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Journal of Agroalimentary Processes and Technologies 2026, 32 (1), 37-46

Journal of Agroalimentary Processes and Technologies

Gluten-free Oatmeal Cookie Enriched with Cranberries (*Vaccinium macrocarpon*) and Matcha Powder (*Camellia sinensis*)

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Received 2 January, 2026; Revised 2 February, 2026, Published 4 February, 2026

Abstract
In recent years, consumer demand for healthier foods with enhanced nutritional value has increased. In this context, this study aimed to develop gluten-free cookies based on oat flour enriched with matcha powder. Three formulations were prepared with 0% (OC), 5% (OCM1), and 10% (OCM2) matcha substitution. The cookies were evaluated for nutritional composition, phenolic compounds, and sensory properties. In addition, the flour composed of 90% oats and 10% matcha powder (FCOM2) was analyzed rheologically. The results showed that FCOM2 exhibited water absorption and mixing parameters suitable for cookie production according to the Chopin Mixolab. Matcha enrichment significantly increased protein and mineral contents, while lipid and carbohydrate levels decreased. Total polyphenol content increased with matcha concentration, reaching 1287.50 mg GAE/kg in OCM2. Sensory evaluation indicated that cookies containing 10% matcha powder were the most preferred due to their taste, color, and appearance. These gluten-free cookies are suitable for individuals with celiac disease.
***Keywords*:** Gluten-free cookies; celiac disease; rheological perspective; matcha powder; cranberries.

1. Introduction

The advent of celiac disease, diabetes, and cardiovascular disease has increased interest in healthy, plant-based foods, functional foods, and dietary supplements in recent years. Indeed, these foods have been identified as potential agents for health maintenance, disease prevention, and even treatment [1]. Utilizing matcha powder and cranberry as bioactive ingredients in the formulation of functional foods is a potential avenue for promoting health and well-being.

Matcha (*Camellia sinensis*) is a finely ground, unfermented Japanese green tea that is available in several forms, including leaves, tea bags, and powder. The powder is derived from young tea shoots that have been shaded for several weeks [2, 3]. In recent years, matcha has gained popularity worldwide due to its flavor, aroma, and health benefits [3]. Consequently, matcha consumption has exhibited a consistent growth trajectory, not only as a beverage but also as a functional ingredient in a variety of other beverages, snacks, chocolates, ice creams, and numerous other products, both within Japan and in international markets [3-5]. A multitude of studies have demonstrated

Citation: S. Dossa, A. Baltatu, C. Dragomir, D. Stoin, Gluten-free oatmeal cookie enriched with cranberries (Vaccinium macrocarpon) and matcha powder (Camellia sinensis), **2026**, *Journal of Agroalimentary Processes and Technologies*, 32 (1), 37-46
DOI: 10.59463/JAPT2026.1.5

that matcha powder is abundant in bioactive compounds, including catechins, phenolic acids, amino acids, vitamins, and caffeine. These compounds are advantageous to human health, exhibiting a variety of biological activities such as chemopreventive, antioxidant, and mood-enhancing properties [1]. Its high content of polyphenols, amino acids, and caffeine potentially enhances its antioxidant properties [6].

Cranberries (*Vaccinium macrocarpon*) are a commercially significant fruit native to North America [7]. The cranberry is notable for its phytochemical constituents, which have been demonstrated to possess a wide range of biochemical and physiological activities. The polyphenols present in cranberries may help reduce the risk of cardiovascular disease by increasing LDL resistance to oxidation, inhibiting platelet aggregation, and reducing blood pressure, as well as through other antithrombotic and anti-inflammatory mechanisms [7].

In consideration of the numerous benefits of matcha powder and cranberries, and in response to the demands of the contemporary world, this study proposes the incorporation of these ingredients into an oatmeal-based cookie. Indeed, the oatmeal-based cookie is also considered a functional food due to its richness in phenolic compounds as well as dietary fiber and antioxidant activity [8]. This study also investigated the nutritional, phytochemical, rheological, and organoleptic potential of enriching oat flour cookies with matcha powder and cranberry berries.

