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Effect of the incorporation of cereals (fonio, rice), tubers (sweet potato, cassava), and a legume (cowpea) on the functional properties of Penne type pasta

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Abstract

The partial replacement of wheat in pasta with local cereals, tubers and legumes could constitute an alternative to the massive imports of wheat into Senegal. For this purpose, three formulations of Penne type pasta were prepared by substituting 50% of wheat semolina with locally available foods (fonio, rice, cassava, sweet potato, and cowpea) with the aim of measuring the impact on functional properties. The three formulations prepared are: PBFN (50% wheat, 40% fonio and 10% cowpea), PBRMN (50% wheat, 2%, rice, 20% cassava and 10% cowpea) and PBPN (50% wheat, 40% sweet potato and 10% cowpea). The Prepared pasta was assessed according to the following parameters: optimal cooking time, weight gain, color, cooking losses, protein content and fiber content. The results obtained on cooking losses vary from 5.175g for PBFN, 6.55g for PBRMN and 7.005g for PBPN per 100g of pasta. Results which place penne made from composite flours in the category of high-quality pasta. In addition, shorter optimal cooking times were obtained for all formulations based on composite flour compared to control wheat. Sensory analyzes showed pasta with acceptability indices greater than 70%, making these pasta acceptable. The best formulation was obtained with sweet potato. This study showed that the partial replacement of durum wheat semolina by cereals, tubers and legumes could be a solution to reduce wheat imports without causing consumer rejection.

Keywords: Pasta; Fonio; Rice; Yam; Cowpea; Cassava

1 Introduction

Pasta is a staple food, which is consumed around the world by children and adults regardless of their socio-economic status (1; 2). World production of pasta increased by 57%, from 9.1 million to 16.9 million tones (3). In Senegal, pasta produced or imported is made from durum wheat semolina. However, as Senegal does not produce wheat, the country resorts to imports to cover its needs. According to statistics, around 149.3 billion FCFA were spent on wheat imports for a quantity estimated at 753,800 tones (4). This constitutes enormous foreign exchange losses, hence the need to find alternatives to wheat. In addition, the coronavirus pandemic and the war in Ukraine have shown the need to base our diet on local foods.

Incorporating local produce into foods like pasta is worth exploring. Indeed, studies have shown that wheat semolina can be partially substituted by exogenous ingredients without altering the physical properties of the final product (5; 6). In addition, some authors consider that wheat-based pasta is an unbalanced food due to its low fat and dietary fiber content (7).

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Therefore, the partial or total substitution of wheat by local tubers, cereals, or legumes rich in fiber and micronutrients in the production of pasta, could improve their nutritional value and reduce dependence on wheat and therefore on imports.

In Senegal, several cereals, legumes, and tubers are cultivated. In the literature, many studies have reported the nutritional properties of these foods. Indeed, fonio (Digitaria, exilis) is known as being rich in proteins and micronutrients including iron and zinc, rice (Oryza sativa L.) is considered a source of vitamins and minerals,while cassava (Manihot esculenta Crantz) is high in calories(8; 9; 10;11; 12). Sweet potato (Ipomoea batata) is rich in carbohydrates and constitutes a good source of vitamin A and cowpea (Vigna unguiculata (L.) is a valuable source of vegetable proteins, (13; 14).

According to Mouette et al. (15), functional properties, determine the quality characteristics of pasta, including firmness, cooking loss, and overall acceptability. Fibers and proteins are two parameters linked to functional properties. This is why their determination is important to better define the functional properties of pastes.

The objective of this study was to measure the impact of incorporating flour from local cereals, tubers, and legumes, on the functional properties of pasta.

2 Material and methods

2.1 Plant material

The sweet potato was purchased at the Castor market in Dakar. It was transformed into chips, then dried before being crushed. A hammer mill composed of sieves with a mesh size of 0.5 mm was used to obtain flours.

