Physical Chemical and Sensory Effects of Pineapple By-product Flour in Cookies: An Upcycling Approach on Food Development

Efeitos Físico-químicos e Sensoriais da Incorporação de Farinha de Subprodutos de Ananás em Bolachas: Uma Abordagem Sustentável no Desenvolvimento de Alimentos

Yasmin Inácio Oliveira

ORIENTADO POR: Prof. Doutor Duarte Paulo Martins Torres

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Abstract

This study aimed to evaluate the application of pineapple core flour (PCF) as a partial substitute for wheat flour (WF) in cookies, exploring its potential as a novel and clean-label ingredient for the food industry (FI). Both flours were first characterised for their nutritional composition and water solubility, considering PCF with different particle sizes (100 - 500 µm). PCF demonstrated significantly higher water solubility than WF, particularly when particle sizes were ≤ 100 µm. Cookies were then prepared with different percentages and granulometries of PCF, and evaluated for their nutritional composition, texture, colour, and sensory aspects. Although the addition of PCF increased hardness, and produced cookies with darker and more yellow hue, sensory acceptability remained unaffected, with a preference towards the sample with 9.6% of PCF. The impacts on nutritional composition were modest, with slightly higher total lipid, ash, and moisture values in the PCF-enriched samples. Overall, the results suggest that PCF has a great potential as a sustainable and profitable alternative for WF in cookies, aligning with upcycling trends in food product development.

Keywords: Cookies, Fruit by-product, Pineapple, Food development, Food waste.

Resumo

Este estudo teve como objetivo avaliar a aplicação da farinha do centro do ananás (FCA) como substituto parcial da farinha de trigo (FT) em bolachas, explorando o seu potencial como ingrediente inovador e *clean-label* para a indústria alimentar (IA). Ambas as farinhas foram inicialmente caracterizadas quanto à sua composição nutricional e solubilidade em água, considerando a FCA com diferentes granulometrias (100 - 500 µm). A FCA demonstrou uma solubilidade em água significativamente superior à da FT, especialmente para as partículas com tamanhos ≤ 100 µm. As bolachas foram preparadas com diferentes percentagens e granulometrias de FCA, sendo avaliadas quanto à composição nutricional, textura, cor e parâmetros sensoriais. Embora a adição de FCA tenha aumentado a dureza e originado bolachas com tonalidade mais escura e amarelada, a aceitabilidade sensorial manteve-se inalterada, com uma preferência pela amostra com 9,6% de FCA. Os impactos na composição nutricional foram modestos, com valores ligeiramente superiores de lípidos totais, cinzas e humidade nas amostras enriquecidas com FCA. No geral, os resultados sugerem que a FCA apresenta um grande potencial como alternativa sustentável e economicamente viável à FT em bolachas, alinhada com as tendências de valorização de subprodutos no desenvolvimento de novos produtos alimentares.

Palavras-chave: Bolachas, Subproduto de fruta, Ananás, Desenvolvimento de alimentos, Desperdício alimentar

List of symbols

cm - Centimetre

°C - Degrees Celsius

g - Gram

kcal - Calories

kg - Kilogram

ml - Millilitre

mm/s - Millimetres per second

rpm - Revolutions per minute

List of abbreviations, acronyms and initialisms

CC - Control cookie

FBF - Fruit by-product flour

FI - Food industry

PCF - Pineapple core flour

PCF_{100} - Pineapple core flour with particle size ≤ 100 μm

PCF_{250} - Pineapple core flour with particle size ≥ 100 μm and ≤ 250 μm

PCF_{500} - Pineapple core flour with particle size ≥ 250 μm and ≤ 500 μm

$PCF_{9.6}TF_{27}$ - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%)

$PCF_{22}TF_{24}$ - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%)

$PCF_{9.6}TF_{24}$ - Formulation containing 9.6% of PCF relative to the total amount of flour in the recipe (24.7%)

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WF - Wheat flour

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Introduction

Food wastage is a social, economic, and environmental issue [1, 2, 3, 4, 5]. The term 'wastage' refers to both food lost in the early stages of production, particularly during post-harvest, storage, and processing, and food wasted at the retail or household level. Globally, it is estimated that 14% of the food produced is lost, and approximately 17% of the food available is wasted [5].

When it comes to fruits and vegetables, which are fragile, perishable, and temperature-sensitive, losses are even more significant, representing almost a quarter of total production [2]. Non-edible parts of fruits and vegetables, such as the leaves, stems, peels, and seeds, are also considered waste, and are often disposed of before they can be repurposed [5]. In pineapples, for example, only 40% of the total fresh weight is consumed, as the crown, peel, bottom, cores, and trimmings are discarded [1].

This linear approach of consumption and waste production is a problem, as it leads to an ever-growing demand for landfill space and waste treatment facilities [3]. Besides, reducing food wastage is crucial to lower the environmental footprint, the unnecessary use of resources and gas emissions, land pollution and water contamination [3, 6]. In the concept of a circular economy [1], once food security is ensured, food waste can be recovered and upcycled into value-added products with functional and technological applications in the food industry (FI), such as enzyme and vitamin extracts, concentrated juices, pectin, and fibre. This perspective is appealing not only from a sustainable point of view, but also from an environmental and economic one, as the use of molecules and extracts from food by-products is well accepted by consumers and markets, especially if they have proven health benefits [7]. Transformation processes, however, often use organic solvents and inorganic salts, which, besides being non-eco-friendly, have a high cost, a low purity rate, and low extraction yields [8]. Debora et al. [8, 9] introduced a new and affordable green technique to extract bromelain from pineapple by-products, an enzyme with several applications in the FI. The method uses natural polymers to precipitate and purify the enzyme, mainly using the juice of pineapple cores and peels as substrate. In addition, this approach is easily scalable, requires simple equipment, and allows alternative precipitants [9], making it an excellent option for industrial applications. The rest of the fruit can then be converted into other secondary ingredients, such as fruit by-product flour (FBF).

Flours obtained from fruits are a clean-label ingredient, full of macro- and micronutrients, especially insoluble fibre [2]. They present distinct and advantageous properties when compared to traditional cereal flours, such as greater fibre content, lower phytic acid levels, reduced energy content, and higher antioxidant concentrations [1, 10]. It is known that a healthy diet must include an adequate fibre intake, as it improves satiety, reduces the risk of non-communicable diseases such as type 2 diabetes, obesity, cancer, and cardiovascular disorders [2], promotes colonic fermentation, and aids glycaemic regulation. In the case of fruit fibre, its structural matrix encapsulates bioactive compounds that, through digestion, are slowly released until reaching the colon, promoting an antioxidant-rich environment within the gut. Ferulic acid is an example that has been reported to form complexes with lignin in fibre [11].

A study evaluating the *in vitro* effects of pineapple core flour (PCF) on the human intestinal microbiota revealed its significant positive modulation of *Firmicutes* and *Bacteroidetes*, two bacterial phyla strongly associated with a healthy gut. Additionally, the fermentation process triggered by PCF reduces simple sugars and enhances the production of short-chain fatty acids (acetic, propionic, and butyric acids) [11], compounds that are well known for supporting immune, digestive, and endocrine functions [12].