2. Materials and methods

2.1. Preparation of composite flour

Two types of compound flours were formulated as part of this study. These were FCOM1 (95% oat flour and 5% matcha powder flour) and FCOM2 (90% oat flour and 10% matcha powder flour).

2.2. Rheological analysis

To determine the effect of partially replacing oat flour with matcha flour on the rheological properties of sample FCOM2, a rheological analysis was performed according to the 'Chopin+' protocol of the Chopin Mixolab [9]. To do this, it was first necessary to determine the moisture content of the sample using a thermostat from Kern & Sohn GmbH, D-72336 Balingen, Germany. 42 g of the sample was weighed and then placed in the Mixolab bowl. There were three bowls, the characteristics of which are shown in Table 1. The mixing speed was 80 rpm.

Table 1. Mixolab parameters used to determine the rheological profile of different flours

Characteristics	First plateau	Second plateau	Third plateau
Temperature	30°C	90°C	50°C
Time	8min	7min	5min
Gradient	4 °C/min	4 °C/min	-

The parameters evaluated in this analysis were as follows: water absorption, mixing, gluten, viscosity, amylase, and retrogradation indices compared with the values required by Mixolab.

2.3. Cookie preparation

The cookies were prepared according to [10, 11], with a few modifications. All ingredients, including oat flour (OF), matcha powder (MP), cranberries, sugar, salt, butter, baking powder, and egg, used in the formulation of the different cookies, were purchased at the Auchan supermarket in Timisoara, Romania. Three (3) types of cookies (OC, OMC1, and OMC2) were formulated with different levels of OF substitution by MP (OC – control cookie with 100% OF; OMC1 – cookie with 5% MP and 95% OF; OMC2 – cookie with 10% MP and 90% OF). The production protocol is shown in the figure 1.

Table 2 shows the different cookies obtained and the composition of the ingredients used in their formulation.

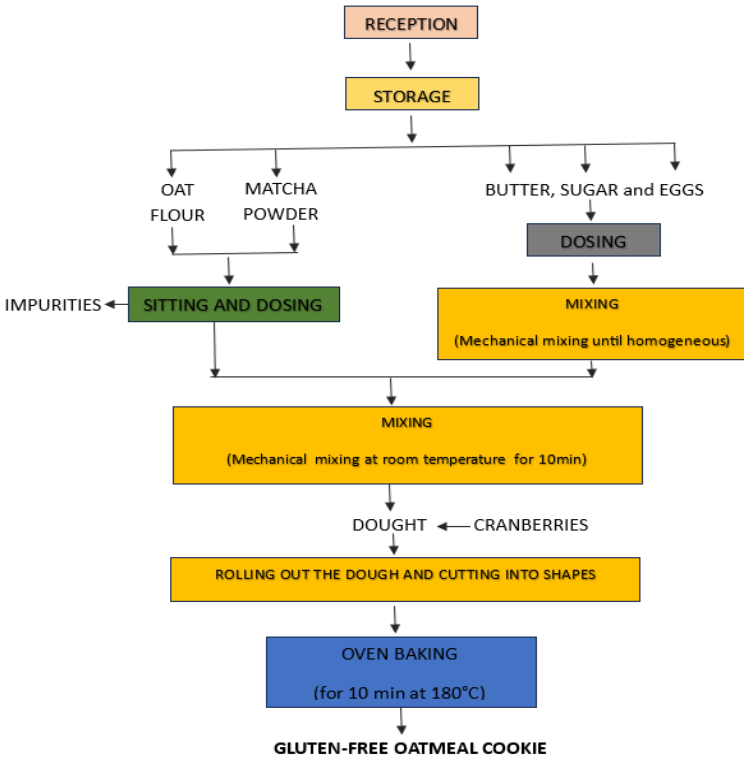

Figure 1. The technological scheme for obtaining cookies

Table 2. Different cookies obtained and the composition of the ingredients used in their formulation.

