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Formulation of gluten-free bread using psyllium husk and chia seed seen from physical and sensory characteristics

Monika Rahardjo [1*], Monang Sihombing [2]
[1]Food Technology Study Program, Faculty of Medicine and Health Science, Universitas Kristen Satya Wacana, Salatiga, Central Java, Indonesia
*Correspondence email: monika.rahardjo@uksw.edu

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ABSTRACT

Introduction: Gluten-free bread is a type of bread product made without gluten, and its consumption has increased in recent years, especially for individuals with celiac disease or driven by health considerations. The absence of gluten in gluten-free bread presents challenges in achieving the desired texture and structure. The incorporation of psyllium husk and chia seed into gluten-free bread formulations offers numerous benefits, both in terms of improving the bread's physical properties. Therefore, this study aims to find gluten-free bread formulations from a mixture of psyllium husk and chia seed seen from physical and sensory characteristics. **Methods**: This research method consists of the making of gluten-free bread, physical analysis (texture), sensory analysis, and statistical analysis. **Results**: For physical characteristics, psyllium husk, and chia seed incorporation affect springiness index, chewiness, adhesive force, and adhesiveness parameters in gluten-free bread, while for sensory characteristics several parameters have significant differences, namely aroma, taste, texture, and overall parameter, meanwhile appearance parameter has no significant difference. For the overall parameter, gluten-free bread with only psyllium husk (Formulation 1) received the highest rating preferred by the panelist. **Conclusion**: The incorporation of psyllium husk and chia seed affects the physical and sensory characteristics of gluten-free bread.

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INTRODUCTION

Gluten-free bread is a type of bread product made without gluten, which is a protein composite found in wheat, barley, rye, and oats (Šmídová & Rysová, 2022). The consumption of gluten-free bread has increased in recent years, especially for individuals with celiac disease, who must strictly adhere to a gluten-free diet (Garnweidner-Holme *et al.*, 2023). However, the general increase in demand for gluten-free products, including bread, is driven by health considerations (Saito *et al.*, 2022). Around 15% of the global population seeks gluten-free products not only because of celiac disease but also to maintain a healthier diet (Azizi *et al.*, 2020). The absence of gluten in gluten-free bread presents challenges in achieving the desired texture and structure. To overcome this, various alternative ingredients and techniques are used in the production of gluten-free bread. Gluten-free bread is typically made using alternative flours such as rice, corn, or starches from sources such as potatoes and cassava (Aguirre *et al.*, 2023).

The incorporation of psyllium husk into gluten-free bread formulations offers numerous benefits, both in terms of improving the bread's physical properties and enhancing its nutritional profile. Psyllium husk, derived from the seeds of *Plantago ovata*, is rich in soluble dietary fiber, which plays a crucial role in the texture and quality of gluten-free products. One of the primary advantages of using psyllium husk in gluten-free bread is its ability to enhance the dough's rheological properties. Studies have shown that the addition of psyllium husk improves the viscoelastic characteristics of gluten-free dough, making it more similar to traditional wheat dough. For instance, Bhattacharjee *et al.*, (2022) demonstrated that psyllium husk significantly enhances the viscoelastic nature of gluten-free dough compared to other binding agents like methylcellulose. This improvement in dough structure is critical for achieving a desirable bread texture, as gluten-free flours typically lack the gluten proteins that provide elasticity and strength in conventional bread (Z. Gao *et al.*, 2024).

The incorporation of chia seeds into gluten-free bread formulations offers a multitude of benefits, primarily enhancing the nutritional profile, improving textural properties, and extending shelf life. Chia seeds (*Salvia hispanica*) are rich in essential nutrients, including omega-3 fatty acids, dietary fiber, proteins, vitamins, and minerals, which contribute to the overall health benefits of gluten-free products. Their high fiber content can aid in digestion and promote satiety, making them particularly beneficial for individuals with dietary restrictions such as celiac disease or gluten intolerance (Pintado *et al.*, 2019). One of the significant advantages of using chia seeds in gluten-free bread is their ability to improve the rheological properties of the dough. The mucilage produced by chia seeds when hydrated can mimic some of the functional properties of gluten, which is crucial in gluten-free baking where the absence of gluten can lead to poor structure and texture (Da Costa Borges *et al.*, 2021; Huerta *et al.*, 2016). However, it is important to note that excessive amounts of chia can lead to a decrease in bread volume due to the high fiber content, which may interfere with gas retention during fermentation (Ziemichód *et al.*, 2019; Steffolani *et al.*, 2014).