Throughout Europe, the recommended total fibre intake is about 25 to 32 g/day for adult women, and 30 to 35 g/day for adult men. On average, intakes for males range from 18 to 24 g/day, and from 16 to 20 g/day for females, with slight variation among countries[14]. In Portugal, the average intake of the population is approximately 18 grams of fibre per day [15]. To increase fibre intake, a smart strategy would be to improve its content in frequently consumed goods, such as cookies, the most popular and consumed baked good worldwide as they are a low-cost and ready-to-eat snack, with a long shelf life and wide variety [16]. In Portugal, the consumption of cookies and biscuits is around 12 to 40 g per day, contributing with 4% of the mean energy intake [15]. Since wheat flour (WF) is typically the main component in cookies, substituting a fraction of it with FBF could be a valuable opportunity to improve their nutritional profile.

Regarding the production process of FBF, it shows little variations across studies, which, in brief, consists of the mechanical treatment of the fruit (by cutting and/or pressing), followed by the separation of the juice from the pomace/bagasse. While the juice contains mainly water, soluble sugars, and bioactive compounds, the pomace is the fibrous part used to make FBF. After being dried at temperatures ranging from 30 to 85 ºC, until reaching a moisture level of 2 to 12%, the pomace is ground and sifted using the desired mesh size until a fine powder is obtained [2]. Variations in granulometry among FBF reported in the literature, however, make comparisons between studies difficult. Varying the size of the flour particles alters their hydrodynamic and emulsifying properties [2, 13], which are important aspects that should be considered when replacing ingredients or developing new food products. Given that the demand for healthier and more sustainable food options is a growing trend, incorporating FBF into frequently consumed goods [17] could provide considerable market advantages. The introduction of a novel and non-conventional ingredient can, however, substantially impact on the product's matrix, aroma, and overall flavour profile.

Objectives

This study aimed to test the application of PCF in cookies as a novel and clean-label ingredient for the FI, not only as a healthier approach to product development but also as a sustainable and profitable one. More specifically, the objectives were:

To evaluate the effect of varying the granulometry of PCF on water solubility and nutritional composition, and to compare these parameters with those of WF.

To assess the effects of partially substituting WF with PCF in a cookie recipe, particularly on its nutritional composition, hardness, and colour.

To evaluate the influence of using PCF with different granulometries in cookies on its nutritional composition, hardness, and colour.

To study the impact of PCF on the cookies sensory' characteristics.

Materials and methods

- **Pineapple core flour**

Pineapple core flour was obtained by drying, grinding, and sifting the pulp (pressed cake) with different mesh sizes, as described by Debora et al.[18]. In this study, PCF with particle sizes ≤ 100 μm (PCF_{100}), ≥ 100 μm but ≤ 250 μm

(PCF_{250}), and ≥ 250 μm but ≤ 500 μm (PCF_{500}) were evaluated. The other ingredients such as margarine, glucose syrup, honey, WF type 65, oat flakes, white sugar, corn starch, powdered milk, chia seeds, salt, ammonium and sodium bicarbonate used to bake the cookies were sourced from local supermarkets and specialised baking stores.

- **Water solubility index**

Solubility of PCF with different particle sizes and of WF was assessed at different temperatures according to the methodology described by Hou et al.[19], in duplicate, with a few modifications. In brief, each flour sample (0.3 g) was mixed with distilled water (30 mL) in 50 mL test tubes using a vortex mixer for 1 minute. Samples were heated in a circulating water bath at controlled temperatures (25 °C and 85 °C) for 30 minutes. After cooling, tubes were centrifuged for 30 minutes at 6000 rpm in a bench centrifuge, separating the supernatant from the pellet. The supernatant was then left overnight in an oven at 105 °C, allowing the water to evaporate. Solubility was calculated according to the formula:

$$\text{Solubility (\%)} = (\text{weight of dry solids from supernatant}/\text{weight of total flour sample}) \times 100$$

- **Nutritional composition analysis**

The proximate composition of PCF with different particle sizes, and that of the cookies studied, was determined following the methodology of the Association of Official Analytical Chemists for total lipid, protein, and ash content. Total carbohydrate was determined by the equation:

$$\text{Total carbohydrate (g/100 g)} = 100 - \text{protein content (g/100 g)} - \text{lipid content (g/100 g)} - \text{moisture content (g/100 g)} - \text{ash content (g/100 g)}$$

Calories were estimated according to the formula below, using a conversion factor of 4 kcal/g applied to total carbohydrates, including dietary fibre. As this method does not account for the partial digestibility of fibre, it may slightly overestimate the total energy content:

$$\text{Calories (kcal/100 g)} = [4 \times \text{protein content (g/100 g)}] + [4 \times \text{total carbohydrate content (g/100 g)}] + [9 \times \text{lipid content (g/100 g)}]$$

WF's nutritional information was used for comparison as indicated on its packaging label.

- **PCF-enriched cookies**

Control cookies (CC) were prepared following a recipe with margarine, water, glucose syrup, honey, WF type 650, oat flakes, white sugar, corn starch, powdered milk, chia seeds, salt, ammonium bicarbonate, and sodium bicarbonate. All dry ingredients were weighed, sifted, and combined in a stainless-steel bowl, followed by the addition of the wet ingredients, kneading the dough by hand until a homogeneous consistency was achieved. The dough was sheeted to a thickness of 0.3 cm, and cookies were cut using a round cookie cutter with a diameter of 5.7 cm. Baking was carried out at 170 °C in an electric oven until the desired colour was reached, as PCF cookies reached a darker colour in a shorter baking time than the CC samples. Test samples were formulated by substituting WF with PCF at different percentages. The substitution considered the bulk density of PCF, which is lower than that of WF, meaning that, for the same mass, it occupies a larger volume. To compensate for the resulting variations in the total flour content of the recipe, a full factorial design was employed, with two variables at two levels. The “Percentage of PCF relative to the total amount of flour in recipe” and “Total amount of flour in the recipe” were the only variables that changed among formulations (Table 1). This experimental design allowed for the assessment of individual effects of each variable (total flour and the fraction of PCF in the total flour) and their interaction on the studied parameters. According to the new recipes (Table 2), cookies were baked using PCF with different granulometries (PCF_{100}, PCF_{250}, and PCF_{500}), resulting in nine samples.

- **Cutting/shearing test**

To compare the effect of the partial substitution of WF with PCF, as well as the influence of the flour particle size on the hardness of each cookie, a cutting/shearing test was carried out using a texturometer (Stable Micro Systems, TA XT plus Texture Analyser), coupled with a Knife Edge probe and a Slotted Insert (HDP/BS) base. Each sample was placed in the middle of the slot, allowing the probe to cut completely through the cookie's structure. The test speed was set at 2 mm/s, with a 30 kg load cell and a trigger force of 25 g. Hardness was measured as the peak force (Fmax) required to break the cookies, expressed in kilograms. Results were based on the mean value of seventeen to twenty cookies of each sample. Tests were performed one day after baking.