OC	OMC1	OMC2
100g oat flour 0g matcha powder	95g oat flour 5g matcha powder 25g cranberries 25 g sugar 1g salt, 45 butters, 50g egg 2g baking powder	90g oat flour 10g matcha powder

2.4. Determination of approximate composition

The approximate composition was determined using the following ISO methods:

Moisture and protein: analyzed using ICC Standard Methods (2003) [12]; lipids: measured following AOAC Official Method (2000); mineral substances: determined according to ISO Method No. 2171:2007 [13]. Carbohydrate content (g/100 g) was determined in accordance with [14] using the equations shown below:

Carbohydrates (g/100 g) = 100 - (fat + protein + water + ash).

2.5. Phytochemical profile

2.5.1. Preparation of alcoholic extracts

Alcoholic extraction was performed according to the procedure described in [15]. Alcoholic extracts were prepared by dissolving 1 g of each sample in 10 ml of 70% ethanol in a tightly sealed plastic container, then filtering after 30 minutes of shaking.

2.5.2. Evaluation of total polyphenol content

The total polyphenol content (mg gallic acid equivalents (GAE)/100 g) of the different cookie samples was determined using the previously prepared extracts. For this purpose, the Folin-Ciocâlteu method, described by Danciu *et al*. in 2019 [16] and Obistioiu *et al.* in 2021[17], was used as the reference method. All determinations were performed three times.

2.6. Sensory analysis

The sensory evaluation of the different cookies was carried out in accordance with ISO 6658:2017 [18]. Eleven (11) evaluators participated in the sensory analysis. The

subjects in the panel were aged between 20 and 45 and had received appropriate training. The panel consisted of 6 women and 5 men.

2.7. Statistical analysis

In order to ensure rigorous statistical analysis, three repetitions were performed for each parameter. It should be noted that all results obtained are expressed as averages, with a standardized margin of error. As part of the analysis of variations between mean values, Microsoft Excel 365 was used to perform a two-sample t-test. This approach was undertaken assuming equal variances. In this study, differences were considered significant if the p-value was less than 0.05.

3. Results and discussions

3.1. Mixolab Profiler Index of OMC2

The Mixolab parameters of the OMC1 formulation (consisting of 90% oat flour and 10% matcha powder) were evaluated and compared with the reference ranges recommended by the Mixolab Profiler for cookies. These ranges define the rheological behavior required for optimal cookie quality. The measured values and reference ranges are summarized in figure 2.

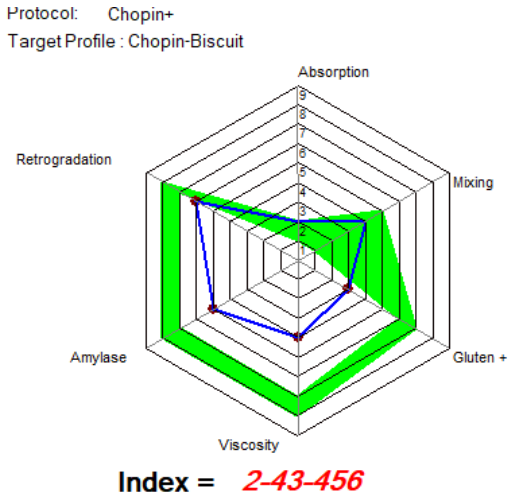

Figure 2. MIXOLAB Profiler index of OMC2. Blue line represents the profile of partially substituted wheat flours, and green line represents the profile of optimal MIXOLAB parameters for bread-making technology

The water absorption index of OMC2 was 2, which corresponds to the upper limit of the recommended range for cookie production (1–2). This result indicates a limited water requirement, which is desirable for cookie doughs as it restricts gluten-like network development and promotes dough shortness. The relatively low water absorption can be attributed to the absence of gluten-forming proteins in oat flour and to the moderate hydration capacity of oat β-glucans, which bind water without contributing to dough elasticity [19, 20]. The mixing index of OMC2 (4) fell within the optimal range (1–5), indicating satisfactory dough stability under mechanical stress. This behavior suggests that the oat–matcha matrix is sufficiently cohesive for industrial handling while remaining weak enough to prevent excessive dough development. It has been documented that analogous mixing profiles have been reported for oat-based cookie formulations that have been enriched with non-gluten plant ingredients [21].

