Effect of cocoa bean shells granulometries on qualitative properties of gluten-free bread during storage

Effect of cocoa bean shells granulometries on qualitative properties of gluten-free bread during storage

Massimiliano Rinaldi[a], Paola Littardi[a]*, Maria Paciulli[a], Augusta Caligiani[a], Emma Chiavaro[a]*

[a] Dipartimento di Scienze degli Alimenti, Università degli Studi di Parma, Parco Area delle Scienze 47/A, 43124 Parma, Italy

Corresponding authors:

* phone: +39 (0521) 905846 fax: +39 (0521) 906028 e-mail: paola.littardi@unipr.it

* phone: +39 (0521) 905888 fax: +39 (0521) 906028 e-mail: emma.chiavaro@unipr.it

Abstract

Cocoa bean shells (CBS) are by-products of cocoa processing. Their rich chemical composition makes them interesting ingredients to improve the overall quality of gluten free bread. The addition of different dimensional fractions (F1, 1.00-1.99 mm; F2, 0.50-0.99 mm; F3, 0.355-0.49 mm) of CBS to gluten-free bread was investigated in terms of volume, moisture content, crumb grain, texture and colour during 3 days of storage. No significant differences in moisture content were observed among fractions, but protein, fat and fibre content resulted influenced by the dimensional range. With reference to water absorption indexes, F2 showed the highest water binding capacity (WBC) and water holding capacity (WHC), having instead the lowest water solubility index (WSI), in comparison to the other fractions, and confirming a good retention of the fibres' structure. Results on bread showed that CBS addition modified crumb grain leading to a lower specific volume, especially for F2. The presence of CBS accelerated significantly the crumb staling process in comparison to the control, resulting however F1 softer than control at the end of the storage period. Finally, colour was improved by the presence of CBS becoming darker, with F3 showing the highest impact on *L** and *a**.

Keywords: cocoa by-products, celiac disease, shelf-life, water absorption, structure, colour

Introduction

World cocoa beans (*Theobroma cacao* L.) production results of 5.2 Mtons in 2018 [1] with Côte d'Ivoire (2.0 Mtons), Ghana (0.9 Mtons), Indonesia (0.7 Mtons), Nigeria (0.3 MTons), Ecuador (0.3 Mtons), Cameroon (0.3 Mtons) and Brazil (0.2 Mtons) as the main producers. Cocoa bean shells (CBS) are the outer portions of beans that encase the nibs and, since they represent 12-20% of the cocoa seed, they result as a by-product produced in great quantity. Chemical composition of CBS is very interesting as protein content ranges from 11 to 18 g/100g dm, fat content from 2 to 21 g/100g dm, fibre content from 43 to 60.5 g/100g dm and polyphenols from 1 to 5.8 g/100g dm [2-4]. Several efforts were spent in valorising this waste material, starting from the use in animal feed with the limit of theobromine content (2–3%) [5] to the use for the production of extracts rich in fibres, polyphenols, antioxidants and pectins [6-9]. In addition, in the last years several studies on application of CBS fibre as a functional ingredient in food products were published. Martínez-Cervera et al. [10] used soluble cocoa dietary fibre as a fat replacer in chocolate muffins with some advantages such as higher moisture, more tender and crumbly structure and a reduction of hardening during storage. Similarly, Collar et al. [11] investigated the effects of soluble dietary fibre from cocoa shell wheat bread and suggested that dietary fibres from cocoa shell added up to 6% could be used to design technologically feasible, sensory acceptable, and long-term stored fibre-enriched wheat bread. In the same way, Grillo et al. [12] obtained dietary fibre powder from CBS and substituted oat and whole wheat with no significant differences between CBS powder and other fibres during organoleptic test. Recently, Jozinović et al. [13] successfully enriched extruded snacks with cocoa husks and reported a proportional increase in resistant starch, polyphenol content and antioxidant activity with the addition of cocoa husks, while starch damage slightly decreased. A similar approach was followed by Rojo-Poveda et al. [14] who successfully obtained new functional beverages with potential health benefits.

Kreibich et al. [15] described CBS structure from a microscopical point of view and observed thick-walled protective cells providing somewhat rigid and flexible support properties. Interestingly, authors established that the shell has different layers and vascular bundles distributed among the tissues: the first tissue (epidermis) layer is comprised of long cells (smaller sizes) with thick walls and the second of long flattened parenchyma cells, closely surrounding the vascular bundles. It is possible to visualize different formats (spiral – tracheid), sizes and numbers of vascular tissues (protoxylem and phloem) for water and nutrient transportation. Starting from this morphological characteristic, a technological approach, similar to what reported by de Sousa et al. [16], could be applied for separating CBS into different granulometric fractions that potentially had different profiles in chemical composition and technological properties, as consequence. Rojo-Poveda et al. [14]

demonstrated that the extraction of polyphenols for obtaining a functional beverage from CBS was directly influenced by the grinding degrees when using percolation techniques, whereas the maceration technique showed no dependence on the particle size. The present paper represents the first attempt to use sieving of CBS as a preliminary method for modifying functional properties of this kind of industrial waste. Thus, the aim of this work was to evaluate the effects of the addition of different CBS granulometries on physico-chemical properties of a commercial gluten-free bread formulation during 3 days of shelf-life.