The incorporation of psyllium husk and chia seeds into gluten-free bread formulations presents a promising avenue for enhancing the nutritional and functional properties of such products. However, several aspects of their incorporation remain under-explored, warranting further investigation. One significant area that requires more research is the optimization of the proportions of psyllium husk and chia seeds in gluten-free bread formulations. Current studies indicate that while both ingredients improve the texture and shelf life of gluten-free bread, the specific ratios that yield the best results in terms of sensory properties and nutritional benefits are not well established. For instance, the addition of chia seeds has been shown to enhance the nutritional profile by increasing dietary fiber and antioxidant content, yet the optimal percentage for maintaining bread volume and texture remains unclear (Da Costa Borges *et al.*, 2021; Steffolani *et al.*, 2014). Similarly, while psyllium husk has been noted for its ability to improve dough structure and reduce glycemic index, the precise amounts that balance these benefits with potential negative impacts on bread volume and texture have not been thoroughly investigated (Fratelli *et al.*, 2021; Gao *et al.*, 2024). Another under-explored aspect is the interaction between psyllium husk and chia seeds when used in combination. The synergistic effects of these two ingredients on dough rheology and bread quality have not been extensively studied. For example, while individual studies highlight the benefits of each ingredient, there is a lack of comprehensive research that examines how their combined use might enhance or inhibit specific properties of gluten-free bread, such as moisture retention, crumb structure, and overall sensory acceptance (Anwar *et al.*, 2024). Understanding these interactions could lead to more effective formulations that leverage the strengths of both ingredients. Therefore, this study aims to find gluten-free bread formulations from a mixture of psyllium husk and chia seed seen from physical and sensory characteristics.

METHODS

Research conducted in Food Processing Laboratory, Faculty of Medicine and Health Science Salatiga. This research method consists of the making of gluten-free bread, physical analysis (texture), sensory analysis, and statistical analysis.

Gluten-free bread making

The preparation of gluten-free bread followed the steps from Ikarini *et al.*, (2023) with modifications. The gluten-free bread formulation in this study can be seen in Table 1.

Table 1. Gluten-free bread formulation

Ingredients	Formulation 1	Formulation 2	Formulation 3	Formulation 4	Formulation 5
Tapioca Flour (g)	150	150	150	150	150
Rice Flour (g)	10	10	10	10	10
Glutinous Rice Flour (g)	10	10	10	10	10
Potato Starch (g)	5	5	5	5	5
Mocaf Flour (g)	125	125	125	125	125
Sugar (g)	30	30	30	30	30
Salt (g)	4	4	4	4	4
Egg (g)	50	50	50	50	50
Butter (g)	30	30	30	30	30
Psyllium Husk Gel (g)	12	8	6	4	0
Chia Seed Gel	0	4	6	8	12

The dry ingredients and wet ingredients were first mixed except for the salt and butter. Mixing is done using a mixer at medium speed until all ingredients are homogeneous and sugar is dissolved. After that, salt and butter were put in a container and mixed again at medium speed for about 2 minutes. The dough was then placed in a basin and awaited bulk fermentation for 30 minutes. After 30 minutes, the dough is shaped and then put into the pan and waited for proofing for 1.5 hours. The dough that has risen is then baked in the oven at 180^{o}C for approximately 30 minutes until the surface is golden brown. Gluten-free bread is finished and ready to be analyzed.

Physical analysis

Physical analysis included texture analysis performed using a Texture Analyzer (Lloyd TA Plus) by the procedure performed by Kulthe *et al.*, (2014) where the resulting analysis results were hardness, cohesiveness, springiness, gumminess, chewiness, fracture force, adhesive force, adhesiveness and stiffness.

Sensory analysis

Sensory analysis was carried out using the acceptance test of preference rating (Meilgaard *et al.*, 2016) of five parameters namely appearance, color, taste, texture, and overall acceptance. The rating used is a rating with 5 scales (scale 1 is the least preferred scale to scale 5 is the most preferred scale). The panelists used for the sensory test were 50 untrained panelists.

