizer for 30 minutes. The extrusion was brief (stopped) because the blend was dry and rich in starch.
	2	Water was added to the mixture and homogenizer step was skipped. Cooker-extruder speed was reduced to 750 rpm. Because of the low speed of rotation, the machine has stopped and there is no product output.
	3	Product too dry and low oil content. So increase liquid content by adding water.
	4	Unable to feed continuously because blend wet was very sticky. Oil content in formula was increased by adding peanuts and no cowpea in formula.
Formula 2	1	None exit because extrusion stopped immediately.
	2	Very little product come out of die. We have tried slow feeding and increase peanuts in formula.
Formula 3	1	Extrusion stopped in a few seconds and very little product come out. Product have high starch. In formula, millet was replaced by cowpea.
Formula 4	1	First successful run, all product come out of die but it was undercooked.

Table 8: Observations of formulas 1 and 3 which are tested again

Formulation	Treatment	Remarks
Formula 3	1 (trial 2)	Successfully extruded, but product was undercooked.
Formula 1*	3 (trial 2)	Successful run, product well-cooked but backed in the feed section after 5 min. try to reduce moisture.
	1 (trial 2)	Extrusion stopped in a few seconds because product was too dry. Try to increase liquid content to 35%.
	5	Extrusion stopped. Bushing in the back touching the feed section barrel. Re-test.
	5 (trial 2)	Grain blend was equilibrated in refrigerator over the weekend. Bushing issue was solved and successful run but product slightly undercooked. Nose cone was 5 pitches out so tried 3 pitches out.
	4 (trial 3)	Feeding issue, the blend was equilibrated and extrusion tested again.
	6	The grain blend was equilibrate for 15hrs. Successfully extruded, product cooked.
	1 (trial 3)	Successful run. One of the 4 rings (1.47mm) was replaced by a 1.59mm diameter ring and nose cone maintained at 3 pitches out of die. Product cooked very well at 280°F.

*equilibrated for 24hrs in refrigerator

Formulation 1 was reprocessed at 40% moisture (oil + water), 900 rpm rotation speed and 4 rings 1.47 mm and put in the refrigerator for 24 hours. The test was successful and the product was well cooked but the mixture showed a tendency to stick on the feed hopper because it was too wet. A mixture of 35% was prepared and homogenized for 30 minutes. The device did not function correctly. Thus, the moisture level of the mixture was further reduced to 30%, the rotation speed left at 900 rpm, and one of the 1.47 mm rings was replaced by a ring of 1.59 mm in diameter. The entire product was cooked well from the appliance at a temperature of 280° F (137°C). The following parameters were applied when extruding a mixture of 70% mil - 15% peanut - 15% cowpea:

Frequency: 48.2 Hz

Speed: 900 rpm

Rings size: 1.47mm (3), 1.59mm (1)

Temperature: 280°F

Moisture: 30%

Composition of unenriched and enriched extruded instant flours

According to [2], water is an important element in the extrusion process as it is necessary for the starch gelatinization and the dispersion of the ingredients. In the formation of a viscous fluid, it is transported and cooked. Moisture is always shown as a separate variable in addition to the ingredients of the food, because it is often controlled separately in the extruder. Water can be added directly to the load, injected into the barrel or added in the form of steam to the pre-conditioner. Our formulation contained in total 30% water, which represented 1.75 kg of the 5 kg of mixture. The moisture content of the extruded products obtained was respectively 4.1g / 100g for unenriched flour and 4.25g / 100g for enriched flour. These values can be explained by evaporation of the water under high temperature at the exit of the hole. These values are lower than those found in the cassava + soy flour and atcheke + soybean of Tchoko et al., 2011 in Ivory Coast which are equal to 5g / 100g. They are also lower than those found by Ponka et al., 2016, in Cameroon in the five meals that vary from 7.19 to 8.21g / 100g, and very weak compared to the moisture levels found in Senegal in corn flour (12.38 g / 100 g) and millet (19.71 g / 100 g)[16, 17] (Table 9).

Protein of unenriched and enriched levels are respectively 13.99 and 12.57g / 100g, which is greater than the levels found by [18]in porridge eaten in the Extreme North of Cameroon (8.91-13.69g / 100g). The improved protein content of the extruded instant flours is, according to ACC/SCN quoted by Ponka et al., 2016, due to millet mixed with groundnut and cowpea (mix cereal/legumes). For Singh et al., 2007, digestible proteins of the extruded product value are higher than that of the non-extruded products. The possible cause could be the denaturation of proteins and the inactivation of the anti-nutritional factors inhibiting the digestion. The nutritional value of vegetable protein is usually enhanced by soft extrusion cooking conditions.