Materials and Methods

Samples, breadmaking and storage

A commercial (NT FOOD S.p.A., Altopascio, Lucca, Italy) gluten-free bread mixture with the following ingredients was used: corn, rice cream soup, tapioca starch, sugar, vegetable fibres, salt, thickening agents: guar flour and hydroxypropylmethylcellulose, flavourings. The proximate composition of the mixture was: moisture 9.7g/100g, carbohydrate 85.7g/100g, fibres 1.9g/100g, protein 1.8g/100g, fat 0.9g/100g, salt 1.9g/100g. Ground CBS were kindly donated by the company Ferri dal 1905, Castel Goffredo (MN), Italy.

To obtain the different particle sizes of CBS, it was classified in sieves with opening sizes 2.00 mm, 1.00 mm, 0.50 mm and 0.355 mm, respectively with an automatic sieve (Giuliani Tecnologie, Torino, Italy). The obtained fractions were named F1 (1.00 to 1.99 mm), F2 (0.50 to 0.99 mm) and F3 (0.355 to 0.49 mm).

Bread samples were prepared with the following recipe: gluten free mixture (250.0 g), water (225.0 g), sunflower oil (12.5 g), compressed yeast (6.25 g) (control, C). CBS from F1, F2 and F3 fractions were then added by substituting the mixture at 4 g/100g in order to achieve a total final fibre content equal to 3 g/100g for the claim “source of fibre” [17]. The amount of water was determined on the basis of preliminary tests until obtaining a workable dough for all the formulations. The same amount of water was added to all the recipes in order to evaluate the unique effect of the different CBS added fractions.

A domestic bread machine (Moulinex, Groupe Seb Italia S.p.A., Milano, Italy) was used for breadmaking, with the rapid program: stirring + kneading + rising, 80 min; baking, 55min at 210 °C, obtaining sandwich bread loaves with mean weight of about 400 g. Cooking losses after baking were measured and ranged from 22.1 ± 1.2 g/100g for C and F1 samples to about 24.5 ± 1.3 g/100g for F2 and F3 breads. The cooked breads were cooled at room temperature, packaged in alcohol-sprayed sealed air-tight plastic bags and stored in a 25 °C temperature-controlled chamber in the dark (ISCO 9000, Milan, Italy). Samples were analysed at 0, 1 and 3 days of shelf life. Three loaves were used for the characterization of the breads at each storage time analysing 9 loaves for each bread type.

Proximate composition and water absorption tests of flour and CBS

Moisture, protein, lipid and ash of cocoa bean shell fractions were determined using standard procedures [18]. Moisture was determined in oven at 105 °C for 24 h. Crude fat content was determined using an automatized Soxhlet extractor (SER 148/3 VELP SCIENTIFICA, Usmate Velate, Italy) using diethylether. Total ash was determined after mineralization at 550 °C for 5 h + 5 h. Total nitrogen was determined with a Kjeldahl system (DKL heating digestor and UDK 139 semiautomatic distillation unit, VELP SCIENTIFICA).

Water absorption tests on CBS fractions were determined as described by Sarangapani et al. [19], as average of three replicates. Water binding capacity (WBC) and water holding capacity (WHC) were expressed as grams of water retained per gram of solid. Water absorption index (WAI) and water solubility index (WSI) were expressed as grams of gel per grams of sample (db) and grams of dried supernatant per grams of sample (db), respectively.

Physical analyses

Specific volume of breads was determined in triplicate according to the AACC Approved Method 10-05.01 [20] and expressed as the volume/weight ratio of cooked bread (mL/g).

Crumb grain was evaluated by means of a digital image analysis system, as reported previously [21]. Images of three central slices (20 mm thickness) of each loaf were acquired with a scanner (Hewlett Packard, Palo Alto, CA, USA) at 600 dots per inch (dpi) taking squares (40x40 mm) from the centre of the images after calibration, standardization and optimization by means of Image-Pro Plus 4.5 (Media Cybernetics Inc., USA) software. The number of pores (expressed as percentage of the total number) was obtained according to pre-selected dimensional classes based on their area. Selected classes were: class-1: 0.01-0.099 mm^2; class-2: 0.1-0.199 mm^2; class.3: 0.2-0.99 mm^2; class-4: > 1 mm^2.

The crumb moisture content (g/100g) within the bread loaves was evaluated in triplicate at each shelf-life time for each bread type following the AACC standard method, 44-15.02 [20].

Texture analysis was performed on crust and crumb using a TA.XT2 Texture Analyzer equipped with a 25 kg load cell (Stable Micro Systems, Godalming, UK) and Texture Expert for Windows software (version1.22) for data analysis on each loaf. Crust hardness was measured by means of a puncture test using a 3 mm diameter stainless steel probe and a test speed of 2 mm/s. Maximum peak force (N) was measured from the penetration curve and taken as crust hardness. Measurements were taken on five preselected points of the crust.

Crumb evaluation was carried out on ten cubes of 20×20×20 mm extracted from two central slices of the samples. A TPA test was performed with a 35 mm diameter cylindrical aluminium probe by means of a double compression with a speed of 2mm/s up to the 40% of the original sample height. The textural parameters considered were hardness (maximum peak force of the first compression cycle, N), cohesiveness (ratio of positive force area during the second compression to that during the first compression area, dimensionless), resilience (area during the withdrawal of the penetration, divided by the area of the first penetration, dimensionless), and chewiness (product of hardness x cohesiveness x springiness, N) [22].

Colour was determined on ten pre-selected locations of the crust and crumb of each bread loaf. The analyses were performed using a Minolta Colorimeter (CM 2600d, Minolta Co., Osaka, Japan) equipped with a standard illuminant D65 and a 10° position of the standard observer. The instrument was calibrated before each analysis with white and black standard tiles. L^* (lightness), a^* (redness) and b^* (yellowness) were quantified on each sample using the Spectramagic software (Ver. 3.6).