Statistical analysis

All datas were obtained with five repetitions and analyzed using analysis of variance (ANOVA) at α = 5% or t test to determine the real effect on each test parameter. Significant results from ANOVA calculations are then continued with Duncan's Multiple Range Test at α = 5% to determine the treatment level that provides a real difference. All statistical tests were assisted by using IBM SPSS Statistics 29 software.

RESULTS AND DISCUSSIONS

Physical analysis

Bread texture includes various aspects such as bread crumb consistency, gas bubble size distribution, and others. Bread texture is closely related to its composition and processing method, for example, high-volume bread tends to have a soft texture and high porosity, while high-density bread is denser and harder in texture (Yamsaengsung *et al.*, 2010). Evaluating bread texture involves measuring parameters such as crumb chewiness, stiffness, and relative elasticity using standardized methods. In this study, gluten-free bread texture was tested with the parameters hardness, cohesiveness, springiness, gumminess, chewiness, fracture force, adhesive force, adhesiveness, and stiffness. However, after statistical analysis using ANOVA (Analysis of Variance) on these parameters, some parameters did not have significant differences, namely the hardness, cohesiveness, springiness, gumminess, fracture force, and stiffness parameters, meanwhile, the parameters that had significant differences were springiness index, chewiness, adhesive force and adhesiveness. The results of the gluten-free bread texture analysis can be seen in Table 2.

Table 2. Physical analysis results

Parameter	Formulation 1	Formulation 2	Formulation 3	Formulation 4	Formulation 5
Hardness (gf)	339,18 ± 57,27[1]	334,78 ± 81,21[1]	430,86 ± 112,38[1]	483,11 ± 182,92[1]	338,38 ± 107, 91[1]
Cohesiveness	0,13 ± 0,01[1]	0,14 ± 0,05[1]	0,11 ± 0,04[1]	0,12 ± 0,04[1]	0,09 ± 0,04[1]
Springiness (mm)	13,14 ± 0,73[1]	13,63 ± 0,72[1]	13,02 ± 1,05[1]	13,46 ± 1,33[1]	12,61 ± 1,72[1]
Springiness Index	0,76 ± 0,04[1]	0,83 ± 0,07[1,2]	1,04 ± 0,23[2]	0,91 ± 0,24[1,2]	0,78 ± 0,20[1]
Gumminess (gf)	44,47 ± 8,52[1]	43,67 ± 15,29[1]	51,05 ± 3,49[1]	57,82 ± 24,96[1]	31,10 ± 12,56[1]
Chewiness (Nmm)	5,76 ± 1,31[1,2]	5,89 ± 2,27[1,2]	6,41 ± 3,65[1,2]	7,78 ± 3,68[2]	3,91 ± 1,78[1]
Fracture Force (kgf)	0,02 ± 0,00[1]	0,02 ± 0,00[1]	0,02 ± 0,00[1]	0,02 ± 0,00[1]	0,02 ± 0,00[1]
Adhesive Force (kgf)	0,04 ± 0,01[1]	0,05 ± 0,01[1,2]	0,07 ± 0,03[2]	0,06 ± 0,02[1,2]	0,04 ± 0,01[1]
Adhesiveness (kgf.mm)	0,07 ± 0,04[1]	0,10 ± 0,02[1,2]	0,16 ± 0,08[2]	0,14 ± 0,09[1,2]	0,08 ± 0,03[1]
Stiffness (kgf/mm)	0,04 ± 0,01[1]	0,04 ± 0,02[1]	0,06 ± 0,02[1]	0,05 ± 0,01[1]	0,06 ± 0,02[1]

Notes: Different superscript numbers in the same row indicate significant differences (α = 5%).

The springiness index is a crucial parameter in evaluating the texture of bread, reflecting its elasticity and ability to recover its original shape after deformation. This parameter is particularly significant in assessing the quality of various types of bread, including whole wheat and gluten-free varieties. Springiness is defined as the extent to which the bread crumb can return to its original height after being compressed, which is indicative of the freshness and overall quality of the bread (Terrazas-Avila *et al.*, 2024; Boz & Karaoğlu, 2013; Matos & Rosell, 2012). Research indicates that springiness is closely associated with other textural attributes such as hardness and cohesiveness. For instance, higher springiness values are typically correlated with a fresher and more elastic product, suggesting that bread with good springiness is less likely to crumble and has a more appealing mouthfeel (Fang *et al.*, 2022; Matos & Rosell, 2012). Conversely, lower springiness values can indicate brittleness, leading to a tendency for the bread to break apart during slicing (Martinez *et al.*, 2013; Matos & Rosell, 2012).

