Traditional process for making cowpea doughnuts: innovating to facilitate production and meet nutritional and sensory expectations

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Abstract :

The study focuses on the processing of cowpeas into Ata doughnuts in Benin, with the aim of improving the work of women processors. Traditionally, cowpeas are dehulled manually using water, a tedious and time-consuming step. Two innovative products have been developed using the dry method: partially dehulled cotyledons and flour made from these cotyledons. The use of these products, and in particular the flour, simplifies the doughnut-making process and reduces water consumption, but with higher material losses. Sensory tests and nutritional analyses show promising results, although adjustments are still needed, particularly to the alpha-galactoside content of the flour. These innovations are helping to improve processing methods and add value to local products, thereby supporting food security and the local economy.

Keywords : Benin, pulses, dehulling, flour, particle size, alpha-galactosides

1. Introduction

Cowpea (*Vigna unguiculata*) is a pulse widely produced and consumed in West Africa (Barimalaa and Okoroji, 2009). Rich in nutrients, cowpea is a significant source of protein, fibre, vitamins (especially B9) and essential minerals such magnesium and zinc (Akissoé et al., 2021). Its benefits for human health are significant, helping to meet recommended nutritional requirements (Jayathilake et al., 2018). However, the presence of alpha- galactosides in cowpea, indigestible molecules that cause bloating and flatulence, is an obstacle to its consumption (Mouquet-Rivier and Amiot, 2019).

The Ata doughnuts, a fried product made from seasoned dough, is one of the most commonly consumed cowpea-based foods in Benin and more widely in West Africa. This doughnuts is appreciated for its spongy texture, crispy crust and characteristic fresh cowpea flavour (Kethireddipalli et al., 2002) . Processing cowpeas into doughnuts is an important source of employment and income, particularly for women, thereby strengthening the economic situation of urban households (Ferré et al., 2019).

The traditional process for making Ata doughnuts involves several operations before frying. Firstly, the whole seeds are broken up into grits (crushed), then dehulled by hand using successive water washes to remove the hulls (black scars from the point of attachment of the seeds) and the husks adhering to the grits. Finally, the seeds are soaked before wet milling (McWatters et al., 1993) . Although these operations are essential to obtain the light-coloured dough that consumers appreciate, they are tedious and time-consuming, requiring labour and the handling of heavy loads (Barimalaa and Okoroji, 2009; Madodé, 2012; Singh et al., 2004) . Ready-to-use hulled seed flours are commercially available to facilitate production. However, these flours have inadequate technological properties, resulting in dry, hard doughnuts with a dense texture. These defects are mainly due to an inadequate particle size distribution of the flour, which is characterised as too fine, limiting the foaming and hydration capacity of the dough (Barimalaa and Okoroji, 2009; Singh et al., 2004).

The aim of this study was to assess the value two innovative products for reducing the arduous workload of doughnut processors: (i) partially mechanically dehulled cotyledons using a dry process, and (ii) flour made from these cotyledons. The processes used to obtain these products were characterised by assessing the production yield and particular attention was paid to the particle size of the flour produced. The impact of the use of innovative products on processing practices was assessed with women processors in Benin, in comparison with the use of grits in the traditional process. Sensory evaluation of the doughnuts was carried out to check that the proposed innovations produce doughnuts that meet consumer expectations. Finally, the evolution of the nutritional compounds during the different shelling processes, carried out according to the traditional process and the innovative processes, was characterised. In the context of agri-food development in developing countries, these innovations aim to improve the efficiency of processing and add value to local products, thereby contributing to food security and the creation of added value.

2. Materials and methods

2.1 Raw materials

The trials were carried out using a batch of cowpeas made up of 50% Atchawé Tola and 50% Nigeria, a mixture often used by women processors for the traditional preparation of doughnuts. These varieties were purchased in 2023 at a market in Cotonou (Benin). Before use, the batch was cleaned by hand to remove damaged seeds and stones. It was stored at the Faculty of Agricultural Sciences in Abomey-Calavi at room temperature, protected from light and humidity, for about a week.

2.2. Production of grits and innovative products

Trials were carried out in triplicate. Yields were determined by mass balance and expressed as a percentage on a dry basis. The grits and the two innovative products were stored at room temperature, protected from light and humidity before use, for a total of 3 months (2023).