The imported durum wheat semolina was supplied by a company based in Dakar. Cowpea, cassava, rice and fonio flours were acquired from a local product processing company based in Dakar.

2.2 Paste formulation and preparation.

Four (4) penne-type pasta formulations were prepared from wheat, cowpea, fonio, rice, cassava, and sweet potato flours (Table 1).

Table 1 Prepared dough formulations

	Composition (%)			
Plant material	**PBFN**	**PBRMN**	**PBPN**	**P.B.**
Wheat semolina	50%	50%	50%	100%
Cowpea	10%	10%	10%	0
Fonio	40%	0	0	0
Rice	0	20%	0	0
Cassava	0	20%	0	0
Yam	0	0	40%	0

PBFN=Wheat, Fonio, Cowpea Pasta / PBRMN=Wheat, Rice, Cassava, Cowpea Pasta; P=Wheat pasta (control pasta) PBPN=Wheat, Sweet Potato, Cowpea pasta

For each formulation, 250 g of flour was hydrated by adding water then extruded cold with the Philips HR2382/15 brand pasta machine after cutting, the extrudates were dried in a dehydrator to obtain a humidity of less than 12%.

2.3 Evaluation of pasta cooking parameters

2.3.1 Optimal cooking time

The optimal cooking time was determined according to AACC method 66-50.01 (American Association of Cereal Chemist, 2010). The pasta was cooked in boiling distilled water. The optimal cooking time is reached when the white center at the heart of the cooked pasta disappears after being compressed between two glasses for 30 seconds apart. The cooking tests were carried out in triplicate for all formulations.

2.3.2 *Weight gain*

The measurement of weight gain was carried out, according to the AACC 66-.01 method (American Association of Cereal Chemist, 2010), with some modifications (16). The samples were cooked to their optimal point then drained for 28.80s.

Weight gain represents the difference in mass between cooked and uncooked pasta.

2.3.3 Determination of colors

Using a colorimeter (model CR-410, Konica Minolta Sensing, Inc.Japan), measurements were taken on the pasta cooked according to the AACC 14-22.01 method. Light absorbance intensities were recorded on a white background with the scales L*(lightness), a*(redness), b*(yellowing). For each sample, the measurements were repeated three times.

2.3.4 *Cooking loss*

The cooking loss was determined on the 4 samples according to the AACC method 66-50.01 (American Association of Cereal Chemist, 2010). The losses were evaluated after cooking 10g of pasta in 100 ml of distilled water for the optimal cooking time of the sample previously determined. The cooked pasta was then removed from the water and the residual liquid evaporated in an oven at 105°C. The cooking loss is equivalent to the mass of the residue after evaporation.

2.4 Determination of protein and fiber content of pasta

2.4.1 Proteins

The protein content was you determined according to the Kjeldahl method described in AOAC (2018). This method consists of measuring the nitrogen in the product. For this purpose, the finely ground sample is hot mineralized with concentrated sulfuric acid in the presence of a catalyst. The nitrogen present in the sample gives, after several transformation processes, ammonia which is distilled and recovered in a boric acid solution then titrated with a sulfuric acid solution. The nitrogen content multiplied by a coefficient (6.25) gives the protein content.

2.4.2 Fibers

Crude fiber content was determined according to the method described in AOAC (2018). To do this, the finely ground sample is subjected to two acid and basic hydrolysis followed by complexation with EDTA. The residue obtained is then filtered, dried in an oven at 130 °C then calcined in an oven at 400°C. The difference in weight between the two stages gives the crude fiber content.

2.5 Sensory analysis

A 9-point hedonic scale is the basis of sensory analysis which provides an idea ofoverall acceptability of pasta.