Lipids have two functions in the extrusion process: 1) they can influence the quality of the product and; 2) act as a lubricant during the process. Most of the lipid based to 40^{0}C. Inactivation by extrusion of lipase and the lipoxygenase helps protect against oxidation during storage. Higher temperatures reduce the lipase activity and the level of humidity, thus reducing the development of free fatty acids (Navale et al., 2015). For Singh et al., 2007, the extrusion process can prevent the release of free fatty acid by denaturation of hydrolytic enzymes. Oxidation of lipids has a negative impact on the sensory and nutritional food qualities. This probably does not occur during extrusion due to the very short residence time. However, rancidity is a concern for the extruded products during storage. Lipids levels analysis of unenriched and enriched extruded instant meals are respectively of 9.37 and 6.86g / 100g against values ranging from 1 to 2.08 g / 100 g found in five meals of Ponka et al., 2016, in Cameroon (Table 9). Ash and acidity of extruded instant flours unenriched and enriched rates respectively are 1.64 and 1.80g / 100g and 0.08 and 0.05 g / 100 g (Table 9).

Unenriched and enriched extruded instant flours comply with the microbiological standards (Table 10) applicable to instant infant flours, and do not contain salmonella or aflatoxins [20].

Table 9: Proximate composition of unenriched and enriched extruded instant flours

Instant flowers	Moisture (%)	Proteins (%)	Fat (%)	Ash (%)	*Acidity (%)
Unenriched	4.1	13.99	9.37	1.64	0.08
Enriched	4.25	12.57	6.86	1.8	0.05

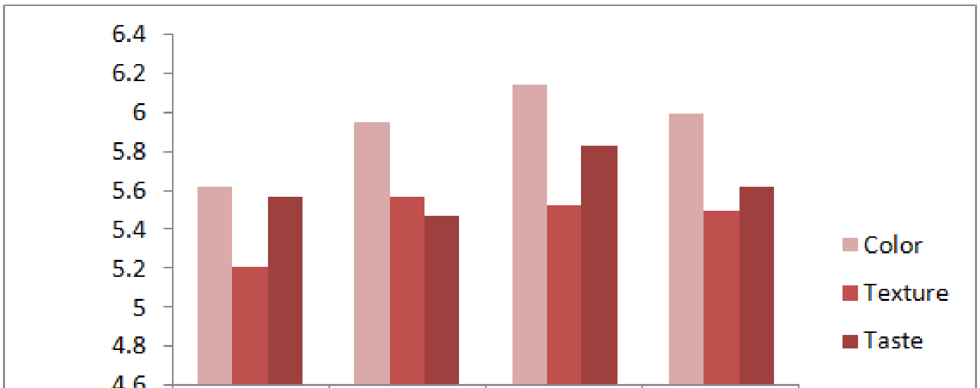
*acidity expressed as sulfuric acid

Table 10: Microbiological composition of unenriched and enriched extruded instant flours

Parameters	Unenriched	Enriched
Yeasts and molds (UFC/g)	6.10^1	$1,0.10^2$
Total aerobic flora at 30°C (UFC/g)	$1,1.10^3$	$7,5.10^2$
Fecal coliforms (UFC/g)	6.10^1	1.10^1
Pathogenic Staphylococci (UFC/g)	0	0
Clostridium sulfito-reducer (UFC/g)	< 10	< 10
Lactobacillus (UFC/g)	< 10	< 10
Listeria monocytogenes (UFC/g)	ND	Absence
Cronobacter sakazakii (UFC/10g)	ND	Absence
Salmonella (UFC/25g)	Absence	Absence

Sensory evaluation

[Figure 1] Results of the sensory analyses performed by the 21 panelists showed that flour C (additional powder: papaya) is the most preferred, followed by flour D (additional powder: mango), flour B (additional powder: carrot) and flour A (additional powder: baobab).



	Bouy	Carot	Papaya	Mango
Color	5.619047619	5.952380952	6.142857143	6
Texture	5.214285714	5.571428571	5.523809524	5.5
Taste	5.571428571	5.476190476	5.833333333	5.619047619

Figure 1: Sensory analyses of 4 instant flours

Conclusion

This study has allowed us to create new products with high nutritional value from Senegal's local products. From the settings of the cooker-extruder to the flour development, several tests were carried out. The results obtained on the nutritional composition (protein, moisture, fat and microbiological quality) of extruded instant infant meals meet the standards recommended by WHO. However, analyses of minerals and vitamins are essential to complete the nutrition facts of these instant flours. The study will be able to develop Senegal's booming food sector by helping processors to develop better production technics and increase their income through the transfer of technology. Lifestyle improvement and a new range of nutritious local products by promoting "local consumption" are additional benefits of extrusion technology.