2.2.1. Grits

The grits were obtained by fractioning the cowpea using a grinder (Taishi model 150, China). The axis of the grinder was set at a distance of 19 mm in order to obtain grits of a size comparable to those traditionally obtained by women processors.

2.2.2. Partially dehulled cotyledons

To process the cotyledons, the cowpeas were dehulled mechanically by abrasion using a wheel dehuller (Electra type DMS 500 'N', France). The same batch of seeds had to be machined twice in succession to remove as many hulls and hilums as possible, without too much impact on the machining yield. After hulling, the cotyledons mixed with the hulls and hilts were isolated by pneumatic separation using a cyclone separator integrated into the huller outlet.

2.2.3. Flour from partially dehulled cotyledons

The flour was obtained after dry milling of the cotyledons in a hammer mill (Electra type BABY "N", France). The mill feed rate was adjusted by opening the hopper door to 30%. A preliminary test was carried out to select the mill outlet grate in order to produce a flour with a particle size distribution close to that recommended in the literature (Vanchina et al., 2007) . Three grates made from perforated sheet metal with holes 1 mm, 2 mm and 3 mm in diameter were used to grind batches of 1 kg of partially dehulled cotyledons (one grind per outlet grate). The 2 mm grid was selected on the basis of the results of the particle size distribution (part 3.1) and used to produce the other two successive grindings. The particle size distribution of the flours was characterised on 100 g of flour using a sieve shaker (Retsch model AS 200, Germany) through a series of sieves (180 µm, 400 µm and 1000 µm) and a collection tray for 10 min. The measurement was carried out in duplicate.

2.3. Preparation of partially dehulled grits and cotyledons

The aim of preparing grits and partially dehulled cotyledons is to obtain fully dehulled products (absence of husks and hilums). Following the operating variables defined by Akissoé (2021)), three batches of grits and three batches of partially dehulled cotyledons were prepared under controlled conditions, with a quantity of 160 g of product per batch. Manual hulling was carried out in six washing cycles, each cycle involving manual trituration of the grits and cotyledons with a product/water ratio of 1:5. At the end of each cycle, the wash water was filtered through a sieve to recover the husks and hilum. This water was then used for subsequent cycles and discarded after the last cycle. Soaking was carried out at room temperature (around 30°C) for 30 min, with a product/water ratio of 1/4. After soaking, the products were drained in a colander for 5 min and the soaking water was removed.

2.4. Assessing the benefits of innovative products

2.4.1. Impact on processing practices

In order to identify the benefits of using partially dry-dehulled cotyledons to facilitate the manual dehulling operation, 5 women processors were given 1 kg of grits and 1 kg of cotyledons. The time required by each processor to manually dehulled the 1 kg of each product was quantified, as was the number of washing cycles required to eliminate all the husks and hilums suspended in the water.

2.4.2. Impact on consumer acceptability of doughnuts

The sensory quality of doughnuts made partially dehulled cotyledons and flour was compared with that of traditional doughnuts made from grits. To do this, these three products were given to different processors. Five processors prepared doughnuts from grits and partially dehulled cotyledons and 2 processors from flour. After production, each type of doughnut was subjected to a sensory evaluation by 60 consumers (naïve subjects) using a hedonic scale ranging from 1 to 7: 1 = very unpleasant, 4 = neither unpleasant nor pleasant, 7 = very pleasant. The tastings took place at doughnut production and sales sites in various districts of the city of Cotonou, with one doughnut per consumer offered a few minutes after frying. The conditions under which the doughnuts were made (preparation, formulation and cooking) were specific to each processor and were not controlled or standardised as part of the sensory analysis.

2.5. Nutritional characterisation

2.5.1. Preparation of samples

The grits (composition identical to the raw material) and partially dehulled cotyledons were ground using a knife mill (Retsch model GM 200, Germany). The fully dehulled products were freeze-dried in a freeze-dryer (Usifroid type SMH 15, France) before being ground. Freeze-drying was carried out at -15°C under a pressure of 2.6×10^{-2} mbar for 48 h. The samples were frozen beforehand at -30°C.