Statistical analysis

Means and standard deviations calculated with SPSS (Version 25.0, SPSS Inc., Chicago, USA) statistical software were used to perform one way (ANOVA) to evaluate the effect of CBS addition at a significance level of 0.05 (p <0.05). A Tukey-Kramer post-hoc test at a 95% confidence level was also applied using the same software to verify the differences among groups.

Results and Discussion

Chemical and technological analyses of CBS fractions

Moisture content of CBS (Table 1) was in the range 4.79-5.01 g/100 g with no significant differences among the considered fractions. Observed moisture content was quite lower compared to those reported by Martínez et al. [2] but the composition of CBS is reported to be quite variable and it depends, among other factors, on its origin and mainly on the process to which it has been subjected. The highest ash content (Table 1) was observed for F3 while the lowest for F2 with F1 as intermediate value: in general, obtained data are in the range previously reported for this cocoa co-product [2]. Regarding protein content, no differences were observed between F2 and F3 while F1 presented a significantly lower value. Obtained data are in the range already published in the scientific literature [3]. Moreover, the fat content resulted significantly different among the three CBS size classes, being the lowest for F1 and the highest for F3, as also reported by other authors [3].

Finally, fibre content of F1 resulted the highest one with no differences between F2 and F3; the observed results confirm the feasibility of fibre enrichment by means of grinding and sieving [23]. Starting with the work of Knuckles et al. [24] separation of different fractions with different chemical composition and technological properties, as consequence, was successfully achieved for cocoa bean shell.

Hydration properties of the fractions are reported in Table 1. WBC and WHC data presented a similar trend with the highest values for F2 probably due to the higher fibre structure retention as WHC and WBC are strictly related to them [25]. The same authors, working on coffee by-products, reported also an inverse relation with the granulometry of the material but in the present work, this relationship was not observed. Technological functionality was in the range published by Lecumberri et al. [26] for cocoa shell and according to their observations, it could be confirmed that all fractions presented only few amounts of soluble fibres.

WAI and WSI can be used to indicate the behaviour of the starches contained in the three fractions [19]: F1 gave the highest values while on the contrary F3 the lowest ones. Low WAI values are generally linked to high level of starch damage and interactions with non-starch components and cell wall matrices [19, 27]. Actually, F3 samples represent the littlest fraction with probably the highest impact of grinding on structure but with the highest content of starch that was subjected to damages during the whole process of cocoa beans. This hypothesis is confirmed by the high WSI value of F3 fraction probably due to the depolymerization of starch, which leads to the production of low molecular weight fragments of amylose and amylopectin [19]. Thus, the decrease in the values of water interaction indexes could be explained by the fact that some of the molecules of the solubilized material, in particular amylose molecules, may interact each other generating a modified structure that impedes water absorption [28] .

Crumb grain characteristics and specific bulk volume of bread

Specific volumes of tested breads are reported in Figure 1: at time 0 significant differences were observed among the cocoa bean shell fractions. Particularly, F2 presented a significantly lower value compared to F1 and F3 probably due to its high WHC and WBC values (Table 1) that are generally related to low volume in bread [29]. Moreover, F2 samples presented both a higher cooking loss (24.8 ±0.6 %) and a higher percentage of holes belonging to the greatest class (Figure 2) compared to the other samples. Results are in agreement with Coda et al. [30] that reported a volume variation depending on wheat bran particle size. Similarly, Gómez et al. [31], studying the effect of fibre size on the quality of fibre-enriched cakes, reported a relation between specific volume, regardless the origin of fibres, and dimensions of them. During storage, specific volume of C samples remained constant with no significant variations. Otherwise, all CBS-enriched breads presented a significant volume reduction (Figure 1), also showing a significant increase in the percentage of holes belonging to the greatest class and a decrease in the lowest one, as consequence, with a significant variation in the total number of holes only for F1 samples (data not shown). During storage F1, F2 and F3 breads showed a little weight loss (data not shown) ranging from 1 to 2 % that, together with water migration from crumb to crust, could have caused the reduction of wall thickness and the increase of holes' dimensions, as consequence. On the contrary, C samples did not show any weight loss during storage.

The presence of fibres contained in cocoa bean shells caused a significant reduction of total number of holes (about 350 holes/16cm^2) compared to C samples (about 600 holes/16cm^2) with a higher presence of holes with large dimensions (Figure 2). Bigger holes are more sensible to collapse and this fact could explain the volume reduction observed for F1, F2 and F3 samples (Figure 1). Probably, cocoa shell fibres interfered with thickening agents (guar flour and hydroxypropylmethylcellulose) of the gluten free mixture used for the preparation of breads as a competitor for water when water is limited [32].

Crumb moisture content (Figure 3) of enriched samples were significantly lower than C ones at all storage times confirming the higher evaporation caused by a coarser crumb grain characteristic observed for F1, F2 and F3 samples (Figure 2). As stated above, weight loss after cooking was significantly higher for F2 and F3 samples while no statistical differences were observed for others. During storage, no samples showed significant difference in crumb water content thanks to packaging and to the short-term shelf life.

Crust colorimetric data (Table 2) showed significant differences due to the addition of cocoa bean shell. Particularly, crust L* values increased and a* decreased thanks to the cocoa bean fibre probably due to the lower moisture content (Figure 3) that generally leads to lighter bread crust [33]. On the contrary, the impact of cocoa bean shell on bread crumb colour was evident: addition of CBS caused a significant reduction of L* and simultaneously a significant increase of a* and b* (Table 2) with darker crumb in accordance with Kārkliņa et al. [34], due to the natural colour of cocoa bean shells. F3 showed the greatest impact on L* and a* values probably due to the very low dimensions of particles. In general, colorimetric changes caused by cocoa bean shells' addition can be positively considered as gluten free breads are generally reported to present pale colour that is not attractive for consumers [35].