- **Colour analysis**

To analyse the influence of the partial substitution of WF with PCF on the colour of the cookies, as well as the influence of the flour particle size, a colour analysis was performed on all nine cookie samples using a Spectrophotometer (ColorLite, sph860, Katlenburg-Lindau, Germany), calibrated against the white calibration standard (Type ODM 01-CUS), with normal reflection. Results for the coordinates a* (green-red), L* (black-white), and b* (blue-yellow) were based on the mean value of five random areas on the surface of five random cookies of each sample. Tests were carried out one day after baking.

- **Sensory analysis**

Sensory aspects of the samples CC, $PCF_{9.6}TF_{27}$ and $PCF_{22}TF_{24}$ baked with PCF_{100}, were evaluated. Extreme formulations from the factorial design and the samples with larger particle sizes were excluded, as they had no applicational interest. Three types of sensory tests were conducted: Discrimination, Preference, and Affective tests, all designed according to established sensory analysis methodologies. In the discrimination test, participants were presented with three coded cookies: control cookies and a different one, either $PCF_{9.6}TF_{27}$ or a $PCF_{22}TF_{24}$. Participants were asked to identify the different sample. In the preference test, participants were presented with three coded cookies, CC, $PCF_{9.6}TF_{27}$, and $PCF_{22}TF_{24}$, and asked to identify their favourite and least favourite cookie out of the three. Affective tests were based on a 9-point hedonic scale (ranging from “Dislike extremely” to “Like extremely”) to assess attributes such as Appearance, Aroma, Flavour, Texture, and Overall consumption experience. A Just-About-Right (JAR) scale (consisting of five points ranging from below, above, or at the ideal level of participants’ liking) was also used considering aspects such as “Crunchiness”, “Fibrous texture”, “Whole grain/cereal-like flavour”, and “Sweetness”. Participants were asked to rank each attribute for each cookie.

The sensory analysis was carried out at the Food and Nutrition Science University of Porto after the approval of the Research Ethics Committee, under reference number Nº193/2025/CEFCNAUP, issued on 6 June 2025. An Informed Consent Form was provided to all 41 participants, who were randomly recruited at the University of Porto. Participants were excluded from the analysis if they had any diagnosed food intolerance to the ingredients used in the cookie formulation. The study was single-blinded, with samples coded using three-digit numbers and letters, and distributed to participants in random order, ensuring that subjects were not informed about the composition of the cookies.

- **Statistical Analysis**

Data obtained from all experiments were statistically analysed using IBM SPSS software, version 30.0, considering values for $p < 0.05$ statistically significant.

To assess significant differences among samples regarding water solubility, nutritional composition, hardness, and colour, a one-way analysis of variance (ANOVA) was applied. When significant differences were detected, post hoc pairwise comparisons using Bonferroni correction were performed to identify specific pairwise differences.

For the sensory analysis, a Chi-square test was used to assess whether the participants' ability to distinguish between the different cookie samples was dependent on the type of cookie presented. Additionally, a one-sample binomial test, with a hypothetical proportion of 0.33, was applied to determine if the participants' ability to select the different sample was likely to have occurred by chance.A binomial test with a hypothetical proportion of 0.33 was also used to evaluate preference tendencies. Subsequently, a Friedman test was applied to detect any significant differences across sample preferences.

A Friedman test was applied to detect significant differences among samples in scores from the 9-point hedonic scale, followed by post hoc comparisons within groups using Bonferroni correction. Finally, a penalty analysis was conducted to evaluate the impact of deviations from the ideal attribute level on overall liking scores. For each sensory attribute assessed using a Just-About-Right (JAR) scale, responses were categorised as “too little,” “JAR,” or “too much.” Mean overall liking scores were then compared across these categories to identify the sensory deviations that negatively influenced consumer acceptance. A Kruskal-Wallis test was applied to detect significant differences in overall liking among JAR categories, followed by Bonferroni correction when differences among samples were significant. Significant drops in liking were associated with non-JAR responses and were considered a "penalty".

The present study was conducted under the supervision of Professor Duarte Paulo Martins Torres (Annex A).

Results and discussion

- **Water solubility index**

Water solubility index measures the amount of soluble components in a sample when dissolved in water. It is an important parameter in food product development, as it can influence dough hydration, mixing and sheeting behaviour, as well as processing suitability, shelf life, stability, texture and mouthfeel. PCF exhibits significantly greater solubility than WF ($p < 0.001$), likely due to its higher content of hydrophilic compounds, such as sugars and minerals, compared to WF, where starch is the main component (Table 3). Among PCF samples, PCF100 shows a considerably greater solubility than the other granulometries, probably because of the increased surface area of the smaller particles that facilitates interactions with water. This indicates that incorporating PCF, particularly in finer granulometries, may require adjustments in dough hydration to ensure optimal consistency and processing performance. While the solubility of WF increases at 80 ºC due to starch gelatinisation, PCF solubility remains largely unchanged, indicating that temperature does not significantly affect its solubility.

- **Nutritional composition**

The different flours exhibit specific particularities regarding nutritional composition (Table 4). PCF contains significantly more total carbohydrates than WF ($p < 0.001$). Although fibre content was not evaluated in this study, carbohydrate values are likely related to the fibre content of PCF, especially the insoluble fraction, aligned with previous literature indicating that FBF are rich in non-digestible polysaccharides [2, 20]. As discussed, fibre has numerous health benefits and PCF can be a cost-effective option to fortify and enhance the nutritional quality of cookies. Significant differences were observed regarding energy, with PCF likely having a lower caloric value, again due to its high insoluble fibre content. Lipid and protein contents are significantly lower in PCF than in WF, which is expected as fruits, unlike cereals, primarily store sugars and water rather than protein and fats. Ash and moisture contents were evaluated only for PCF samples with different particle sizes. PCF_{100} had a significantly lower ash content than PCF_{250} and PCF_{500}, suggesting that the fibre in coarser particle sizes is more strongly associated with mineral compounds. Moisture values were also significantly higher for PCF_{100} than for PCF_{250} and PCF_{500}, probably due to its greater surface area which allows for faster water absorption.

Looking at the nutritional composition of the cookies, although some significant differences were observed, variations were relatively minor (Table 5). The effects on calories, total carbohydrates, and protein are not linear, with some samples showing higher values than theCC, and others lower. For total lipids, values increase compared to CC, probably as the “total flour content in the recipe” decreases from 30% to 24% and 27%, slightly raising the proportion of fat in the formulation. Values for ash and moisture also increased in the enriched samples compared to CC, which may reflect the higher fibre and mineral content contributed by PCF. Overall, substituting WF with PCF does not substantially impact the cookies' on the nutritional profile, except for likely increasing its fibre content.