2.5.2. Analysis

Dry matter content was determined using the oven drying method to constant weight in accordance with ISO 24557. In practice, approximately 5 g of sample was dried at 130°C for 2 h. The measurement was carried out in triplicate. Protein content was determined in duplicate by the Kjeldahl method using a test sample of approximately 1 g. A factor of 6.25 was used to convert the nitrogen content into protein. The starch content was determined in duplicate on a test portion of approximately 0.5 g of sample by enzymatic assay using the method adapted from Holm et al. (1985) . The total dietary fibre content was determined gravimetrically using the AOAC 2017.16 method. This method is used to determine the high molecular weight fibre fraction (HMWDF) and the low molecular weight fibre fraction (LMWSDF). The determination was carried out on a test sample of approximately 0.5 and was performed once. Alpha-galactosides were determined in duplicate from a 0.8 mg sample using the method described by Akissoé et al. (2021)

2.6. Statistical processing

The levels of nutritional compounds and the sensory ratings obtained for the different types of doughnut were compared using a non-parametric Kolmogorov-Smirnov test. The significance level was set at $p \leqslant 0.05$. XLSTAT Version 2023.1.1 was used for statistical processing.

3. Results and discussion

3.1. Flour production: fine-tuning the milling process

Figure 1 shows the particle size distributions of the flours produced using different outlet grids. The different diameters of the holes (1 mm, 2 mm and 3 mm) determine the grain size of the flour: the smaller the diameter, the finer the flour. According to the literature, one of the key elements in producing sensorially acceptable Ata doughnuts (crispy crust and spongy crumb) from flour is the particle size distribution. The literature shows that using flour containing 65% (w/w) of particles in the size range [180 µm - 425 µm] and 35% (w/w) in the range [425 - 1000 µm] leads to the production of doughnuts with a sensory quality similar to traditional doughnuts (Vanchina et al., 2007) . Flour made with a perforated grid 2 mm holes has distribution closest to these recommendations: 25% (w/w) by mass of particles in the range [180 µm - 400 µm] and 38% (w/w) in the range [400 - 1000 µm]. However, the use of this grid is not optimal because the percentage of particles in the [180 µm - 400 µm] range remains low, with a significant proportion of particles smaller than 180 µm (31%). However, the flour produced with a 1 mm perforated grid has too high a proportion of fine particles (more than 50% smaller than 180 µm), while that produced with a 3 mm perforated grid contains too high a proportion of coarse particles.

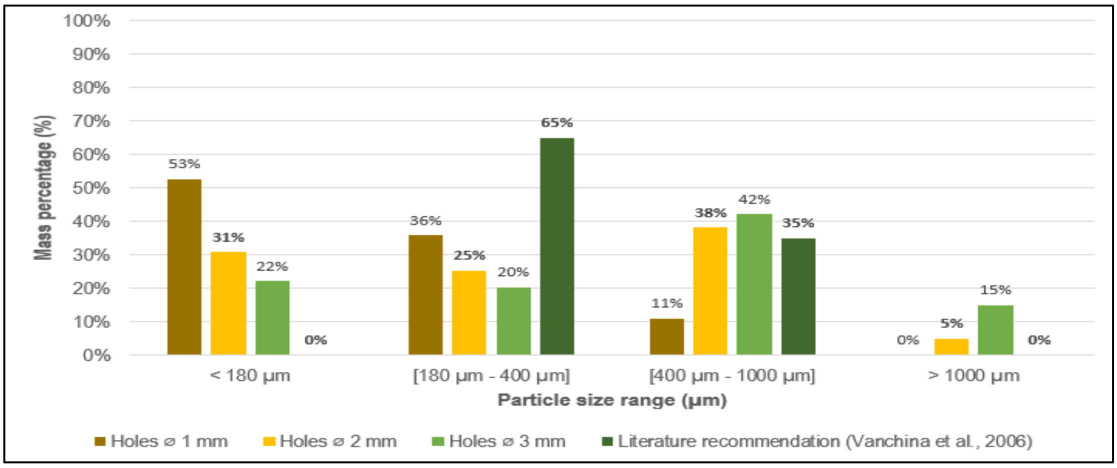

Figure1 : Particle size distributions of flours produced with different hammer mill outlet screens

This preliminary test led to the selection of a perforated outlet screen with 2 mm diameter holes for producing flour from partially dehulled cotyledons. This grate was the best compromise between literature recommendations and production performance. Milling with the hammer mill is a repeatable operation (Figure 2). Indeed, for batches of 1 kg of product and a 30% opening of the hopper door, the standard deviations calculated after three grindings (with the perforated grate with 2 mm diameter holes) are low, indicating a low dispersion of the results. The product feed rate to the mill, controlled by the hopper gate opening level, is a variable that influences the particle size distribution of flour (Balasubramanian et al., 2011; Goswami and Singh, 2003) and could therefore be used to vary this distribution.