In this research, the highest springiness index value was in bread that utilized both psyllium husk and chia seed with the same value in Formulation 3. Thus it can also be seen that with the increase and decrease in the value of psyllium husk and chia seed used in bread formulation, there is no significant difference in the gluten-free bread produced. Moreover, the springiness of bread can be influenced by various factors, including the ingredients used and the baking process. The decline in the springiness index is also a critical factor in bread texture, where the bread loses moisture and elasticity, leading to a harder texture (Fik *et al.*, 2012). This relationship underscores the importance of springiness in the sensory evaluation of bread, as it contributes significantly to consumer acceptability (Pan *et al.*, 2021).

Chewiness is an important parameter in evaluating the texture of bread, representing the resistance to deformation when the bread is chewed. When the chewiness parameter of bread is high, it indicates that the bread requires more effort to chew and has a more elastic and chewy consistency. Chewiness in bread is one of the desirable attributes that can significantly influence consumer preference. Research shows that a soft and chewy texture is generally preferred by consumers (Gorman *et al.*, 2023). In this study, gluten-free bread with Formulation 4 using a higher value of chia seed than psyllium husk obtained the highest chewiness value and it was significantly different from other formulations. Meanwhile, gluten-free bread with Formulation 5 using only chia seeds obtained the smallest chewiness value.

The chewy texture of gluten-free bread made with psyllium husk and chia seeds can be attributed to several interrelated factors, including the unique properties of these ingredients, their interactions with water, and their effects on dough rheology. Psyllium husk, derived from the seeds of *Plantago ovata*, is known for its high mucilage content, which forms a gel-like substance when hydrated. This mucilage contributes significantly to the viscoelastic properties of gluten-free dough, mimicking the role of gluten in traditional bread. The gel formation enhances the dough's ability to retain moisture and provides a network that supports the structure of the bread, leading to a chewy texture (Filipčev *et al.*, 2021; Ren *et al.*, 2020). Studies have shown that the incorporation of psyllium husk improves the dough's rheological properties, resulting in better elasticity and viscosity, which are crucial for achieving a desirable texture in gluten-free products (Bhattacharjee *et al.*, 2022).

Chia seeds, on the other hand, are rich in soluble fibers and can absorb significant amounts of water, forming a gel when mixed with liquid. This property not only contributes to moisture retention in the bread but also aids in binding the ingredients together, enhancing the overall texture (Huerta *et al.*, 2018). Research indicates that the addition of chia flour or seeds can reduce the specific volume of gluten-free bread, which is often associated with a denser and chewier crumb structure (Steffolani *et al.*, 2014). The interaction between chia's gel-forming ability and the mucilage from psyllium creates a synergistic effect that further enhances the chewiness of the final product. Moreover, the balance of hydration in the dough is critical. Both psyllium and chia require adequate water to fully develop their gelling properties, which in turn influences the dough's texture.

Adhesive force and adhesiveness in bread are parameters that contribute to the overall sensory experience when consuming bread. Adhesiveness in bread texture refers to the extent to which a bread sample sticks to the palate (J. Gao *et al.*, 2015). It is an important factor in evaluating bread quality, especially in terms of texture evaluation. Adhesive force relates to the stickiness felt when consuming bread as a whole (Carson *et al.*, 2002). Studies have shown that low and uniform adhesive force values are generally desirable for bread (Dong *et al.*, 2024). In this study, it was found that gluten-free bread with Formulations 1 and 5 using only psyllium husk and chia seed had the smallest adhesive force and adhesiveness values compared to other formulations, and they were not significantly different.