- **Cutting/shearing test**

A food product's hardness is influenced by its ingredients' properties, proportions, and interactions. Results show that increasing PCF content from 9.6% to 22% significantly increased the hardness of the cookies (Table 6) (Figure 1, $p = 0.004$), a finding consistent with other studies that incorporated FBF in cookies [21, 22, 23]. This effect may be attributed to the interaction between the insoluble fibre in PCF and the gluten network, which can stiffen the dough, resulting in denser and more compact cookies. Simultaneously, decreasing the total flour content also increased cookie hardness (Figure 2, $p < 0.001$), likely because of the increase in proportion of the other ingredients in the recipe, other than the effects of the flour. The graphs further indicate no significant interaction between “Total amount of flour in the recipe” and “PCF relative to the total amount of flour in the recipe” ($p = 0.480$). Regarding the different granulometries, no significant differences were observed in hardness for cookies containing 22% of PCF (Figure 3, $p = 0.246$). However, for cookies with 9.6% of PCF, hardness varied significantly among samples, with the highest mean hardness found in cookies containing PCF250 (Figure 4, $p < 0.001$). This suggests that medium-sized particles may create more structural disruption in the dough matrix than finer or coarser particles. Results for texture highlight the importance of balancing the percentage of PCF incorporated ands particle size to modulate texture, especially as consumer acceptance is a priority. While increased hardness may be desirable for certain cookie types (e.g., crunchy cookies), excessive firmness could negatively impact palatability.

- **Colour analysis**

Colour analysis has several important purposes across various industries, allowing for this characteristic to be measured and quantified rather than relying on subjective visual assessment. In the food industry, colour influences consumer acceptance [24], aids in product labelling and description, and helps ensure batch uniformity. Among the samples, no significant differences in lightness (L*) were observed, although values tended to increase in PCF-enriched cookies, indicating a darker colour than the CC (Table 7). This faster colour development occurs because FBF are more susceptible to Maillard reactions [21], which can be considered an advantage, as it reduces exposure time to thermal stress and lowers production costs. Regarding the b* coordinate, which indicates yellowness when positive, all enriched samples differed significantly from CC ($p < 0.001$). This was expected as oxidation and Maillard reactions tend to provide a yellow-brownish color to the test samples. Although colour stability over time was not evaluated in this study, future work could explore the oxidative behaviour of phenolic-rich FBF in baked products to assess potential discolouration during shelf life. No significant differences were observed among sample for the a* coordinate, that indicates redness when positive. PCF cookies showed a slight increase, consistent with previous studies [25], which may be attributed to residual pigments present in FBF, and to those formed during the Maillard reaction.

- **Sensory analysis**

Despite the economic, environmental, and nutritional advantages of using FBF, its addition to cereal-based products can sometimes lead to a decline in quality and in consumer acceptance [26]. Indeed, previous results demonstrated significant changes in the hardness and colour of the test samples, making it essential to understand those effects on consumer perception.

Results from the discrimination test indicate that participants were clearly able to differentiate the PCF cookies from the CC, regardless of whether they contained 9.6% or 22% PCF relative to the total flour content (Table 8, $p < 0.001$). Although the preference test indicated a tendency for the sample enriched with 9.6% of PCF to be the preferred cookie, differences among groups were not statistically significant (Table 9, $p = 0.281$). Results from the hedonic test further support this interpretation. While attributes like appearance and aroma did not differ significantly among samples, flavour, texture and overall consumption experience showed relevant differences (Table 10; $p = 0.028$ and $p < 0.001$, $p = 0.033$, respectively). In particular, the formulation with 9.6% of PCF was significantly better rated in terms of texture than the cookie with 22%, in line with the results from the texture analysis (Table 6), reinforcing that high levels of PCF increase hardness beyond the acceptable. Although the cookie with 9.6% of PCF received the highest scores for flavour and overall consumption experience, this trend was not statistically significant in pairwise comparisons.

According to the penalty analysis, the overall consumption experience was significantly influenced for all three samples when participants perceived the cookie too crunchy. Specifically for the cookie with 22% of OCF, the perception of a too fibrous texture also had a significant negative impact on the experience.

In the case of the CC, the consumption experience appeared to be compromised for participants who found the cookie not sweet enough ($p = 0.015$).

Conclusion

This study evaluated the physical, chemical, and sensory characteristics of cookies formulated with varying proportions and particle sizes of PCF as a partial replacement for WF, with particular attention to the effects on the final product's nutritional composition, hardness, colour and consumer acceptability. Results highlighted that PCF has a significantly higher solubility than WF, which remains stable across temperatures. Understanding this behaviour is important as it may affect dough properties during processing. Nutritional analysis revealed that PCF contains lower protein and lipid levels than WF, while the higher total carbohydrate content may reflect an increased proportion of insoluble fibre. Among the granulometries studied, PCF_{100} exhibited significantly higher moisture content than PCF_{250} and PCF_{500}, suggesting its ability to retain water. Regarding the nutritional composition of the cookies, variations among samples were relatively modest, with values for total lipid, ash, and moisture content slightly higher in PCF-enriched samples. Adding PCF also led to harder and darker cookies, most likely due to interactions between fibres and gluten and Maillard reactions during baking. Regarding sensory aspects, the sample with 9.6% of PCF surprisingly tended to be the preferred one, and texture was significantly more pleasing for the 9.6% than the 22%, as was the flavour. Yet, negative perceptions related to excessive crunchiness, fibrousness, or insufficient sweetness were associated with reduced overall acceptability. These findings support the potential of PCF as a functional ingredient aligned with circular economy principles and product development.

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Appendix index

Table 1 - Variables studied from the factorial design

	PCF relative to the total amount of flour in the recipe (%)	Total amount of flour in the recipe (%)
CC	0	30
$PCF_{9.6}TF_{27}$	9.6	27.4
$PCF_{22}TF_{24}$	22	24.7
$PCF_{22}TF_{27}$	22	27.4
$PCF_{9.6}TF_{24}$	9.6	24.7

CC - Control cookie
PCF9.6TF27 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%)
PCF22TF24 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%)
PCF22TF27 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (27.4%)
PCF9.6TF24 - Formulation containing 9.6% of PCF relative to the total amount of flour in the recipe (24.7%)

Table 2 - Recipe table

	CC	$PCF_{9.6}TF_{27}$	$PCF_{22}TF_{24}$	$PCF_{22}TF_{27}$	$PCF_{9.6}TF_{24}$
Margarine (%)	13	13.5	14	13.5	15
Water (%)	9.8	10.1	10.5	10.1	10.5
Glucose syrup (%)	1.6	1.7	1.7	1.7	1.7
Honey (%)	0.7	0.7	0.7	0.7	0.7
Powdered milk (%)	1	1	1	1	1
Chia seeds (%)	1	1	1	1	1
Corn starch (%)	1.6	1.7	1.7	1.7	1.7
Salt (%)	0.3	0.3	0.4	0.3	0.4
Ammonium bicarbonate (%)	0.4	0.4	0.4	0.4	0.4
Sodium bicarbonate (%)	0.3	0.3	0.4	0.3	0.4
Sugar (%)	13	13.5	14	13.5	14
Oat flakes (%)	27.3	28.3	29.4	28.3	29.4
Wheat flour (%)	30	24.8	19.3	21.4	22.4
Pineapple core flour (%)	0	2.6	5.4	6	2.4