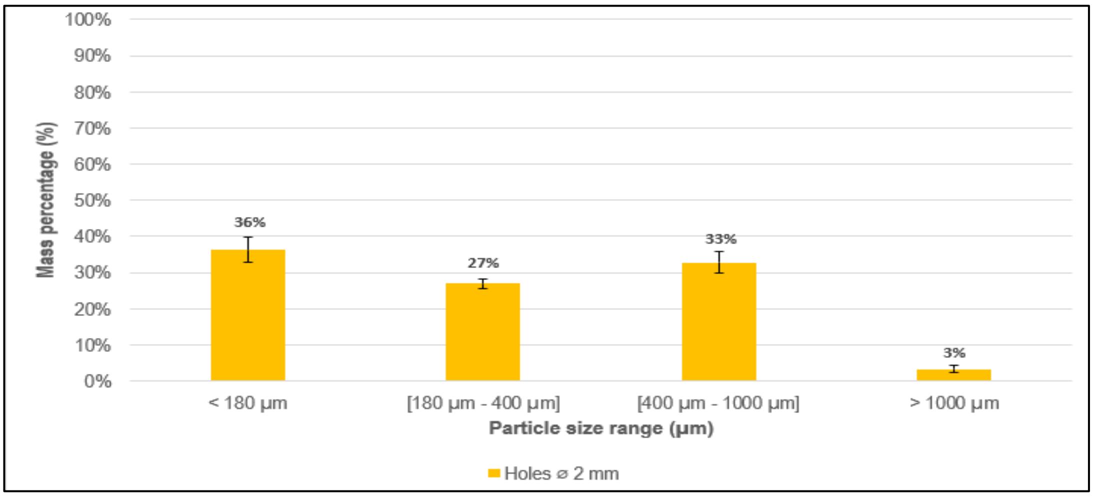

Figure2 : Repeatability of the shredding operation using a grate with 2 mm diameter holes

3.2. Transformation processes: successive unit operations and material yields

The manufacturing diagram shown in Figure 3 illustrates the sequence of unit operations for doughnut production using three processes: the traditional process (P1) referenced in the literature (Akissoé et al., 2021) , and the innovative processes developed in this study (P2 and P3). Yields, expressed as a percentage of dry matter, are also shown in this figure.

Processes P1 and P2 both involve the removal of husks and hilums by wet milling, soaking and draining before wet milling. However, processors who obtain partially dehulled cotyledons (processes P2 and P3) can avoid the fractionation stage, saving time and costs. With partially dehulled cotyledon flour (P3 process), the preliminary stages (fractionation, manual dehulling, soaking, draining, wet milling) are no longer necessary, allowing faster production of doughnut dough and easy adaptation of quantities according to demand. What's more, using ready-to-use flour also reduces water consumption, making the process more sustainable and less susceptible to microbiological risks.

However, the mechanical dehulling and milling used in processes P2 and P3 result in greater losses than the traditional process (process P1). Mechanical dehulling of cowpeas not only partially removes the husks and hilums, but also abrades part of the cotyledons, reducing production yield to 77%. Losses are also increased during dry milling to produce flour, with an estimated production yield of only 60%. However, this low yield should be put into perspective, and is partly explained by the fact that only small quantities of cowpea are milled. In fact, with each milling, a dead volume of product (machine losses) is generated, regardless of the initial quantity of cowpea. This milling yield will have to be reconsidered when flour is produced on a scale appropriate to the practices of the processors.

Even so, the greater loss of material during the production of innovative products will mean a higher purchase cost for processors compared with buying cowpeas. However, this additional cost could be offset by the advantages in terms of convenience, time saving and microbiological stability offered by the use of these products.