Bread crumb and crust hardness (Table 3) at time 0 days were not significantly affected by cocoa bean shell addition. During storage, F2 samples showed the highest hardness increase at time 3 with a value two folds higher compared to the control. This could be due to the presence of largest holes that generally tend to collapse (Figure 3) and to the high WHC value (Table 1) of this fraction with a probably strong competition for water with starches and thickening agents [36]. On the contrary, F1 gave the lowest hardness value at time 3 with significant lower values also compared to C, demonstrating an antistaling effect probably due to the high WAI value (Table 1) of this fraction related to a high water retention capacity which could help to prevent the retrogradation of amylopectin [37]. Cohesiveness (Table 3) decreased for all samples with increasing storage time, as expected [38]. All samples added with cocoa bean shell fractions exhibited lower values at day 1 compared to C in accordance with Rocha Parra et al. [39] probably in relation with crumb moisture content that resulted lower in F samples.

Regarding resilience data at time 0 (Table 3), F2 bread showed a significantly lowest value compared to the others probably due to the lowest volume and to the presence of a highest percentage of holes belonging to the greatest class. Characteristics of F2 breads could be probably related to water hydration properties of this CBS fraction. In general, CBS enriched breads presented significantly lowest resilience values compared to C at all times probably due to the lowest total number of holes per area and to the highest presence of holes with great dimensions. Collar et al. [11] already reported significant reduction of resilience in breads with soluble dietary fiber preparations obtained from cocoa shell.

Finally, chewiness values of C samples were in almost all cases significantly higher compared to the enriched ones: chewiness is a secondary texture parameter that is associated with difficulty in chewing the sample and forming a bolus before swallowing. These results could be related to the greater moisture retained by C samples (Figure 3), making them denser to chew [10].

Conclusions

This study attempted to evaluate the effect of the addition of three different dimensional fractions from cocoa bean shells on gluten free bread during 3 days of storage. Different proximate composition and water absorption properties observed for the different fractions of cocoa bean shell were reflected also in bread characteristics. The fibre deriving from CBS fractions, probably, negatively influenced the crumb grain, with coarser structure, as well as specific volume and moisture content, with significantly lower values. On the other hand, the CBS supplementation led to a pleasant darker colour, with F3 showing the more consistent improvement. Moreover, textural attributes (hardness) confirmed the possibility to add CBS F1 fraction with limited impact on product quality also during storage.

Overall, it was evidenced that cocoa bean shell fractions represent a promising functional ingredient for the development of improved gluten free bread formulations. Nevertheless, further studies would be necessary to improve the characteristics of final product also evaluating sensorial attributes as well as water dynamic during shelf life.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Compliance with ethics requirements This article does not contain any studies with human or animal subjects.

References

1. Faostat, 2018. Food and Agriculture Organization of the United Nations. (accessed 12/05/2020) http://www.fao.org/faostat/en/#data/QC
2. Martínez R, Torres P, Meneses MA, Figueroa JG, Pérez-Álvarez JA, Viuda-Martos M (2012) Chemical, technological and in vitro antioxidant properties of cocoa (*Theobroma cacao* L.) co-products. Food Res Int 49:39-45
3. Okiyama DC, Navarro SL, Rodrigues CE (2017) Cocoa shell and its compounds: Applications in the food industry. Trends Food Sci Technol 63:103-112
4. Okiyama DC, Soares ID, Cuevas MS, Crevelin EJ, Moraes LA, Melo MP, Rodrigues CE (2018) Pressurized liquid extraction of flavanols and alkaloids from cocoa bean shell using ethanol as solvent. Food Res Int 114:20-29
5. Panak Balentić J, Ačkar Đ, Jokić S, Jozinović A, Babić J, Miličević B, Šubarí D, Pavlović N (2018) Cocoa Shell: A By-Product with Great Potential for Wide Application. Molecules 23: 1404
6. Arlorio M, Coisson JD, Restani P, Martelli A (2001) Characterization of pectins and some secondary compounds from theobroma cacao hulls. J Food Sci 66:653-656
7. Barbosa-Pereira L, Guglielmetti A, Zeppa G (2018) Pulsed electric field assisted extraction of bioactive compounds from cocoa bean shell and coffee silverskin. Food Bioproc Tech 11:818-835

8. Hernández-Hernández C, Viera-Alcaide I, Sillero AMM, Fernández-Bolaños J, Rodríguez-Gutiérrez G (2018) Bioactive compounds in Mexican genotypes of cocoa cotyledon and husk. Food Chem 240:831-839
9. Mazzutti S, Goncalves Rodrigues LG, Mezzomo N, Venturi V, Ferreira SRS (2018) Integrated green-based processes using supercritical CO_2 and pressurized ethanol applied to recover antioxidant compounds from cocoa (*Theobroma cacao*) bean hulls. J Supercrit Fluids 135:52-59
10. Martínez-Cervera S, Salvador A, Muguerza B, Moulay L, Fiszman SM (2011) Cocoa fibre and its application as a fat replacer in chocolate muffins. LWT-Food Sci Technol, 44:729-736
11. Collar C, Rosell CM, Muguerza B, Moulay L (2009) Breadmaking performance and keeping behavior of cocoa-soluble fiber-enriched wheat breads. Food Sci Technol Int 15:79-87
12. Grillo G, Boffa L, Binello A, Mantegna S, Cravotto G, Chemat F, Dizhbite T, Lauberte L, Telysheva G (2019). Cocoa bean shell waste valorisation; extraction from lab to pilot-scale cavitational reactors. Food Res Int 115:200-208
13. Jozinović A, Panak Balentić J, Ačkar Đ, Babić J, Pajin B, Miličević B, Guberac S, Šubarić D (2019) Cocoa husk application in the enrichment of extruded snack products. J Food Process Pres, e13866
14. Rojo-Poveda O, Barbosa-Pereira L, Mateus-Reguengo L, Bertolino M, Stévigny C (2019) Effects of Particle Size and Extraction Methods on Cocoa Bean Shell Functional Beverage. Nutrients 11:867.
15. Kreibich HH, Moecke EOH, Scussel VM (2017) In: Méndez-Vilas A. (ed) Microscopy and imaging science: practical approaches to applied research and education. Formatex Research Center, Badajoz, Spain