CC - Control cookie
PCF9.6TF27 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%)
PCF22TF24 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%)
PCF22TF27 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (27.4%)
PCF9.6TF24 - Formulation containing 9.6% of PCF relative to the total amount of flour in the recipe (24.7%)

Table 3 - Water solubility index

	T = 25ºC	Sig	T = 80ºC	*p*.
WF	6.91 ± 0.34 [a, b]	< 0.001	13.75 ± 0.22 [a, b]	< 0.001
PCF100	40.38 ± 0.77 [a, b]		41.45 ± 1.33 [a, b]	
PCF250	16.47 ± 0.36 [a, b]		17.22 ± 0.15 [b]	
PCF500	14.34 ± 1.91 [a, b]		16.89 ± 0.23 [b]	

WF - Wheat Flour
PCF100 - Pineapple core flour with particle size ≤ 100 μm
PCF250 - Pineapple core flour with particle size ≥ 100 μm and ≤ 250 μm
PCF500 - Pineapple core flour with particle size ≥ 250 μm and ≤ 500 μm

Values are reported as the mean ± standard deviation; n = 2

p-Value corresponds to One-Way ANOVA results

[a] Statistically significant differences compared to WF ($p < 0.05$)
[b] Statistically significant differences compared to PCF100 ($p < 0.05$)

Table 4 - WF and PCF nutritional composition analysis

	WF	PCF_{100}	PCF_{250}	PCF_{500}	*p.*
Calories (kcal / 100 g)	341 [a]	336.8 ± 0.13 [a, b]	344.94 ± 0.37 [a, b, c]	348.65 ± 0.81 [a, b, c]	< 0.001
Total lipids (g / 100 g)	1.2 [a]	0.6 ± 0.03 [a]	0.48 ± 0.03 [a]	0.69 ± 0.08 [a]	0.002
Total carbohydrates (g / 100 g)	71.6 [a]	79.86 ± 0.20 [a, b]	80.48 ± 0.18 [a]	80.95 ± 0.01 [a, b]	< 0.001
Protein (g / 100 g)	9.8 [a]	2.98 ± 0.24 [a, b]	4.66 ± 0.02 [a, b]	4.66 ± 0.03 [a, b]	< 0.001
Ashes (g / 100 g)	-	2.42 ± 0.15 [b]	5.21 ± 0.15 [b]	5.74 ± 0.24 [b]	0.002
Humidity (%)	-	14.13 ± 0.15 [b]	9.16 ± 0.01 [b]	7.9 ± 0.34 [b]	< 0.001

WF - Wheat Flour
PCF100 - Pineapple core flour with particle size ≤ 100 μm
PCF250 - Pineapple core flour with particle size ≥ 100 μm and ≤ 250 μm
PCF500 - Pineapple core flour with particle size ≥ 250 μm and ≤ 500 μm

Values are reported as the mean ± standard deviation; n = 2

p-Value corresponds to One-Way ANOVA results

[a] Statistically significant differences compared to CC ($p < 0.05$)
[b] Statistically significant differences compared to PCF100 ($p < 0.05$)
[c] Statistically significant differences compared to PCF250 ($p < 0.05$)

Table 5 - Nutritional composition of the cookie samples

	CC	PCF9.6 TF27 PCF100	PCF9.6 TF27 PCF250	PCF9.6 TF27 PCF500	PCF22TF24 PCF100	PCF22 TF24 PCF250	PCF22 TF24 PCF500	PCF22 TF27 PCF100	PCF9.6 TF24 PCF100	*p.*
Calories (g / 100 g)	424 ± 0.23 [d]	421 ± 0.60 [d, c, e]	422 ± 0.28 [d, c]	424 ± 0.86 [d]	421 ± 0.25 [d]	426 ± 1.13 [d, e]	447 ± 1.49 [d]	425 ± 0.24 [d, c]	426 ± 0.08 [d]	< 0.001
Total lipids (g / 100 g)	10.25 ± 0.00 [a, d, e]	10.57 ± 0.14 [d, e]	10.74 ± 0.04 [a, c, d, e]	10.88 ± 0.24 [d, e]	10.42 ± 0.18 [d, e]	11.68 ± 0.21 [d, e]	16.03 ± 0.33 [d, e]	11.06 ± 0.22 [c, d, e]	13.35 ± 0.16 [d, e]	< 0.001
Total carbohydrates (g / 100 g)	74.96 ± 0.38 [d, e]	73.17 ± 0.36 [d, e]	73.46 ± 0.24 [d, e]	74.22 ± 0.52 [d, e]	73.63 ± 0.43 [d, e]	72.29 ± 0.09 [d]	67.95 ± 0.41 [e]	73.09 ± 0.93 [d, e]	67.04 ± 0.57 [d, e]	< 0.001
Protein (g / 100 g)	8.12 ± 0.33	8.30 ± 0.11	7.87 ± 0.22 [e]	7.53 ± 0.21	8.30 ± 0.03 [e]	8.03 ± 0.10 [e]	7.75 ± 0.04 [e]	8.41 ± 0.39	9.44 ± 0.19 [e]	0.005
Ashes (g / 100 g)	1.61 ± 0.02	2.07 ± 0.19	1.84 ± 0.07	1.41 ± 0.16	1.69 ± 0.34	1.80 ± 0.05	1.86 ± 0.02 [e]	1.63 ± 0.25	2.50 ± 0.0 [e]	0.041
Humidity (%)	5.05 ± 0.34 [a, e]	5.88 ± 0.13 [a, e]	6.09 ± 0.08 [a, e]	5.94 ± 0.24 [e]	5.95 ± 0.05 [a, e]	6.19 ± 0.04 [a, e]	6.40 ± 0.02 [a, e]	5.80 ± 0.07 [a, e]	7.67 ± 0.21 [a, e]	< 0.001

CC - Control cookie
PCF9.6TF27, PCF100 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≤ 100 μm
PCF9.6TF27, PCF250 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≥ 100 μm and ≤ 250 μm
PCF9.6TF27, PCF500 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≥ 250 μm and ≤ 500 μm
PCF22TF24, PCF100 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≤ 100 μm
PCF22TF24, PCF250 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≥ 100 μm and ≤ 250 μm
PCF22TF24, PCF500 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≥ 250 μm and ≤ 500 μm
PCF22TF27, PCF100 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≤ 100 μm
PCF9.6TF24, PCF100 - Formulation containing 9.6% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≤ 100 μm

Values are reported as the mean ± standard deviation; n = 2

p-Value corresponds to One-Way ANOVA results.