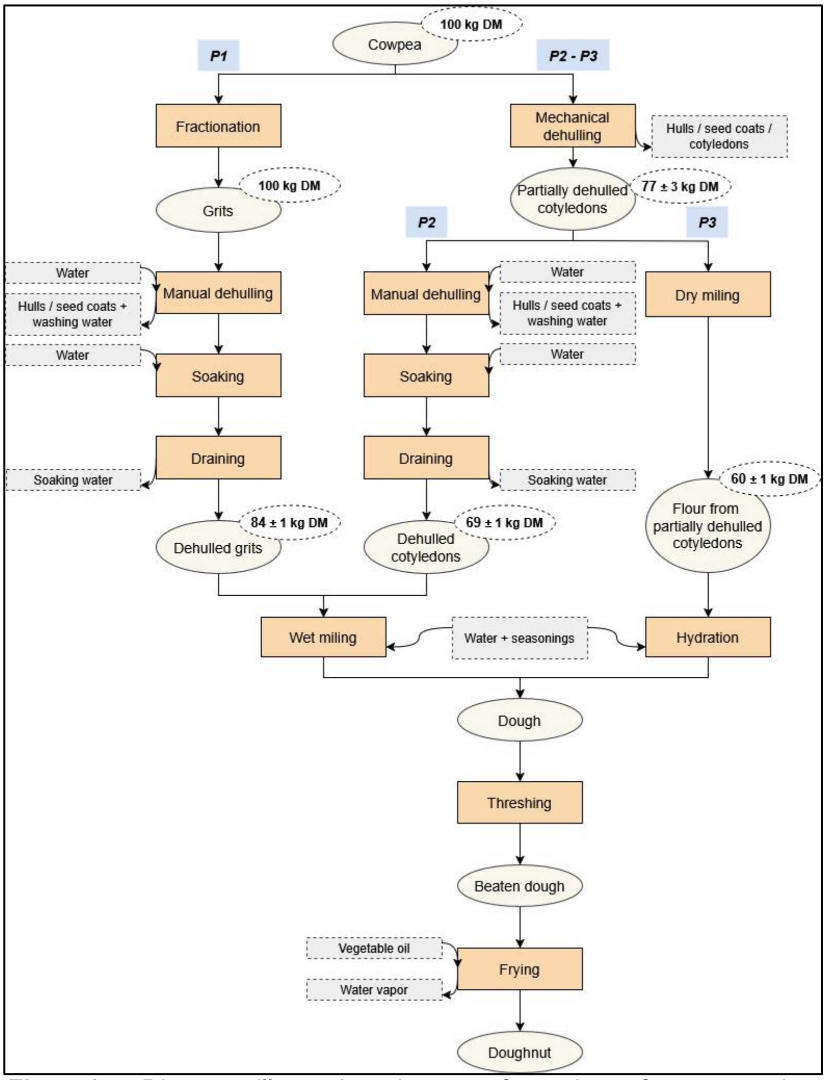

Figure3 : Diagram illustrating the transformation of cowpeas into doughnuts using three different production processes (P1, P2 and P3) and material yields.

DM: dry matter. **P1**: traditional process using grits. **P2**: innovative process using partially dehulled cotyledons. **P3**: innovative process using partially dehulled cotyledon flour. Rectangle with solid line: unit operation; rectangle with dotted line: inputs, outputs; circle with solid line: raw material, intermediate products, finished product; circle with dotted line: material yields expressed as a percentage on a dry basis (mean ± standard deviation; n = 3).

3.3. Nutritional composition: changes during manual shelling - soaking - draining operations

The dry matter, nutrient and alpha-galactoside contents of grits, partially dehulled cotyledons and their fully dehulled wet form are presented in Table 1. The nutritional composition of the grits is identical to that of the raw material because the fractionation operation not generate any loss of material (Figure 3). Similarly, the composition of the flour is identical to that of the partially dehulled cotyledons. The protein content is in line with the values reported by Madodé et al., (2012) , as is the starch content (Coffigniez et al., 2018) . With regard to alpha-galactosides, the measured content is comparable to the values determined by Sreerama et al. (2012) . The total fibre content is 36.8 g/100g bs, mainly high molecular weight fibre (HMWDF), highlighting the importance of cowpea in meeting recommended fibre intakes. However, the literature reports lower levels: 14.9 g/100g bs (Akissoé et al., 2021) and 14.5 g/100g bs (Eashwarage et al., 2017) . These differences can be explained by the quantification methods used (AOAC 985.29 and AOAC 991.42), which do not measure or only partially measure resistant starch and ethanol-soluble fibre (LMWSDF), unlike the method used in this study (AOAC 2017.16). For information, the resistant starch content of cowpea seeds is estimated at 13.4 g/100g bs according to Granito et al., (2005) .

