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Nutritional and Sensory Properties of Penne-Type Pasta Based on Cereals (*Oryza sativa* (L.), *Digitaria exilis*, *Pennicetum glaucum*), Tubers (*Ipomoea batata*, *Manihot esculenta* Crantz), and a Legume (*Vigna unguiculata* (L.))

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Abstract

This study aimed to evaluate the nutritional and sensory characteristics of penne-type pasta produced from locally sourced cereals, tubers, and legumes. To achieve this, we formulated four different types of pasta with varying levels of incorporation ranging from 10 to 50% cereals such as millet, fonio, and rice, tubers such as manioc and sweet potato, and legumes such as cowpea. The results showed that the incorporation of local products considerably improved the nutrient content of penne without being rejected by consumers. Sensory analysis showed that the best results were obtained with mixtures of sweet potato, cowpea, and wheat, as well as with rice, manioc, cowpea, and sample wheat. These results are of great importance to manufacturers in a world where developing nutritious and attractive food products is a crucial challenge.

Keywords

Pasta, Tubers, Cereals, Legumes

1. Introduction

Pasta is traditionally made from durum wheat semolina and is valued for its nutritional and sensory characteristics [1] [2]. Their popularity stems from many factors, including their low fat and sodium content, low glycemic index, affordability, ease of cooking, and long shelf life [3] [4]. However, pasta is low in dietary fiber, minerals, and vitamins [5] [6] [7]. Nonetheless, pasta is a good vehicle for adding other non-traditional ingredients to its formulation without any apparent loss of functional properties [8] [9] [10]. The importance of incorporating functional ingredients (cereals, legumes) to improve their nutritional value is well documented [9] [11] [12]. As a result, the latest trend in the pasta market is to partially replace wheat semolina with ingredients with health benefits [13].

In Senegal, wheat is the second most consumed cereal after rice and is heavily dependent on imports, which amounted to almost 700,000 tonnes in 2020, worth CFAF 110 billion [14]. However, it is possible to reduce these imports by replacing wheat semoliná with tubers (cassava, sweet potato), cereals (rice, fonio, millet), and/or legumes (cowpea). This substitution can also improve the nutritional value of pasta by reciprocal correction of their amino acid profiles, and their fiber content. Pasta lacks fiber and certain essential amino acids such as lysine and threonine, whereas legumes provide enough of these amino acids and are a good source of fiber [10] [15] [16]. Sweet potatoes offer a vitamin alternative due to their high content of vitamins A, B, and C [17]. According to Petitot *et al.* [10], one of the major challenges is to develop inexpensive foods that are both nutritionally sound and acceptable to the target consumers.

The incorporation of various cereals, tubers, and legumes in pasta formulations could therefore play a crucial role in improving their nutritional value. However, beyond their nutritional value, pasta products must also have desirable functional and sensory characteristics [17].

This is the context of this study, which consists of investigating the nutritional and sensory properties of wheat-based penne-type pasta, partially substituted by local cereals, tubers, and legumes.

2. Materials and Methods

2.1. Experimental Materials

The cowpea, fonio, and cassava flours were purchased from a local product processing unit in Dakar. For sweet potato, millet, and rice, the flours were obtained after processing at the Institute of Technology Alimentary in Dakar. The various flours obtained were graded using a 1 mm mesh sieve (Chopin).

2.2. Preparation of Penne-Type Pasta

Five formulations were produced. A control formulation with 100% durum wheat semolina, four other formulations with different incorporation rates of millet, rice, fonio, sweet potato, manioc, and cowpea PB = wheat pasta; PBRMN = wheat, rice, manioc, cowpea pasta; PBPN = wheat, sweet potato, cowpea pasta; PBFN = wheat, fonio, cowpea pasta; PBMPN = wheat, millet, sweet potato, cowpea pasta.

Two hundred and fifty grams of each formulation were mixed with 100 ml of water, kneaded, and then cold extruded using a commercial dough machine (Philipps HR2382/10). This stage was followed by cutting and drying the extrudates in a dehydrator at a temperature of 55˚C for 3 hours to obtain a moisture content of less than 12%.

2.3. Physical and Chemical Analysis

2.3.1. Moisture Content

The moisture content is determined according to the method described in AOAC (2018). The sample is oven dried (105˚C ± 2˚C) for 4 hours to constant weight. The weight loss is calculated as the moisture content of the sample.