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The gluten index of OMC2 was found to be 3, which is substantially lower than the target range for conventional cookie wheat flours (6–7). However, this deviation is indicative of the inherent absence of gluten in oat flour, as opposed to a technological limitation. In the context of cookie production, the presence of a weak protein network is advantageous, as the development of strong gluten is known to have a detrimental effect on both doughs

spread and the final texture of the product [22]. Furthermore, the polyphenolic compounds present in matcha have been shown to interact with cereal proteins, potentially reducing protein aggregation and further limiting network formation.

The starch viscosity index of OMC2 was 4, which is below the recommended range of 7–8. This reduced viscosity suggests limited starch swelling during heating, which may be explained by both the structural characteristics of oat starch and the interaction between starch granules and matcha polyphenols. As demonstrated in previous studies, the presence of phenolic compounds has been shown to impede the processes of starch gelatinization and viscosity development. This effect is attributed to the formation of non-covalent complexes between the phenolic compounds and the amylose and amylopectin chains [23].

The amylase activity index (5) also remained below the reference range. It is widely accepted that low amylolytic activity is beneficial for cookies, as it has been demonstrated to limit excessive sugar release, reduce uncontrolled Maillard reactions, and prevent undesirable surface darkening or stickiness. The partial inhibition of amylases by green tea catechins may contribute to this behavior [24].

The retrogradation index of OMC2 was found to be 6, which is lower than the optimal range for standard cookie formulations (7–8). A reduced tendency towards starch retrogradation is advantageous for cookie shelf life, as it helps maintain crispness and delays textural hardening during storage. The presence of oat β-glucans and matcha polyphenols has been shown to interfere with amylopectin recrystallization by increasing molecular mobility and steric hindrance, thereby slowing down retrogradation processes [25, 26].

Even though several Mixolab indices of OMC2 were lower than the reference values defined by the Mixolab Profiler for cookies, these differences are consistent with the functional characteristics of oat-based, gluten-free systems enriched with bioactive ingredients. In summary, OMC2 demonstrated low water absorption, limited protein structuring, moderate starch viscosity, and reduced retrogradation tendency. These properties are generally favorable for the production of cookies with a friable texture and improved storage stability. Moreover, the incorporation of matcha powder has the potential to introduce nutritional and antioxidant benefits without compromising the rheological behavior required for cookie processing.

3.2. Proximate composition of composite flours and cookies

The proximate composition of oat flour (OF), matcha flour (MF), composite flours (FCCOM1 and FCCOM2), and cookies prepared from the different formulations (OC, OMC1, and OMC2) is shown in Table 3.

Table 3. Proximate composition of oat flour (OF), matcha powder (MF), oat/matcha composite flours and the cookies obtained.

Samples	Nutritional characteristics				
	Humidity (%)	Ash (%)	Proteins (%)	Lipids (%)	Carbohydrates (g/100 g)
Composite flours					
OF	9.80 ± 0.02	1.83 ± 0.01	14.26 ± 0.05	5.33 ± 0.03	68.78 ± 0.04
MF	6.01 ± 0.01	5.2 ± 0.02	31.28 ± 0.05	3.65 ± 0.02	58.86 ± 0.06
FCOM1	9.69 ± 0.24	2.66 ± 0.02	16.05 ± 0.06	4.40 ± 0.05	67.2 ± 0.13
FCOM2	9.55 ± 0.01	3.1 ± 0.18	19.16 ± 0.05	4.12 ± 0.03	64.07 ± 0.17
Cookies					
OC	11.15 ± 0.02	1.95 ± 0.03	11.21 ± 0.01	15.12 ± 0.02	60.57 ± 0.02
OMC1	10.80 ± 0.04	2.89 ± 0.01	12.91 ± 0.01	14.65 ± 0.03	58.75 ± 0.06
OMC2	10.66 ± 0.05	3.95 ± 0.03	13.25 ± 0.02	14.05 ± 0.01	58.09 ± 0.03