Surprisingly, mechanical dehulling does not affect protein or alpha-galactoside content. Nor does it affect fibre content, although the husks are mainly made up of fibre (Jayathilake et al., 2018) . It would be relevant to analyse the composition of the gaps resulting from mechanical dehulling (mixture of husks, hilums and parts of abraded cotyledons) to clarify this point. The starch content is higher in partially dehulled cotyledons than in grits, a 'passive' increase also observed by Akinjayeju and Bisiriyu (2004) , who explain this by a relative reduction in protein and fibre.

After the stages of manual dehulling - soaking - draining before wet milling, the products have a reduced dry matter content as a result of water absorption. In the case of cotyledons, the dry matter content is higher than in the case of grits, due to their larger size, which reduces the exchange surface and therefore water absorption. An increase in protein and starch content was observed with grits, probably due to the removal of the husks during manual dehulling. An increase in starch was also observed in dehulled cotyledons, while their protein content remained unchanged. This result requires further investigation to be better understood. Total fibre content does not seem to be affected by the dehulling generated by these stages, despite the total removal of husks and hilums. Alpha-galactosides decrease in products before milling due to their diffusion in water during soaking and to enzymatic degradation. Khattab and Arntfield (2009)observed a similar phenomenon when soaking two varieties of cowpea, with a reduction of up to 40% in the initial alpha-galactoside content after 18 hours of soaking. These preliminary results confirm that the use of partially mechanically dehulled cotyledons (P2 process) does not adversely affect the initial nutritional potential of cowpeas compared with the traditional P1 process. However, further analysis and research are needed to better understand the mechanisms underlying the observed variations in nutrient content.

Flour made from partially dehulled cotyledons (Figure 3 - process P3) contains the same alpha-galactoside content as partially dehulled cotyledons. To reduce this content, it would be beneficial to offer processors a flour made from soaked cotyledons dried after being mechanically dehulled. However, the addition of soaking and especially drying operations would lead to a more expensive processing route, making it more difficult for processors to adopt.

Table1 : Nutritional composition of grits, partially dehulled cotyledons and fully dehulled cotyledons

Processes		*Traditional process with the use of grits*		*Innovative process using partially dehulled cotyledons*	
Products		Grits *	dehulled grits (n=3)	Cotyledons partially dehulled ** (not all cotyledons are dehulled)	Dehulled cotyledons (n=3)
Dry matter (g/100g)		93,0	51.3 ± 1.6 ^{a}	93,3	57.4 ± 1.9 ^{b}
Proteins (g/100g db)		21,6	24.2± 1.3 ^{a}	20,6	20.7± 0.6 ^{b}
Starch (g/100g db)		46,1	54,7 ± 1,8 ^{a}	51,4	53,5 ± 2,3 ^{a}
Fibers (g/100g db)	**HMWDF**	28,5	30,8 ± 1,7 ^{a}	29,0	29.5± 1.4 ^{a}
	LMWSDF	8,2	7.1± 1.0 ^{a}	8,4	7.5± 0.2 ^{a}
	Total	36,8	37.9± 0.9 ^{a}	37,4	37.0± 1.5 ^{a}
Alpha-galactosides (g/100g db) ***		4,6	3,9 ± 0,1 ^{a}	4,5	3,6 ± 0,3 ^{a}

n: number of batches prepared; **db**: dry basis; **HMWDF :** High Molecular Weight Dietary Fiber; **LMWSDF:** Lower Molecular Weight Soluble Dietary Fiber; **Total:** HMWDF + LMWSDF.
*: nutritional composition identical to that of the raw material. **: Nutritional composition identical to that of partially dehulled cotyledon flour (P3 process). ***: Sum of raffinose, stachyose and verbascose contents.
Results are mean ± standard deviation (inter-sample variability). Values in the same row with different superscript letters are significantly different ($p \leqslant 0.05$, non-parametric Kolmogorov-Smirnov test).