[a] Statistically significant differences compared to CC ($p < 0.05$)
[b] Statistically significant differences compared to PCF9.6TF27, PCF100 ($p < 0.05$)
[c] Statistically significant differences compared to PCF9.6TF27, PCF250 ($p < 0.05$)
[d] Statistically significant differences compared to PCF22TF24, PCF250 ($p < 0.05$)
[e] Statistically significant differences compared to PCF22TF24, PCF500 ($p < 0.05$)

Table 6 - Cutting test, hardness values

	Hardness Value (Kg)
CC	8.54 ± 2.85
$PCF_{9.6}TF_{27}$ PCF_{100}	9.43 ± 2.62
$PCF_{9.6}TF_{27}$ PCF_{250}	13.64 ± 5.03
$PCF_{9.6}TF_{27}$ PCF_{500}	11.03 ± 7.91
$PCF_{22}TF_{24}$ PCF_{100}	19.37 ± 7.26
$PCF_{22}TF_{24}$ PCF_{250}	16.40 ± 5.94
$PCF_{22}TF_{24}$ PCF_{500}	20.09 ± 7.79
$PCF_{22}TF_{27}$ PCF_{100}	15.12 ± 6.78
$PCF_{9.6}TF_{24}$ PCF_{100}	11.89 ± 3.84

CC - Control cookie
PCF9.6TF27, PCF100 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≤ 100 μm
PCF9.6TF27, PCF250 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≥ 100 μm and ≤ 250 μm
PCF9.6TF27, PCF500 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≥ 250 μm and ≤ 500 μm
PCF22TF24, PCF100 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≤ 100 μm
PCF22TF24, PCF250 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≥ 100 μm and ≤ 250 μm
PCF22TF24, PCF500 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≥ 250 μm and ≤ 500 μm
PCF22TF27, PCF100 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≤ 100 μm
PCF9.6TF24, PCF100 - Formulation containing 9.6% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≤ 100 μm

Table 7 - Colour analysis

	CC	PCF9.6 TF27 PCF100	PCF9.6 TF27 PCF250	PCF9.6 TF27 PCF500	PCF22 TF24 PCF100	PCF22 TF24 PCF250	PCF22 TF24 PCF500	PCF22 TF27 PCF100	PCF9.6 TF24 PCF100	*p.*
L*	63.67 ± 4.55	61.22 ± 3.33	60.82 ± 2.92	60.85 ± 2.32	62.27 ± 2.64	61.34 ± 3.30	62.03 ± 2.67	59.75 ± 2.24	59.60 ± 2.87	0.542
a*	5.75 ± 1.27	10.02 ± 0.98	7.71 ± 0.80	10.43 ± 0.96	7.71 ± 0.80	8.66 ± 1.14	7.61 ± 0.65	9.84 ± 1.29	7.98 ± 0.96	0.470
b*	25.10 ± 2.58 [a]	30.03 ± 1.22 [a, b]	29.00 ± 1.95 [a, b]	29.61 ± 1.55 [a, b]	27.02 ± 1.67 [a, b]	29.61 ± 1.55 [a, b]	28.34 ± 1.75 [a, c]	30.06 ± 1.49 [a, b, c]	28.79 ± 2.14 [a, b]	< 0.001

CC - Control cookie
PCF9.6TF27, PCF100 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≤ 100 µm
PCF9.6TF27, PCF250 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≥ 100 µm and ≤ 250 µm
PCF9.6TF27, PCF500 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≥ 250 µm and ≤ 500 µm
PCF22TF24, PCF100 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≤ 100 µm
PCF22TF24, PCF250 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≥ 100 µm and ≤ 250 µm
PCF22TF24, PCF500 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≥ 250 µm and ≤ 500 µm
PCF22TF27, PCF100 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≤ 100 µm
PCF9.6TF24, PCF100 - Formulation containing 9.6% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≤ 100 µm

Values are reported as the mean ± standard deviation; n = 25

p-Value corresponds to One-Way ANOVA results.

[a] Statistically significant differences compared to CC (p < 0.05
[b] Statistically significant differences compared to PCF9.6TF27, PCF250 (p < 0.05)
[c] Statistically significant differences compared to PCF22TF24, PCF500 (p < 0.05)

Table 8 - Discrimination test results

Different sample	Wrong answer	Right answer	Total	*p.* (Binomial)	*p.* (Qui-square)
$PCF_{22}TF_{24}$, PCF_{100}	7	15	22	<0,001	0.338
$PCF_{9.6}TF_{27}$, PCF_{100}	4	15	19	<0,001	

PCF22TF24, PCF100 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≤ 100 µm
PCF9.6TF27, PCF100 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≤ 100 µm

p-Values correspond to One-Sample Binomial test and Chi-Square test results, respectively.

Table 9 - Preference test results

Sample	Prefered	Least preferred	*p.* (Binomial)	*p.* (Friedman)
CC	8	19	0.047	
$PCF_{9.6}TF_{27}$ PCF_{100}	19	11	0.049	0.281
$PCF_{22}TF_{24}$ PCF_{100}	14	11	0.500	

CC - Control cookie
PCF22TF24, PCF100 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≤ 100 μm
PCF9.6TF27, PCF100 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≤ 100 μm

p-Values correspond to the One-Sample Binomial test and to Friedman's test results, respectively.

Table 10 - Hedonic scale results

Appearance

Scale	1	2	3	4	5	6	7	8	9	Percentile	*p.*
CC Frequency				4	4	7	8	12	6	7 (6, 8)	
$PCF_{9.6}TF_{27}$ PCF_{100} Frequency		1	1	3	1	4	10	11	10	8 (7, 8)	0.427
$PCF_{22}TF_{24}$ PCF_{100} Frequency		1		2	4	2	8	16	8	8 (7, 8)	

Aroma

Scale	1	2	3	4	5	6	7	8	9	Percentile	*p.*
CC Frequency			1		13	4	10	9	4	7 (5, 8)	
$PCF_{9.6}TF_{27}$ PCF_{100} Frequency			1		9	7	1	12	5	7 (5.5, 8)	0.392
$PCF_{22}TF_{24}$ PCF_{100} Frequency				4	9	5	7	11	5	7 (5, 8)	

Flavour

Scale	1	2	3	4	5	6	7	8	9	Percentile	*p.*
CC Frequency			1	3	5	7	12	7	6	7 (6, 8)	
$PCF_{9.6}TF_{27}$ PCF_{100} Frequency			1	1	2	4	11	18	4	8 (7, 8)	0.028
$PCF_{22}TF_{24}$ PCF_{100} Frequency				5	5	11	5	11	4	7 (5.5, 8)	

Texture

Scale	1	2	3	4	5	6	7	8	9	Percentile	*p*.
CC Frequency	1		2	4	3	7	9	10	5	7 (5.5, 8)	
PCF$_{9.6}$TF$_{27}$ PCF$_{100}$ Frequency			1	2	1	3	10	18	6	8 (7, 8) [a]	< 0.001
PCF$_{22}$TF$_{24}$ PCF$_{100}$ Frequency		1	1	8	4	9	7	4	7	6 (4.5, 8) [a]	

Overall consumption experience

Scale	1	2	3	4	5	6	7	8	9	Percentile	*p*.
CC Frequency		1		1	7	6	13	8	5	8 (7, 8) [b]	
PCF$_{9.6}$TF$_{27}$ PCF$_{100}$ Frequency			1	1	1	2	11	18	7	7 (6, 8) [a, b]	0.033
PCF$_{22}$TF$_{24}$ PCF$_{100}$ Frequency				5	3	9	8	10	6	6 (7, 8) [a]	

CC - Control cookie
PCF22TF24, PCF100 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≤ 100 μm
PCF9.6TF27, PCF100 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≤ 100 μm

p-Value corresponds to Friedman's test.