Forty (40) panelists evaluated sensory parameters such as color, odor, texture, and taste of the 4 formulations (PB, PBFN, PBPN and PBRMN). The pasta was tested without accompaniment. The acceptability index (AI) was calculated according to the formula of Fernandes and Salas Mellado (17):

$$AI\ (\%) = (score*100) / \text{hedonic scale}$$

2.6 **Statistical analysis**

Statistical analysis was performed using Minitab, a data analysis software package. The statistical significance of the terms was verified by one-way analysis of variance (ANOVA) for each parameter.

3 Results

3.1 Pasta cooking parameters

The results of the culinary characterization of the different formulations are presented in Table 2 below.

Table 2 Pasta cooking settings

Type of Dough	Optimal cooking time (min)	Cooking loss (g/100g of raw pasta)	Weight gain (g/100g of raw pasta)	Color	
				b *	L *
PBFN	3.47±0.008^{b}	5,175±0.799^{b}	221.5±1.41^{b}	19,223±0.885^{d}	63.9550±0.00771^{b}
PBRMN	2.51±0.014^{c}	6.55±0.0495^{a}	212.5±0.707^{c}	22,197±1.409^{c}	69,280±0.226^{a}
P.B.	6.26±0.007^{a}	3,090± 0.184^{c}	207±1.41^{d}	34,203±0.205^{a}	70,315±0.997^{a}
PBPN	2.48±0.007^{c}	7,005±0.0919^{a}	239.5±0.70^{a}	23.98±1.92^{c}	60.8450±00771^{c}

The results presented in the table are expressed as mean value ± standard deviation (SD) for at least three repetitions. Different letters $^{a-d}$ in the same columns represent statistically significant differences ($P < 0.05$).
L*-lightness, b* (+) yellow.

3.2 Protein and fiber content

The results for fiber and protein contents are summarized in Table 3 below.

Table 3 Fiber and protein content of pasta

Pasta	Protein %	Fiber %
Rice/Cassava/Cowpea Pasta (PBRMN)	11,190^{bc}	1,485^{c}
Fonio pasta, cowpea (PBFN)	11.440^{b}	1.140^{b}
Control pasta (PB)	13.260^{a}	0.890^{a}
Sweet potato/cowpea pasta (PBPN)	10.610^{c}	1,800^{d}

The results presented in the table are expressed as mean value ± standard deviation (SD) for at least four repetitions. Different letters $^{a-d}$ in the same columns represent statistically significant differences ($P < 0.05$).

3.3 Sensory analysis

Sensory evaluation makes it possible to assess the overall characteristics of the pasta; it is one of the most reliable tests (15). Figure n° 1 presents the results of the sensory analyzes of the pasta without accompaniment, i.e., without sauce.

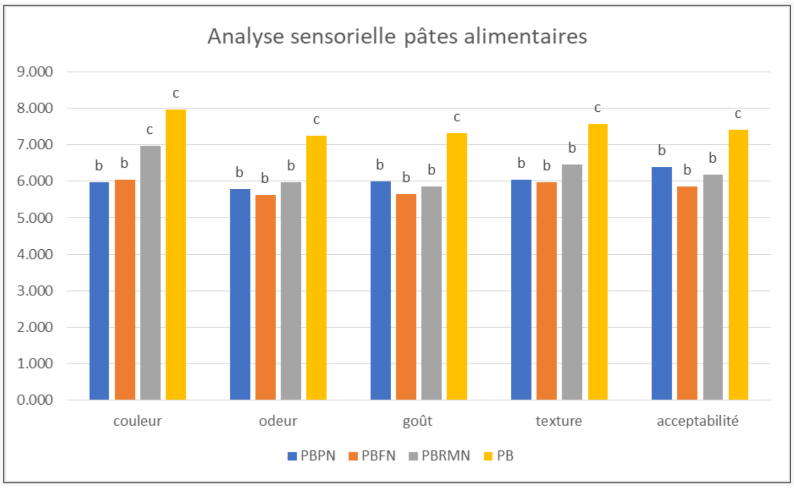

Figure 1 Results of sensory analyzes of penne without accompaniment (the different letters indicate a statistical difference between the samples p<0.05)

The appreciation scores obtained made it possible to calculate the acceptability index (AI) using the Fernandes and Salas-Mellado equation (17). The indices are shown in the table below.