Significant differences were found between the samples, illustrating the disparity in composition between oat flour and matcha powder. The moisture content of OF was found to be 9.80%, while that of MF was significantly lower (6.01%), consistent with the extensive drying processes applied during green tea powder production [27]. The incorporation of matcha up to a level of 10% did not result in a significant impact on the hygroscopicity of the composite flours, which exhibited moisture levels comparable

to those of OF. The content of ash increased progressively with the addition of matcha, from 1.83% (OF) to 2.66% (FCCOM1) and 3.10% (FCCOM2). This increase is indicative of the elevated mineral content of matcha, which has been demonstrated to be abundant in potassium, calcium, magnesium, and iron [28]. Analogous trends have been documented in cereal-based formulations fortified with tea powders [29]. The protein content of MF was found to be significantly higher than that of OF, with a marked increase in composite flours from 14.26% in OF to 19.16% in FCCOM2. Notwithstanding the fact that tea proteins do not form gluten, their incorporation nonetheless enhances the overall protein content, thereby contributing to the nutritional value of the flour blends [30].The addition of matcha led to a modest decrease in lipids, indicative of the reduced fat content of MF relative to oat flour. The carbohydrate content exhibited an inverse trend to that of protein and ash, decreasing as the matcha proportion increased, due to the dilution effect of non-carbohydrate components. With regard to formulated cookies, it was observed that the moisture content varied, with values ranging from 11.15% (OC) to 10.66% (OMC2). The slight decrease observed with increasing levels of matcha can be attributed to the water retention capacity of matcha fibers and polyphenols. These compounds can reduce free water retention after baking [31]. Moisture values were kept within acceptable limits to ensure the stability and shelf life of the cookies [32]. The analysis revealed a significant increase in ash content with matcha enrichment, from 1.95% (OC) to 3.95% (OMC2). This observation validates the hypothesis that the addition of matcha contributes significantly to the mineral enrichment of baked goods, a hypothesis already validated in previous studies on tea-enriched cookies and cakes [33-35].

The protein content exhibited an increase from 11.21% in OC to 12.91% and 13.25% in OMC1 and OMC2, respectively. Despite the potential for baking to induce protein denaturation and Maillard reactions, the observed relative increase validates the efficacy of matcha powder as a protein-enriching agent in oat-based cookies. Analogous enhancements in protein content have been documented in cookies fortified with plant powders abundant in non-gluten proteins [36]. From a nutritional perspective, this enhancement is particularly relevant for gluten-free or oat-based products, which often exhibit inadequate protein density [37]. Lipids constituted the predominant macronutrient fraction in all cookies, attributable to the presence of fat in their formulation. However, a gradual decrease was observed with matcha addition, from 15.12% (OC) to 14.05% (OMC2). This reduction may be attributable to the partial replacement of oat flour, which contains elevated levels of lipids, with matcha powder [38]. A significant decrease in carbohydrate content was observed with increasing matcha incorporation, indicative of both flour substitution and the higher proportions of proteins, minerals, and bioactive compounds introduced by matcha. This reduction may be nutritionally advantageous, contributing to lower glycemic load products [39].

Overall, the incorporation of matcha at concentrations of 5% and 10% led to the development of oat-based cookies with significantly improved nutritional quality. These cookies are characterized by a notable increase in protein and mineral content, as well as a significant reduction in carbohydrate content. These changes respond to current consumer demand for functional baked goods with an improved nutritional profile. It should be noted that the changes observed remained within technologically acceptable limits for cookie quality, indicating that matcha powder can be used effectively as a functional ingredient in oat-based cookie formulations.