[a] Statistically significant differences among PCF9.6TF27, PCF100 and PCF22TF24, PCF100 ($p < 0.05$)
[b] Statistically significant differences among CC and PCF9.6TF27, PCF100 ($p < 0.05$)

Table 11 - Penalty analysis of "JAR" attributes in overall consumption experience

CC Attributes		"Too little"	JAR	"Too much"	p.
Crunchiness	n	5	24	12	
	Med (P25, P75)	5 (5, 7.5)	7.5 (7, 8)[b]	6 (5, 7)[b]	0.002
Fibrous texture	n	5	27	9	
	Med (P25, P75)	5 (5, 7)	7 (6.5, 8)	6 (5, 7)	0.112
Whole grain/ cereal-like flavour	n	8	25	8	
	Med (P25, P75)	6.5 (4.5, 7)	7 (7, 8)	5.5 (5, 7)	0.018
Sweetness	n	11	27	3	
	Med (P25, P75)	5 (5, 6.5)[c]	7 (7, 8)[c]	6 (5.5, 6.5)	0.015

$PCF_{9.6}TF_{27}$, PCF_{100} Attributes		"Too little"	JAR	"Too much"	p.
Crunchiness	n	8	29	4	
	Med (P25, P75)	7 (6.5, 8)	8 (8, 8)[b]	6 (4.5, 7)[b]	0.005
Fibrous texture	n	4	32	5	
	Med (P25, P75)	7 (5, 7.5)	8 (7, 8)	7 (6,7)	0.017
Whole grain/ cereal-like flavour	n	4	31	6	
	Med (P25, P75)	7.5 (6, 8.5)	8 (7, 8)	7.5 (6, 8)	0.388
Sweetness	n	7	30	4	
	Med (P25, P75)	7 (7, 8)	8 (7, 8)	8 (7.5, 8)	0.700

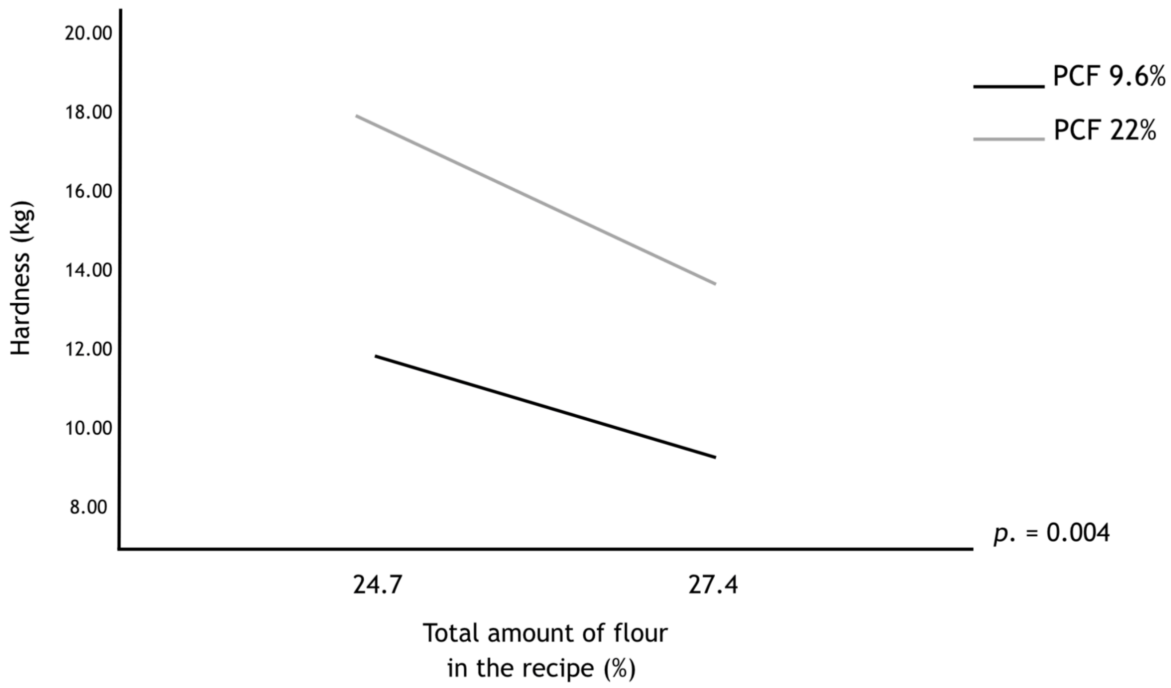
PCF22TF24, PCF100 Attributes		"Too little"	JAR	"Too much"	*p.*
Crunchiness	n	14	20	7	0.001
	Med (P25, P75)	7 (6, 7)	8 (6.5, 9)[b]	5 (4, 5.5)[b]	
Fibrous texture	n	6	24	11	
	Med (P25, P75)	6 (6, 7)	8 (7, 8.5)[b]	6 (5, 6.5)[b]	0.008
Whole grain/ cereal-like flavour	n	7	24	10	
	Med (P25, P75)	6 (5.5, 7)	8 (6.5, 8)	6 (5.5, 7)	0.054
Sweetness	n	10	26	5	
	Med (P25, P75)	6 (6, 7)	8 (6, 8)	5 (5, 6)	0.045

CC - Control cookie
PCF22TF24, PCF100 - Formulation containing 22% of PCF relative to the total amount of flour in the recipe (24.7%), using PCF with particle size ≤ 100 μm
PCF9.6TF27, PCF100 - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe (27.4%), using PCF with particle size ≤ 100 μm

p-Value corresponds to Kruskal–Wallis test.