Table 4 Acceptability index

Type of pasta	Acceptability index
PBRMN	68.55%
PBFN	65.11%
P.B.	82.33%
PBPN	70.77%

4 Discussion

4.1 Cooking loss

Cooking loss or the amount of residue in the cooking water is often used as an indicator of quality in pasta; low residues indicate good pasta quality (18; 19; 15). The control dough recorded a lower cooking loss than those obtained with the other formulations. This could be due to a gluten deficiency (20). This causes the starch polymers to be less effectively trapped in the matrix, resulting in a product with high cooking loss and low firmness. However, the cooking losses (5.175%, 6.55% and 7.005%) obtained with the incorporated pastes (PBFN, PBRMN, PBPN) could be indicative of good quality pastes.

According to the work of Fu (21), a cooking loss of 12% or less is considered an indicator of high-quality pasta and in the same vein, Delcour and Hoseney. (22) qualify as high-quality pasta, pasta where the residue must not exceed 7 to 8%.

A strong negative correlation ($r = -0.958$; $p \leq 0.05$), was noted between the protein content and the cooking loss. In fact, the richer the sample is in protein, the less it loses during cooking. Results which corroborate with those of Brockway. (23) in his work where he reports that the major effect of proteins is the trapping of starch granules, thus helping to reduce cooking losses.

4.2 Weight gain

After cooking, the wheat pasta used as a control absorbed less water than the penne produced with local flours. The same results were obtained by Solis et al (24) in the design of pasta with oats. According to Sozer et al. (25), this is due to a higher protein network formed by the gluten of wheat semolina. PBPN recorded the highest water absorption rate, i.e., 239.5g/100g of raw pasta.

Various factors can explain this result; the high fiber content of this potato sample compared to others may facilitate water penetration. In fact, the starch protein matrix plays a role in preventing cooking water from penetrating the starch; fibers would weaken this matrix, which would encourage water penetration (26, 27, 28). This factor could be the main reason for more water absorbed in the sweet potato sample.

4.3 Optimal cooking time

Another important parameter in pasta design is the optimal cooking time which corresponds to the minimum time needed to gelatinize the starch (29). It differed significantly depending on the pinnae. In addition, those based on incorporated flours overall had shorter cooking times than the control penne. These results corroborate those of Pen and Manthey (30) on doughs made from non-functional ingredients such as corn. A reduction in cooking time was reported by Petitot et al. (5) as being due to the reduction in the quantity of gluten in mixed flour mixtures. Indeed, in the latter, the gluten matrix is weakened and disrupted, the penetration of water into the pasta thus becomes easy (31). Three batches were obtained: the first batch consists of starch-based penne PBPN and PBRMN which recorded the shortest cooking times respectively 2.48 minutes and 2.51 minutes, the second batch concerns PBFN with a time of intermediate cooking (3.47 mins) and the third batch (PB) has the longest cooking time, i.e., 6.26 mins.

The same trend in first batch cooking times was observed by Krishnan JG et al. (32) in their work on sweet potato pastes. Indeed, according to Morengo et al. (33), the decreased cooking time of PBPN and PBRMN could be attributed to the ability of starch granules to absorb water and high fiber content. Increasing fiber content leads to increased cooking losses due to fiber interference in the starch matrix (34). Moreover, a strong negative correlation between fiber content and optimal cooking time was obtained ($r=-0.922 p\leq 0.05$): the higher the fiber content, the less cooking time. This result corroborates those of Bustos et al. (35). It is also in agreement with those of Aravind et al. (36) who had to work on the enrichment of pasta with dietary fiber and who found that the fiber generates a dilution of the gluten causing a reduction in cooking time.