16. de Sousa MF, Guimarães RM, de Oliveira Araújo M, Barcelos KR, Carneiro NS, Lima DS, Egea MB (2019) Characterization of corn (*Zea mays* L.) bran as a new food ingredient for snack bars. LWT-Food Sci Technol 101: 812-818
17. EC Regulation No 1924/2006 of the European Parliament and of the Council of 20 December 2006 on nutrition and health claims made on foods. Official Journal of the European Union, L404 (2006): 9-25.
18. AOAC, Association of Official Analytical Chemists (2002). Official Method of Analysis (16th Edition), Association of Official Analytical, Washington DC.
19. Sarangapani C, Thirumdas R, Devi Y, Trimukhe A, Deshmukh RR, Annapure U.S. (2016) Effect of low-pressure plasma on physico–chemical and functional properties of parboiled rice flour. LWT-Food Sci Technol, 69:482-489.
20. AACC, American Association of Cereal Chemists (2000) Approved Methods of the AACC (10th ed.) St. Paul, USA: Am Assoc Cereal Chem
21. Rinaldi M, Paciulli M, Caligiani A, Scazzina F, Chiavaro E (2017) Sourdough fermentation and chestnut flour in gluten-free bread: A shelf-life evaluation. Food Chem 224: 144-152
22. Bourne MC (1978) Texture profile analysis. Food Technol 32: 62-66
23. Wu YV, Doehlert DC (2002) Enrichment of β-glucan in oat bran by fine grinding and air classification. LWT-Food Sci Technol 35:30-33
24. Knuckles BE, Chiu MM, Betschart AA (1992) Beta-glucan-enriched fractions from laboratory-scale dry milling and sieving of barley and oats. Cereal Chem 69:198-202
25. Raghavendra SN, Rastogi NK, Raghavarao KSMS, Tharanathan RN (2004). Dietary fiber from coconut residue: effects of different treatments and particle size on the hydration properties. Eur Food Res Technol 218: 563-567

26. Lecumberri E, Mateos R, Izquierdo-Pulido M, Rupérez P, Goya L, Bravo L (2007) Dietary fibre composition, antioxidant capacity and physico-chemical properties of a fibre-rich product from cocoa (*Theobroma cacao* L.). Food Chem 104:948-954
27. De Angelis D, Madodé YE, Briffaz A, Hounhouigan DJ, Pasqualone A, Summo C (2020) Comparing the quality of two traditional fried street foods from the raw material to the end product: The Beninese cowpea-based ata and the Italian wheat-based popizza. Legum Sci, e35.
28. Pérez Sira E, Méndez A, León M, Hernández G, Sívoli L (2015) In: Pérez Sira E (ed) Cocoa byproducts technology, rheology, styling, and nutrition. Nova Science Publishers, New York.
29. Martínez MM, Díaz Á, Gómez M (2014) Effect of different microstructural features of soluble and insoluble fibres on gluten-free dough rheology and bread-making. J Food Eng 142:49-56
30. Coda R, Kärki I, Nordlund E, Heiniö RL, Poutanen K, Katina K (2014) Influence of particle size on bioprocess induced changes on technological functionality of wheat bran. Food Microbiol 37:69-77
31. Gómez M, Moraleja A, Oliete B, Ruiz E, Caballero PA (2010) Effect of fibre size on the quality of fibre-enriched layer cakes. LWT-Food Sci Technol 43:33-38
32. Cappa C, Lucisano M, Mariotti M (2013) Influence of Psyllium, sugar beet fibre and water on gluten-free dough properties and bread quality. Carbohydr Polym 98:657-1666
33. Almeida EL, Chang YK, Steel CJ (2013) Dietary fibre sources in bread: Influence on technological quality. LWT-Food Scie Technol 50:545-553
34. Kārkliņa D, Gedrovica I, Reca M, Kronberga M (2012) Production of biscuits with higher nutritional value. Proceedings of the Latvian Academy of Sciences. Section B. Natural, Exact, and Applied Sciences 66:113-116
35. Masure HG, Fierens E, Delcour JA (2016) Current and forward looking experimental approaches in gluten-free bread making research. J Cereal Sci 67:92-111

36. Guimarães RM, Pimentel TC, de Rezende TAM, de Santana Silva J, Falcão HG, Ida EI, Egea MB (2019) Gluten-free bread: effect of soy and corn co-products on the quality parameters. Eur Food Res Techn 245:1365-1376
37. Sharma P, Gujral HS (2014) Anti-staling effects of β-glucan and barley flour in wheat flour chapatti. Food Chem 145:102-108
38. Cai L, Choi I, Hyun JN, Jeong YK, Baik BK (2014). Influence of bran particle size on bread-baking quality of whole grain wheat flour and starch retrogradation. Cereal Chem 91:65-71
39. Rocha Parra AF, Ribotta PD, Ferrero C (2015) Apple pomace in gluten-free formulations: effect on rheology and product quality. Int J Food Sci Tech 50:682-690

Captions for figures

Figure 1: Specific volume of tested breads. Error bars represent +/- 1 standard deviation, (n = 3, sample size = 3 for each bread type). Different capital letters indicate significant differences ($p < 0.05$) among different times for the same bread while different lowercase letters indicate significant **0differences ($p < 0.05$) among the four types of bread at the same storage time.