2.3.2. Ash Content

The mineral matter or crude ash content is determined using the method described in AOAC (2018). This involves calcining the finely ground sample contained in a porcelain crucible on a hot plate. The sample is then incinerated in an oven at 550˚C for 4 hours until ash is obtained.

2.3.3. Protein Content

Protein content is determined using the Kjeldahl method described in AOAC (2018), the technique of which consists of measuring the nitrogen content of the product. The finely ground sample is mineralized under heat using concentrated sulphuric acid in the presence of a catalyst. After several transformation processes, the nitrogen yields ammonia, which is distilled, recovered in a boric acid solution and titrated with a sulphuric acid solution. The nitrogen content multiplied by a coefficient (6.25) gives the protein content.

2.3.4. Carbohydrates

The carbohydrate content of the feed is obtained by taking the difference between the dry extract and the sum (protein + fat + crude fiber and mineral matter).

$$\%\text{Carbohydrate} = \%\text{DE} - (\%\text{Protein} + \%\text{Fat} + \%\text{Fiber} + \%\text{Earth}) \quad (1)$$

where DE is dry extract.

2.3.5. Crude Fiber

Crude fiber content is determined using the method described in AOAC (2018). The finely ground sample is subjected to two acid and base hydrolyses followed by complexation with EDTA. The residue obtained is then filtered, dried in an oven at 130˚C, and then calcined in an oven at 400°C for 2 hours. The difference in weight between the two stages gives the crude fiber content.

2.3.6. Fat Content

Determination of the fat content involves freeing the lipids by extraction using an organic solvent (N hexane), followed by evaporation of the solvent, and weighing of the lipid extract after oven drying at 105˚C for 30 mn (AOAC, 2018).

2.3.7. Mineral Elements

Calcium, potassium, iron, and zinc were determined by Atomic Absorption Spectrophotometry using the method described in [1] AOAC (2018). After incineration of the samples and dissolution of the ash in hydrochloric acid, the concentrations of the various minerals in the samples are determined from calibration curves established with a range of standard solutions characteristic of each element.

2.3.8. Phosphorus Content

Phosphorus is determined in the form of phosphate by the UV-visible spectrophotometric method using the vanadate-molybdate reagent. Phosphorus is combined with ammonium molybdate to form a phosphomolybdic complex which, in the presence of ammonium metavanadate, gives an orange-yellow color. The absorbance of the latter is measured at a wavelength of 470 nm.

2.4. Sensory Test

A 9-point hedonic scale was used as the basis for our sensory analysis. Forty panelists evaluated sensory parameters such as taste, color, appearance, texture, and acceptability. The pasta was evaluated with and without a sauce. As pasta is rarely eaten on its own, a sensory analysis with an accompaniment (tomato sauce) was carried.

2.5. Statistical Analysis

Statistical analysis was performed using a Minitab data analysis package. A statistical evaluation of the differences observed was carried out using analysis of variance (ANOVA) at a significance level of $p \leq 0.05$.

3. Results

1) Composition of the penne

The results of the nutritional analyses carried out on the penne are presented in **Table 1**.

The results presented in **Table 1** are expressed as mean value ± standard deviation (SD) for at least four repetitions. Different letters a - e in the same columns represent statistically significant differences ($p < 0.05$).

PB = wheat penne; PBRMN = wheat, rice, cassava, cowpea penne; PBPN = wheat, sweet potato, cowpea penne/PBFN = wheat, fonio, cowpea penne; PBMPN = wheat, millet, sweet potato, cowpea penne.

The results presented in **Table 1** are expressed as mean value ± standard deviation (SD) for three replicates. Different letters in the same line represent statistically significant differences ($p < 0.05$). Ash levels obtained from the different pasta varieties ranged from 0.75% to 1.84%.

Control penne made with wheat semolina alone had the lowest ash content, while penne made with sweet potato, rice, cassava, fonio, cowpea, and wheat had the highest ash content. Significant differences were noted between penne made with PBMPN, PBFN, PBRMN, and PBPN composite flours and the PB controls.

Penne with low ash content tended to have the highest protein content. PB penne had the highest protein content at 13.26%. Among the mixed penne, the PBMPN pasta with the highest cowpea flour content (12.5%) had the highest protein content at 11.48%. In terms of fiber composition, penne made with composite flours had the highest fiber content. PBPN and PBMPN pasta contained twice as much fiber as the control pasta. The micronutrient content of penne incorporating fonio, sweet potato, millet, rice, manioc, and cowpea was higher than that of the wheat-based control penne. The potassium content of the PBPN pasta was four times higher than that of the control pasta.