4.4 Color assessment

Color constitutes an important parameter in the acceptability of pasta by consumers. The (L*) of the pasta which represents the value of the lightness and darkness of the pasta according to Laleg et al (37); Kowalczewski et al, (38), ranged between 60.84 and 70.31. The PB and PBRMN presented the highest values, the lowest values were recorded in the PBFN and PBPN. The b* character (yellow, blue) gave results between 19.223 and 34.203. The color depends partly on the raw material (39).

Therefore, the incorporation of fonio, rice, sweet potato and cassava flours into pasta should influence this parameter. However, the values observed for the L* parameter of penne made from wheat/rice/cassava/cowpea did not present a significant difference with the controls made solely from wheat semolina. A result which is distinct from those reported in the literature on doughs made from incorporated flours whose values recorded for the color parameter L* differ from those of the control depending on the incorporation rate (21, 18, 15, 36).

For the b* parameter, significant differences were observed between the control and the incorporated flours. According to Bustos et al. (35,18) One of the most important attributes of good quality pasta is its yellow color which results from the carotenoid content of durum wheat semolina. The control penne being composed of 100% wheat semolina, this would explain the greater values of b* (yellow color) obtained with the latter.

4.5 Protein and fiber content

The protein content of the control sample (PB) is higher than that of the other samples. This could be explained by the fact that proteins are one of the essential components of wheat semolina (5, 40). This hypothesis was confirmed by the results of a mixture without wheat semolina which had a protein content half that of conventional wheat pasta (41). In addition, there is a strong correlation between protein content and cooking losses. Thus, taking into account the mixtures of the authors Hélène de la Pen and Frank A Manthey. (41) with 80% wheat semolina and 20% fonio compared to the PBFN mixture composed of 50% wheat semolina, 40% fonio and 10% cowpea, the losses recorded should in principle be lower than the PBFN, given the greater quantity of wheat semolina. However, the losses recorded at 5.1% on PBFNs are lower than the 5.5% of Hélène de la Pen and Frank A Manthey (41). Consequently, the 10% of cowpea flour from PBFN could explain this difference in losses.The high protein content of cowpea (around 25% of its dry weight) which makes it possible to reduce the protein deficit noted in cereals according to Aly et al. (42); Omoigui et al. (43), could have a positive effect on incorporated pinnae.As mentioned by Bresciana A et al. (44), a rigid protein network leads to better cooking behavior. Thus we could correlate the results obtained on cooking losses, weight gain and optimal cooking time with the addition of 10% cowpea flour.Regarding fiber, significant differences were noted between the different samples and the control penne had the lowest fiber content. This could be explained by the fact that fonio cereals (7 to 8g/100g) of fiber; the tubers (sweet potato 17g, cassava 7g and the cowpea legume 16 to 20.9g used are much richer in fiber than wheat semolina (3.6g) (45,46). Penne made from sweet potato presents the higher fiber content. This could be due to the high fiber content of sweet potato flour.With a high fiber content, an increase in cooking losses is noted in pasta made from rice and cornmeal (47).

4.6 Sensory analysis

The results of sensory analyzes showed no significant difference between the wheat/rice/cassava/cowpea sample and the 100% wheat control for the color parameter. For all other parameters (taste, odor, texture and acceptability), the wheat sample dominates the incorporated flours.However, the wheat/sweet potato/cowpea mixture has an acceptability index greater than 70%, which is the minimum score for a food to be considered acceptable (48)

5 Conclusion

The results of the pasta obtained with mixed mixtures are much richer in fiber, the addition of legume flour has a beneficial effect on the protein intake but also on the functional properties. The best formulations after sensory analysis are PBPN and PBRMN penne. They have a color like the control. Reduced cooking losses place all PBRMN, PBPN, PBFN samples in the high-quality pasta category. The optimal cooking times determined could be used by manufacturers to incorporate local products into their production. This will reduce high wheat imports into Senegal.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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