Figure 2: Number of holes, as percentage of the total number, for the selected dimensional classes at time 0 day. Error bars represent +/- 1 standard deviation, (n = 9, sample size = 3 for each bread type). Bars of histograms with the same letters for each class are not significantly different ($p < 0.05$).

Figure 3: Crumb moisture content for tested breads during storage. Error bars represent +/- 1 standard deviation, (n = 9, sample size = 3 for each bread type). Different capital letters indicate significant differences ($p < 0.05$) among different times for the same bread while different lowercase letters indicate significant differences ($p < 0.05$) among the four types of bread at the same storage time.

Table 1. Water binding capacity (WBC), water absorption index (WAI), water holding capacity (WHC), water solubility index (WSI) and proximate composition of cocoa bean shell fractions[a]

	moisture	ash	protein	fat	fibre	WBC	WAI	WHC	WSI
F1	4.9±0.3a	6.0±0.1b	15.2±0.4b	6.9±0.6c	63.7±0.6a	2.89±0.16b	5.52±0.16a	3.22±0.18ab	0.124±0.062a
F2	4.7±0.2a	5.7±0.1c	17.3±0.3a	14.6±1.6b	59.4±0.6b	3.75±0.13a	4.38±0.23b	3.50±0.03a	0.023±0.004b
F3	5.1±0.2a	6.7±0.1a	18.2±0.6a	21.8±1.9a	57.2±0.7b	2.95±0.20b	3.98±0.18c	3.08±0.11b	0.150±0.073a

[a] n=3. Means in columns followed by different letter differed significantly ($p < 0.05$).
Hydration properties are expressed as g/g while proximate data are expressed as g/100g

Table 2. Crumb and crust colorimetric parameters for analysed breads. [a]

	day	*L**	*a**	*b**	*L**	*a**	*b**
		Crust			*Crumb*		
C	0	78.77±0.01**b**B	1.84±0.01**a**A	13.01±0.03**a**B	86.99±2.42**a**A	0.128±0.035**c**B	6.59±0.13**a**A
	1	83.83±1.27*b*A	1.98±0.31*a*A	15.97±0.99*a*A	81.12±2.18*a*B	0.440±0.121*d*A	6.97±0.43*c*A
	3	83.26±0.38bA	0.42±0.10bB	7.92±0.36cC	83.26±0.38aAB	0.307±0.135dA	6.70±0.78cA
F3	0	84.04±0.88**a**A	2.03±0.16**a**A	12.67±0.71**a**A	71.96±1.56**c**A	2.207±0.251**a**A	9.27±0.46**b**A
	1	84.75±2.11*b*A	1.61±0.28*a*B	11.46±0.89*b*A	73.82±2.18*b*A	2.038±0.301*a*AB	8.80±0.66*b*B
	3	83.12±1.49bA	1.84±0.22aB	11.76±1.08bB	75.42±2.18bA	1.866±0.316aB	10.21±0.99aA
F2	0	84.23±2.10**a**A	1.37±0.38**b**A	14.09±1.30**a**A	81.08±1.92**b**A	1.367±0.38**b**A	14.33±1.28**a**A
	1	86.76±0.69*ab*A	0.84±0.16*a*A	10.89±0.54*b*B	76.42±2.19*ab*B	1.050±0.286*c*B	8.46±0.48*b*B
	3	84.36±1.72bA	1.63±0.37bA	15.17±1.16aA	81.84±2.97aA	1.321±0.2001bA	11.08±0.94aAB
F1	0	86.26±2.33**a**A	1.19±0.13**b**A	10.54±0.88**b**A	73.09±1.85**c**A	1.398±0.155**b**AB	8.88±1.25**b**B
	1	88.02±1.37*a*A	0.80±0.19*b*B	11.58±1.05*b*A	74.75±2.11*b*A	1.609±0.284*b*A	11.45±0.89*a*A
	3	87.85±1.37aA	0.82±0.19bAB	10.88±1.05aA	73.73±5.01bA	0.907±0.270cB	8.03±0.88bB

[a] n=10. Means in column followed by different capital letters significantly differ ($p < 0.05$) among different times for the same bread. Means followed by different lowercase letters significantly differ ($p < 0.05$) among the four types of bread at the same storage time.