3.4. Use of innovative products: impact on processing and sensory appreciation of doughnuts

The use of partially mechanically dehulled cotyledons in the dry process offers several advantages to processors: reduction in time required to remove husks and hilums during manual dehulling before milling (4 minutes per kg processed) and in the number of washing cycles required for this (3 per kg processed) (Table 2). This efficiency can be explained by the mechanical dehulling operation, which eliminates a significant proportion of cowpea husks and hilums. These results show that processors are interested in using partially dehulled cotyledons for the preparation of doughnuts. Although they do not completely eliminate the husks and hilums, they facilitate this stage, saving time for other lucrative activities and reducing the handling of heavy loads (basins filled with water and products), thus improving working conditions and reducing physical fatigue. This is particularly advantageous on busy production days, when some processors can handle up to 15 kg of cowpeas (personal communication from processors, October 2023).

Analysis of the sensory ratings shows that the use of the innovative products developed does not affect the acceptability of the doughnuts to consumers. Doughnuts made from grits (P1 process), partially dehulled cotyledons (P2 process) and partially dehulled cotyledon flour (P3 process) obtained mean scores of 6.6, 6.7 and 6.4 respectively ($p \geqslant 0.05$, non-parametric Kolmogorov-Smirnov test). As for the flour, despite a particle size distribution different from that recommended in the literature, consumers liked these doughnuts as much as the traditional version.

Table2 : Comparison of dehulling times and number of washing cycles between traditional (P1) and innovative (P2) processes.

	Transformer	*Traditional process using grits*	*Innovative process using partially dehulled cotyledons*	**Difference * (%)**
Manual dehulling time (min/kg)	T1	33	22	**11**
	T2	12	10	**2**
	T3	9	9	**0**
	T4	8	2	**6**
	T5	12	12	**0**
			Average spread (min/kg)	**4**
Wash cycle (number/kg)	T1	9	5	**4**
	T2	10	8	**2**
	T3	10	7	**3**
	T4	7	4	**3**
	T5	9	7	**2**
			Average spread (number/kg)	**3**

* Difference = P1 value - P2 value.

4. Conclusion

In this study, several alternatives to the traditional Ata doughnut-making process were explored, revealing promising opportunities for processors. This highlighted the potential for improving the working conditions of processors, taking into account nutritional and sensory aspects. The use of partially mechanically dehulled cotyledons in the dry process and the flour produced from milling these cotyledons offer advantages in terms of practicality and shorter working hours. However, these innovations lead to greater losses of material, which can have an impact on the purchase cost for processors. As far as nutrition is concerned, mechanical dehulling causes only minor variations. On the other hand, the manual dehulling, soaking and draining operations required for partially dehulled cotyledons, as with the traditional process, lead to a reduction in alpha-galactoside content. This does not happen with flour, which is a disadvantage and opens up avenues for future research. Sensory analysis reveals that the use of innovative products does not affect the acceptability of doughnuts to consumers, which underlines the potential of these innovations to meet market expectations.

Ethics

The authors declare that the experiments were carried out in compliance with the applicable national regulations.

Declaration on the availability of data and models

The data supporting the results presented in this article are available on request from the author of the article.

Declaration on Generative Artificial Intelligence and Artificial Intelligence Assisted Technologies in the Drafting Process.

The authors have used artificial intelligence-assisted technologies to translate from French to English.

Declaration of interest

The authors declare that they do not work for, advise, own shares in, or receive funds from any organisation that could benefit from this article, and declare no affiliation other than those listed at the beginning of the article.

Authors' contributions

Yvanez F.: Conceptualisation, Formal analysis, Investigation, Methodology, Supervision, Visualisation, Writing - original version, Writing - revision and editing. Madodé Y.E.: Conceptualisation, Methodology, Resources, Writing - revision and editing. Ezin R.: Conceptualisation, Investigation, Methodology, Writing - revision and editing. Mouquet-Rivier C.: Conceptualisation, Methodology, Resources, Writing - revision and editing. Rivier M.: Conceptualisation, Methodology, Writing - revision and editing. Delpech C.: Investigation. Chapron M.: Investigation. Grondin G.: Investigation. Arnaud E.: Conceptualisation, Methodology, Resources, Writing - revision and editing.

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