2) Sensory analysis of penne

The results of this analysis are shown in Figure 1 and Figure 2.

The results of the sensory analysis of the unaccompanied penne revealed significant differences between the control sample and the penne made with composite flours ($p < 0.05$).

Table 1. Characterization of the different penne products.

Pâtes / Paramètres	PB	PBRN	PBPN	PBFN	PBMPN
Cendres	0.755 ± 0.01^{e}	1.345 ± 0.02^{b}	1.835 ± 0.01^{a}	1.044 ± 0.01^{d}	1.14 ± 0.08^{c}
Protéines %	13.260 ± 0.21^{a}	11.190 ± 0.55^{bc}	10.610 ± 0.06^{c}	11.440 ± 0.14^{b}	11.48 ± 0.30^{b}
Glucides %	78.335 ± 0.15^{b}	78.460 ± 0.93^{b}	77.550 ± 0.07^{cd}	79.480 ± 0.07^{a}	77.09 ± 0.39^{d}
Fibres %	0.890 ± 0.89^{a}	1.485 ± 0.02^{c}	1.800 ± 0.04^{d}	1.140 ± 0.14^{b}	1.84 ± 0.15^{e}
V.E (kcal/100g)	372.320 ± 0.76^{d}	365.350 ± 1.15^{c}	356.420 ± 0.38^{a}	366.290 ± 0.92^{c}	363.29 ± 0.74^{b}
Zn (mg/100g)	1.125 ± 0.04^{a}	1.305 ± 0.04^{b}	1.725 ± 0.01^{d}	1.630 ± 0.03^{c}	1.88 ± 0.01^{e}
Fe (mg/100g)	2.320 ± 0.01^{a}	2.780 ± 0.27^{b}	3.325 ± 0.08^{c}	3.015 ± 0.01^{bc}	2.99 ± 0.43^{b}
Ca (mg/100g)	14.125 ± 1.17^{a}	18.065 ± 0.35^{b}	18.165 ± 1.29^{b}	18.585 ± 0.18^{b}	19.06 ± 0.25^{c}
P (mg/100g)	160.095 ± 0.46^{b}	167.870 ± 0.20^{bc}	180.365 ± 0.11^{c}	153.690 ± 1.90^{ab}	213.52 ± 2.05^{d}
K (mg/100g)	132.68 ± 11.29^{a}	334.290 ± 6.39^{c}	505.225 ± 7.32^{e}	258.19 ± 0.29^{b}	351.73 ± 0.27^{d}

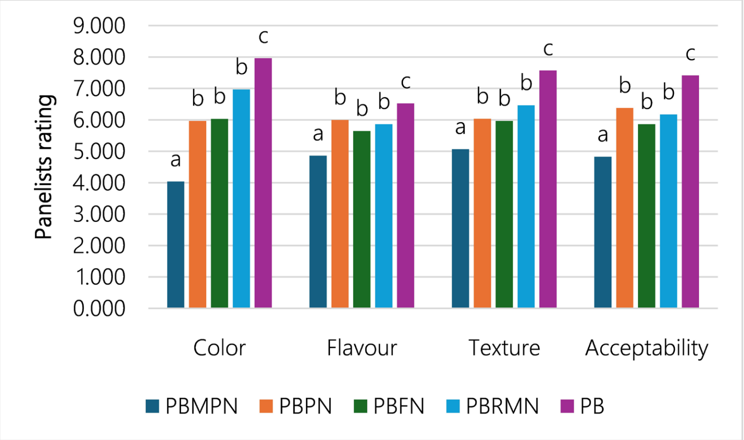

Figure 1. Sensory analysis of unaccompanied penne (the different letters indicate a statistical difference between the samples $p < 0.05$).

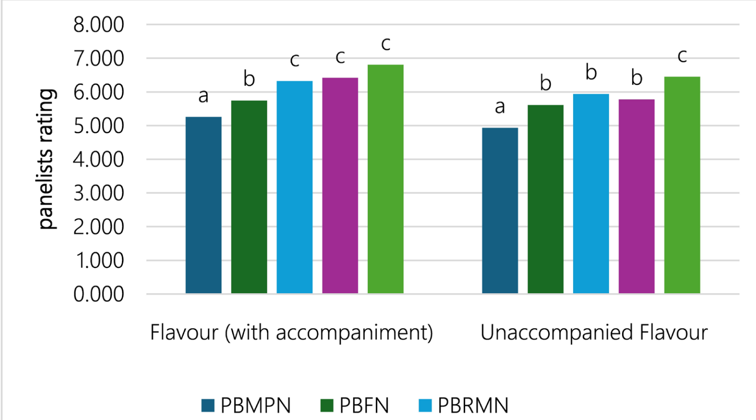

Figure 2. Sensory analysis of penne with accompaniments (the different letters indicate a statistical difference between the samples $p < 0.05$).