3.3. Total polyphenol content

The results of the determination of the total polyphenol content of the different cookie samples are presented in the figure 3.

The addition of matcha powder to oatmeal cookies resulted in a significant increase in total polyphenol content, which rose from 992.81 mg GAE/100 g for the control cookie (OC) to 1093.59 mg GAE/100 g and 1287 mg GAE/100 g. The concentrations of GAE in the formulations containing 5% (OMC1) and 10% (OMC2) matcha were found to be 51 mg/100 g and 102 mg/100 g, respectively.

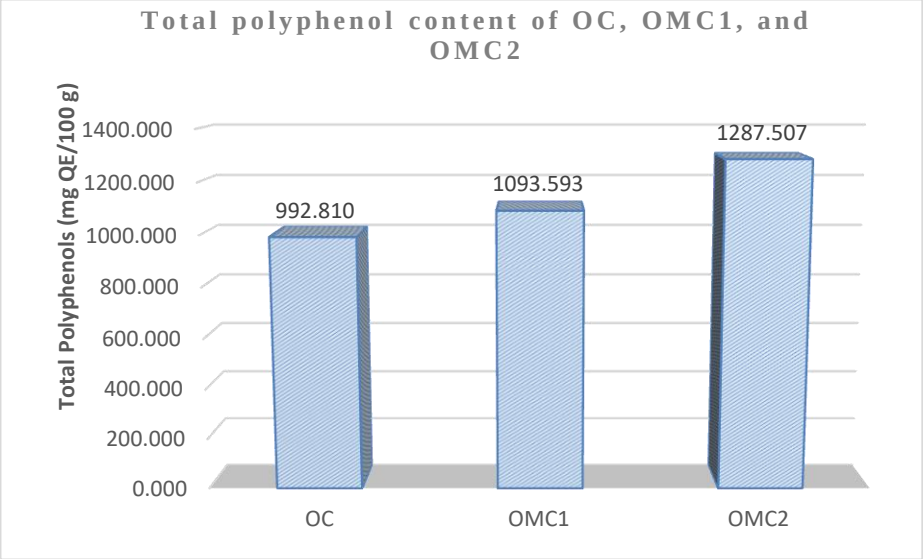

Figure 3. Total polyphenol composition of the various samples.

This increase serves to confirm the role of matcha as a concentrated source of phenolic compounds, particularly catechins such as epigallocatechin gallate, which are known for their high antioxidant properties [28, 40]. Moreover, the relatively elevated polyphenol content of the control cookie can be ascribed to the inherent presence of specific antioxidants in oats, such as avenanthramides, whose extractability can be enhanced by heat treatment [41, 42]. The incorporation of matcha has been demonstrated to enhance the functional and antioxidant potential of oat-based cookies, while preserving the contribution of endogenous cereal polyphenols [43].

3.4. Sensory profile

The sensory evaluation of cookies made with oat flour enriched with matcha powder (figure 4) demonstrates that a gradual increase in the substitution rate leads to an enhancement in the overall organoleptic attributes under investigation.