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References

1. Singh S, Gamlath S, Wakeling L. Nutritional aspects of Foods extrusion: A review, International Journal of Food Science and Technology. 2007;42(8):916-929.
2. Navale SA, Swami SB, Thakor NJ. Extrusion Cooking Technology for Foods: A review, Journal of Ready to Eat Food. 2015;2(3): 66-80.
3. Riaz M. Introduction to Extrusion. Presented at the Extru Africa Conference, "Needs, barriers and opportunities for extrusion in Africa", at Protea hotel Kruger Park, Skukuza Mpumalanga province, South Africa. 2013;1–2.
4. Filli KB, Jideani AIO, Jideani AV. Extrusion Bolster Food Security in Africa, Food Technology. 2015;46-55.
5. Meng X, Threinen D, Hansen M, Driedger D. Effects of extrusion conditions on system parameters and physical properties of a chickpea flour–based snack. Food Res. Intl. 2010;43(2):650–658.
6. Filli KB, Nkama I, Abubakar UM, Jideani VA. Influence of extrusion variables on some functional properties of extruded millet-soybean for the Manufacture of fura: A Nigerian traditional food. African Journal of Food Science. 2010;4(6):342-352.
7. Iwe MO, Van Zauilichem DJ, Ngoody PO, Ariahu CC. Residence time distribution in a single-screw extruder processing of soysweet potato mixtures. Lebensm – Wiss. U. – Technol. 2001;34(7):57-61.
8. Iwe MO, Van Zuilichem DJ, Stolp W, Ngoddy PO. Effect of extrusion cooking of soy–sweet potato mixtures on available lysine content and browning index of extrudates. Journal of Food Engineering. 2004;62(2):143-150.
9. Nwabueze TU. Bioavailability of vitamins and minerals in adult rats fed raw and extruded African breadfruit (Treculiaafrican) mixtures, Journal of Food Agriculture and Environment. 2007;5(314):465-470.
10. Filli KB, Nkama I, Jideani VA, Ibok IU. System parameters and product properties responses during extrusion of fura from Millet – Soybean Mixtures. Nigerian Food Journal. 2012;30(1):82-100.
11. Oke MO, Awonorin SO, Workneh TS. Expansion ratio of extruded water yam (Dioscoreaalata) starches using a single screw extruder, African Journal of Agricultural Research. 2013;8(9):750-762.
12. Oluwole OB, Awonorin SO, Henshaw F, Elemo GN, Ebuehi OAT. Assessment of microbial changes and nutritional qualities of extruded white yam (Dioscorearotundata) and bambara groundnut (Vigna subterranean) blends, Food and Nutrition Science. 2014;4:100-107.
13. Obatolu VA. Nutrient and sensory qualities of extruded malted or unmalted millet/soybean mixture, Food Chemistry. 2002;76(2):129-133.
14. USAID. ProjetCroissanceEconomique, Le marché de la farine infantile : Evaluation du potentiel et étude préalable au développement d'une offre pour le marché sénégalais, Rapport final. 2010;47.
15. Tchoko VJZ, Bouaffou KGM, Kouamé KG, Konan BA. Etude de la valeur nutritive de farines infantiles à base de manioc et de soja pour enfant en âge de sevrage, Bulletin de la Société Royale des Sciences de Liège. 2001;80:748-758.
16. Ponka R, Nankap ELT, Tambe ST, Fokou E. Nutritional composition of selected cameroonian local baby flours, International Journal of Innovation and Applied Studies. 2016;16(2):280-292.
17. Sall K. Contrôle de qualité des farines céréalières mises sur le marché au Sénégal. Thèse pour obtenir le grade de docteur en pharmacie, université Cheikh Anta Diop de Dakar, faculté de médecine de pharmacie et d'odontostomatologie. 1998.
18. Ponka R, Bouba AA, Fokou E, Beaucher E, Piot M, Leonil J, Gaucheron F. Nutritional composition of five varieties of Pap commonly consumed in Maroua (Far-North, Cameroon), Polish Journal of Food and Nutrition Sciences. 2015;65(3):183-190.
19. Allen LH, Gillespie SR. What works? A review of the efficacy and effectiveness of nutrition interventions. (eds). Geneva, WHO. 2001.
20. Mouquet C, Bruyeron O, Trèche GS. Caractéristiques d'une bonne farine infantile. 1998.