Table 3. Crumb textural profile analysis (TPA) and crust penetration parameters for the four analysed breads during storage.[a]

		crumb				*crust*
	day	*Hardness (N)*	*Cohesiveness*	*Resilience*	*Chewiness (N)*	*Hardness (N)*
C	0	0.53± 0.06**a**B	0.77± 0.10**a**A	100.10±0.32**a**A	0.43±0.09**a**B	1.92±0.11**a**A
	1	0.76±0.12*b*B	0.84±0.09*a*A	102.67±3.02*a*B	0.90±0.22*a*A	1.16±0.15*b*B
	3	1.57±0.48bA	0.64±0.08aB	103.16±3.87aC	1.10±0.42abA	2.22±0.46bA
F3	0	0.52±0.10**a**B	0.78±1.07**a**A	98.68±0.02**a**A	0.40±0.19**a**B	1.83±0.49**a**C
	1	1.21±0.24*a*AB	0.58±0.02*a*B	97.05±0.71*b*A	0.63±0.15*b*A	2.39±0.51*a*B
	3	1.43±0.34bA	0.55±0.06bB	91.53±3.99bA	0.72±0.16bA	3.30±0.31aA
F2	0	0.61±0.21**a**C	0.74±0.06**a**A	81.55±15.48**b**B	0.35±0.10**a**B	1.84±0.43**a**A
	1	1.31±0.29*a*B	0.60±0.04*b*B	98.00±0.53*b*A	0.71±0.16*b*B	1.52±0.31*b*B
	3	2.93±0.47aA	0.58±0.09aB	97.06±1.14bA	1.64±0.25aA	1.81±0.19bA
F1	0	0.57±0.16**a**B	0.72±0.02**a**A	98.77±0.42**a**A	0.43±0.11**a**A	2.18±0.60**a**AB
	1	0.84±0.07*b*A	0.60±0.04*b*B	97.55±0.51*b*AB	0.51±0.06*b*A	2.61±0.27*a*A
	3	0.95±0.24cA	0.57±0.08aB	92.62±4.46bB	0.49±0.13bA	1.91±0.26bB

[a] n=5 for crust and n=10 for crumb. Means in column followed by different capital letters significantly differ ($p < 0.05$) among different times for the same bread. Means followed by different lowercase letters significantly differ ($p < 0.05$) among the four types of bread at the same storage time

Figure 1.

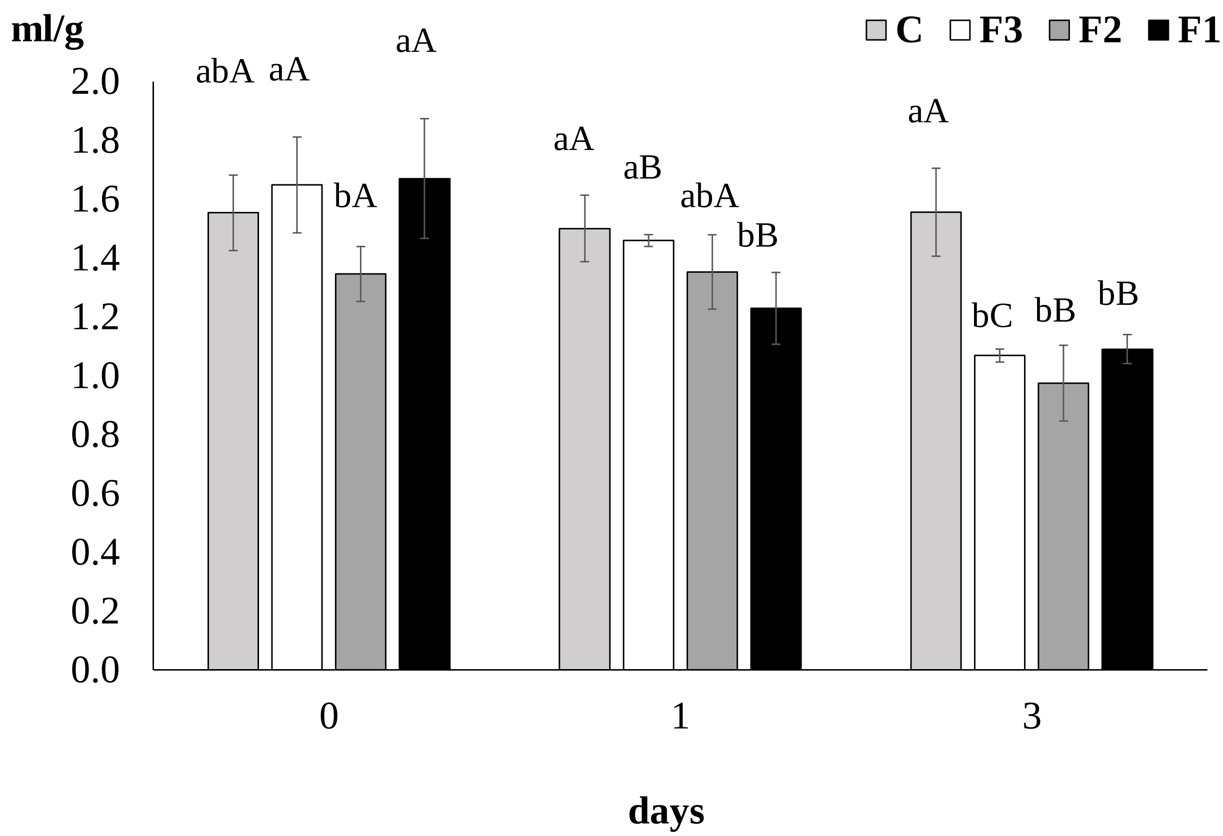

ml/g
C
F3
F2
F1
abA
aA
bA
aA
aA
aB
abA
bB
aA
bC
bB
bB
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
3
days

Figure. 2.