[a] Statistically significant differences compared to "Too much" and "Too little" ($p < 0.05$)
[b] Statistically significant differences compared to "Too much" and "JAR" ($p < 0.05$)
[c] Statistically significant differences compared to "Too little" and "JAR" ($p < 0.05$)

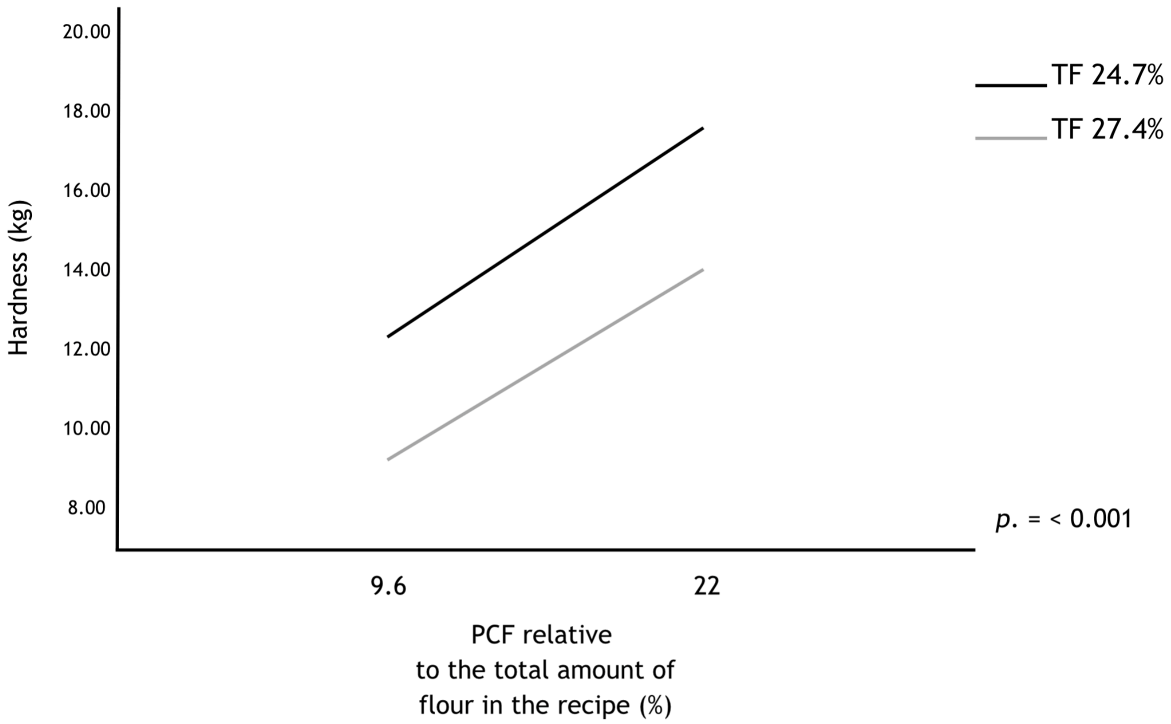
Figure 1 - Effect of the total amount of flour in the recipe on hardness (graph)



PCF 9.6% - Formulation containing 9.6%of PCF relative to the total amount of flour in the recipe
PCF 22% - Formulation containing 22% of PCF relative to the total amount of flour in the recipe

p-Value corresponds to One-Way ANOVA results

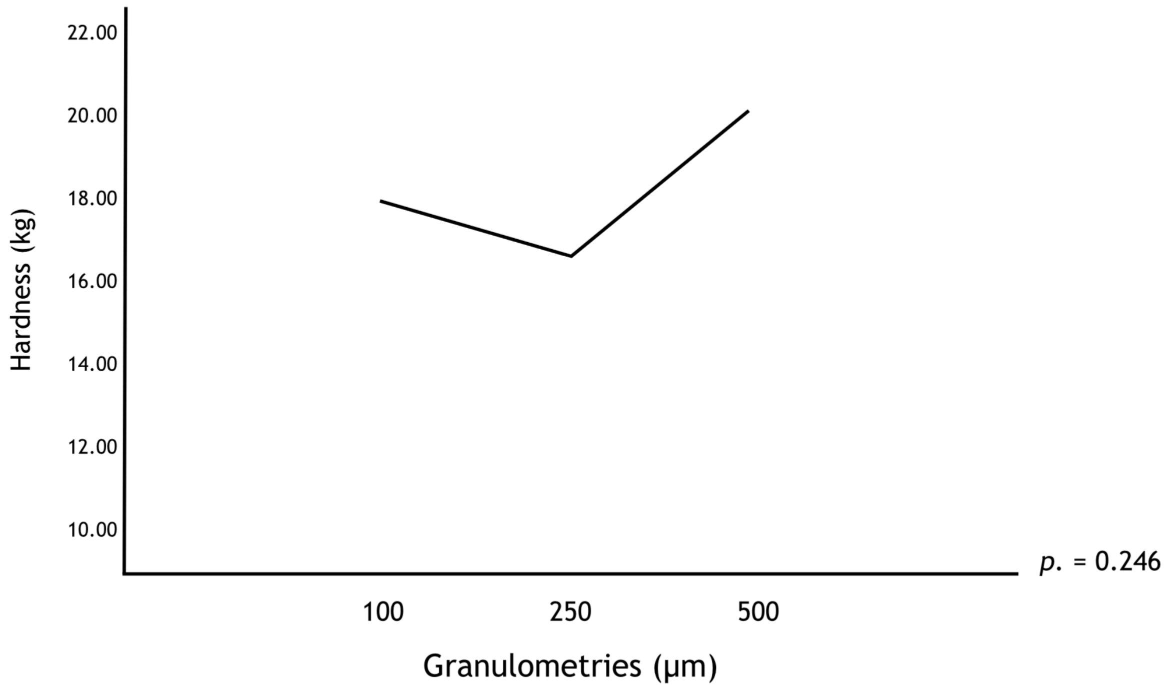
Figure 2 - Effect of PCF relative to the total amount of flour in the recipe on hardness (graph)



TF 24% - Formulation containing 24.7% of total flour
TF 27% - Formulation containing 22% of total flour

p-Value corresponds to One-Way ANOVA results

Figure 3 - Effect of different granulometries on the hardness of cookies with 22% of PCF (graph)



p-Value corresponds to One-Way ANOVA results

Figure 4 - Effect of different granulometries on the hardness of cookies with 9.6% of PCF (graph)

p-Value corresponds to One-Way ANOVA results

Appendix index

Annex A - Parecer do orientador do Trabalho Complementar

U.PORTO

FACULDADE DE CIÊNCIAS DA NUTRIÇÃO E ALIMENTAÇÃO
UNIVERSIDADE DO PORTO

PARECER

Na qualidade de coorientador do trabalho desenvolvido pela estudante Yasmin Oliveira, no âmbito do seu Trabalho Complementar de Dissertação, venho manifestar a minha apreciação muito positiva quanto à sua dedicação, empenho e competências demonstradas ao longo do processo de investigação.
A Yasmin revelou uma excelente capacidade para conduzir um trabalho de investigação com uma forte componente experimental, demonstrando autonomia na realização de ensaios laboratoriais, rigor na recolha de dados, bem como uma postura crítica na interpretação dos resultados. O seu trabalho foi marcado por um elevado sentido de responsabilidade, persistência na resolução de problemas técnicos e boa gestão do tempo, mesmo perante desafios inerentes ao desenvolvimento de um trabalho experimental desta natureza.
Além disso, mostrou uma atitude colaborativa, estando recetiva a feedback e revelando um interesse genuíno em aprofundar os aspetos científicos e metodológicos do projeto.
Face ao exposto, considero que a Yasmin reuniu as competências técnicas e científicas essenciais à realização de um trabalho de qualidade, sendo merecedora de uma avaliação muito positiva pelo trabalho realizado.

Porto, 27 de junho de 2025

Assinado por: **Duarte Paulo Martins Torres**
Num. de Identificação: 10821943

Duarte Paulo Martins Torres
Professor Associado da FCNAUP