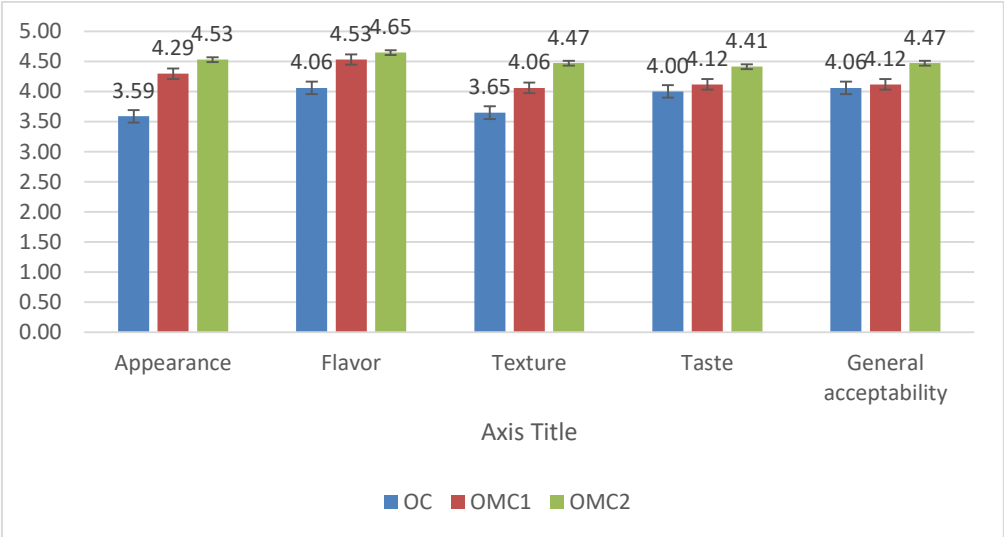

Figure 4. Sensory evaluation of cookies made with oat flour enriched with matcha powder

The control cookie (OC), formulated with 100% oat flour, has moderate sensory scores, while the incorporation of 5% (OMC1) and 10% (OMC2) matcha powder results in a noticeable improvement in appearance, flavour, texture, taste, and overall acceptability. The substantial enhancement in appearance is chiefly ascribed to the green coloring provided by the chlorophyll in matcha, which is perceived favorably by consumers and has

previously been documented in the literature for green tea-enriched baked goods [44]. The elevated flavour and taste scores observed for OMC1 and OMC2 imply that there is adequate sensory compatibility between the aromatic compounds of matcha and the oat-based matrix. Nevertheless, the extant literature highlights that elevated polyphenol content can induce bitterness and astringency, depending on the formulation [45]. The enhancement in texture observed with increasing matcha content can be attributed to the interaction of the fine fibers in matcha with the β-glucans in oats, resulting in a more homogeneous structure, as evidenced in other enriched cereal products [21].The overall acceptability of the samples, which incorporates all sensory perceptions, was found to be highest for OMC2. This finding indicates that enrichment up to 10% is well accepted by the panelists. Furthermore, these enriched formulations offer increased nutritional benefits thanks to the antioxidant polyphenols in matcha, while retaining the beneficial effects of oat β-glucans, recognized by the European Food Safety Authority (EFSA) for their role in reducing blood cholesterol [46].

4. Conclusion

This study demonstrated that incorporating matcha powder at levels of 5% and 10% into oatmeal cookies significantly improves their nutritional and functional properties without compromising their technological suitability. Rheological analyses, carried out using Mixolab, revealed dough behavior compatible with cookie-making requirements. This dough is characterized by low protein structure, moderate water absorption, and limited starch retrogradation. These parameters are favorable for obtaining crumbly cookies that are stable during storage. From a nutritional point of view, the addition of matcha led to an increase in protein, mineral, and total polyphenol concentrations, accompanied by a relative decrease in carbohydrate content. Despite the thermal constraints induced by the baking process, high retention of phenolic compounds was observed, suggesting a protective effect of the oat-matcha matrix. The results of the sensory analysis reveal that the gradual addition of matcha, at concentrations of 5% and 10%, leads to a significant improvement in appearance, flavor, texture, taste, and overall acceptability compared to the control cookie, formulated exclusively with oat flour.

Analysis of these results suggests that matcha could be a promising functional ingredient in the development of oat-based cookies, offering nutritional and antioxidant benefits. This approach meets growing consumer demand for healthier cereal products. Further research on the bioavailability of polyphenols could support the industrial use of these formulations.

Compliance with ethics requirements: Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human / or animal subjects (if exist) respect the specific regulation and standards.

Disclosure statement: No potential conflict of interest was reported by the authors.

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