No significant differences were found by the panelists between the control penne (PB) the potato/cowpea-based penne (PBPN) and the cassava/rice/cowpea-based penne (PBRMN); however, there were significant differences between the control penne and the fonio-based penne (PBFN) and the millet-based penne (PBMPN).

4. Discussion

The incorporation of cereals, tubers, and legumes affects the composition and structure of penne. The significant differences in ash content show that the blends of composite flours have more mineral matter than the wheat-based control penne. However, work by ITCF [18] has shown that good quality wheat semolina should have an ash content of less than 1.1% (DM) for better clarity in penne. According to Feillet *et al.* [19], the extraction rate has an impact on the color of semolina, which is clearer and more attractive the lower the extraction rate. Wheat-based penne with a lower mineral content is therefore favored because of its positive effect on color.

The protein content of the control penne was higher than that of the other penne, which is consistent with the findings of Laleg *et al.* [20], who showed that penne without wheat semolina contained around 8% protein, whereas penne produced with wheat semolina contained 12 to 13% protein.

This could be explained by the fact that wheat semolina is enriched with protein [21]. On the other hand, the protein content of composite flours (around 11%) is still high enough to produce Penne of good functional quality, with an optimum range of 10.5% and 11% for standard pasta [22].

As far as fiber content is concerned, penne made with composite flours is richer than wheat-based penne. This could be due to the high fiber content of manioc (7 g), fonio (8 g), and sweet potato (17 g), which exceeds that of wheat semolina (3.6 g) [23] [24].

Increasing the rate of incorporation of cowpea flour helps to improve the fiber content of penne. Cowpea flour would also have beneficial effects on improving fiber content. Similar results have been obtained for lentils and broad beans [23].

Concerning micronutrients, penne made with composite flours recorded superior results compared with the control. The significant differences obtained in the composition of iron, zinc, phosphorus, calcium, and potassium could be explained by the incorporation of tubers and legumes. Our results are similar to those of Pinel *et al.* [25] who showed that legumes such as cowpea contain higher quantities of micronutrients than cereals. For potassium, the results obtained with sweet potato penne are 4 times higher than those obtained with wheat penne. Potassium is an important nutrient that the World Health Organization strongly recommends increasing dietary intake to lower blood pressure, reduce the risk of cardiovascular disease, and mitigate the negative effects of sodium consumption (WHO, 2013) [26]. Furthermore, according to the authors La Frano *et al.* [27], the composition of sweet potatoes is low in phytates and high in ascorbic acid, which has a positive impact on the bioavailability of micronutrients. This general finding on enrichment is consistent with that of Wang *et al.* [6] that mineral enrichment of pasta through the addition of functional ingredients is a very important step in providing complete nutrition to consumers.

Sensory analysis showed that panelists preferred wheat penne to penne made with composite flours. In fact, according to Vignola *et al.* [28], pasta enriched with functional ingredients is often reported as having a sensory quality inferior to that of traditional durum wheat pasta. Furthermore, Bustos *et al.* [29] have suggested that the level of substitution of functional ingredients should generally be less than 10% to minimize the impact on cooking quality and sensory acceptability. Furthermore, the wheat/sweet potato/cowpea blend had an acceptability index of over 70%, which is the minimum score for a food to be considered acceptable according to Spehar *et al.* [30]. This result differs from those of Shogren *et al.* (2006) [31] who, with a 50% substitution of wheat flour for soya flour, obtained an undesirable bean and bitter flavor and excessive cohesion.

However, it should be noted that penne made with the sweet potato/cowpea/wheat and rice/manioc/cowpea/wheat mixtures and tested with tomato sauce showed no significant difference compared with the control penne. According to Sun-Waterhouse *et al.* [17], for a functional food product to be commercially successful, its nutritional value and health-promoting functionality must be accompanied by desirable sensory characteristics.

5. Conclusion

This study has shown that the incorporation of cereals, tubers, and legumes improves the nutritional and sensory characteristics of penne, which is low in minerals and essential nutrients. Future studies should look at the cost and effectiveness of incorporating local products to reduce wheat imports.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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