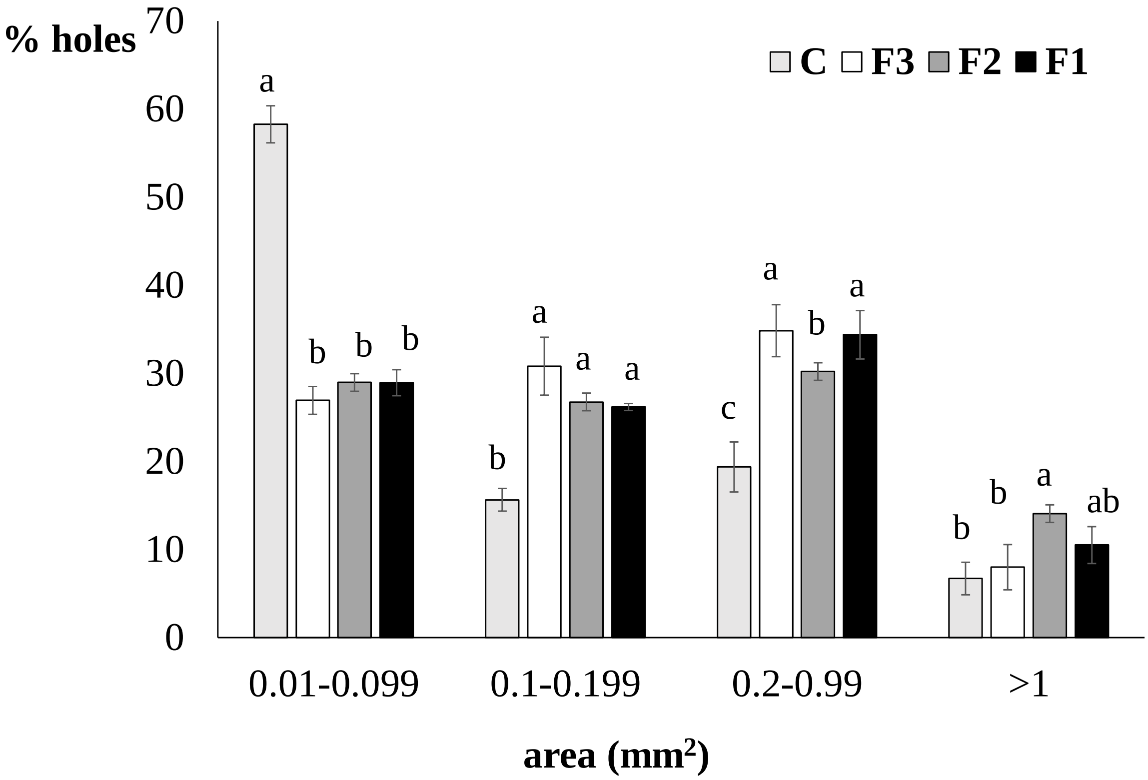
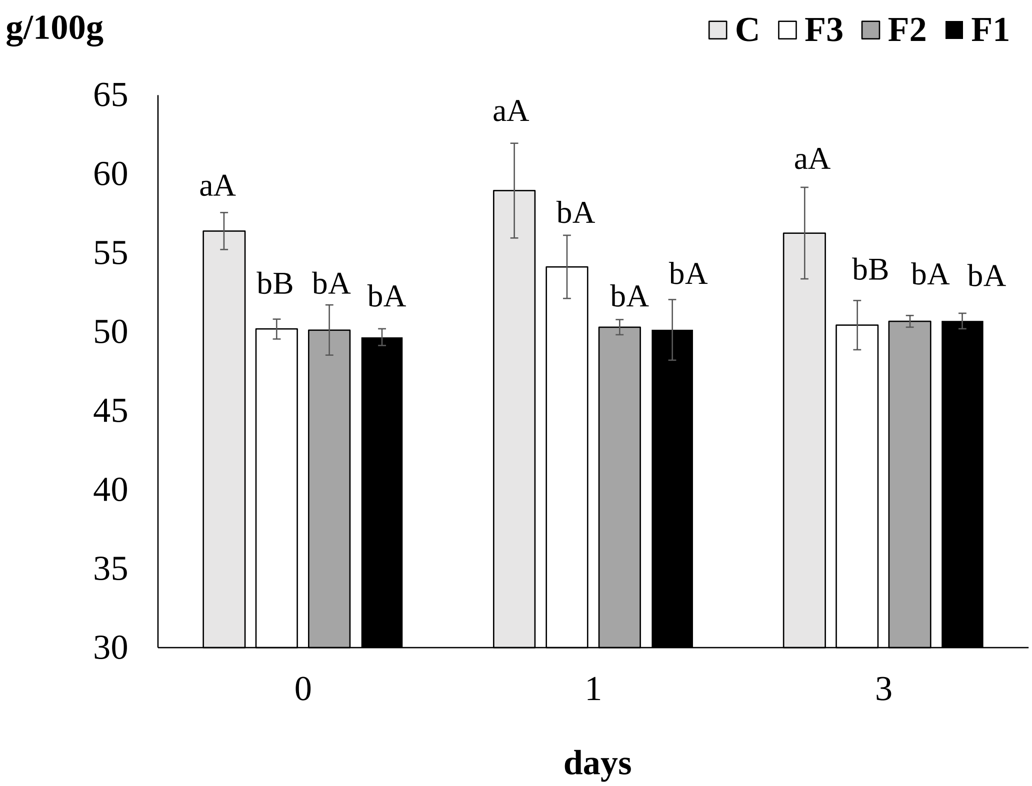

% holes
70
60
50
40
30
20
10
0
C
F3
F2
F1
a
b
b
b
b
a
a
a
c
a
b
a
b
b
a
ab
0.01-0.099
0.1-0.199
0.2-0.99
>1
area (mm2)

Figure. 3.


g/100g
C
F3
F2
F1
65
60
55
50
45
40
35
30
aA
bB
bA
bA
aA
bA
bA
bA
aA
bB
bA
bA
0
1
3
days