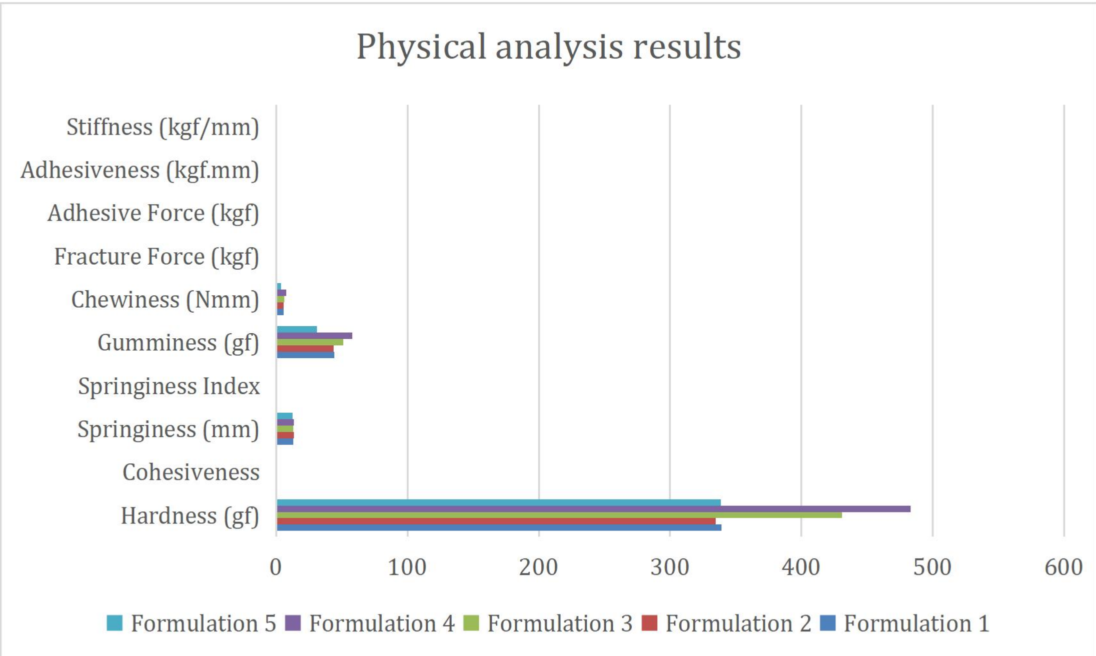

Figure 1. Physical analysis results

The use of psyllium husk and chia seeds in gluten-free bread formulations has been shown to significantly influence texture parameters, particularly adhesiveness and adhesive force. These effects can be attributed to the unique properties of both ingredients, which contribute to the overall structure and moisture retention of the bread. Psyllium husk, known for its high water absorption capacity, is crucial in gluten-free formulations, and reduces the stickiness of the dough, allowing for easier handling and shaping (Anwar *et al.*, 2024; Filipčev *et al.*, 2021). Furthermore, the incorporation of psyllium has been associated with improved dough workability and reduced adhesive force, which enhances the overall texture of the bread (Pejcz & Burešová, 2022; Belorio & Gómez, 2020).

Similar to psyllium, chia seeds can absorb large amounts of water due to their mucilaginous properties, which helps maintain moisture levels within the bread (Rados *et al.*, 2022). Studies have shown that the incorporation of chia seeds can lead to a reduction in the specific volume of gluten-free bread, which is often linked to a denser texture but can also enhance the perception of moistness (Ziemichód *et al.*, 2019; Torres-Perez *et al.*, 2023). This balance between moisture retention and texture is crucial in achieving a desirable mouthfeel while minimizing the bread's adhesiveness. Overall, the physical analysis results can be seen also in Picture 1.

Sensory analysis

Sensory analysis is an important indicator for determining food quality, which mainly uses human senses such as sight, smell, and taste to evaluate the sensory characteristics of a food, to understand people's preferences for products. Sensory analysis of gluten-free bread in this study used 50 untrained panelists with an age range of 24 to 40 years (20 men and 30 women). One significant advantage of employing untrained panelists is their ability to provide insights that are directly aligned with consumer preferences. Most consumers are not skilled in the sensory evaluation of food products; instead, they have personal experiences and preferences that inform their judgments. As such, untrained panelists can convey authentic responses that might be more relevant to the actual consumption of gluten-free bread. This aligns with findings from Bourekoua *et al.* (2018), which illustrated that using habitual bread consumers who are untrained can yield more applicable data regarding the acceptability and sensory characteristics of novel gluten-free formulations. The results of the sourdough bread sensory acceptance test can be seen in Table 3. It can be seen in Table 3 that several parameters have significant differences, namely aroma, taste, texture, and overall parameter, meanwhile appearance parameter has no significant difference.

Table 3. Sensory analysis results

Parameter	Formulation 1	Formulation 2	Formulation 3	Formulation 4	Formulation 5
Appearance	2,15 ± 0,86^{1}	2,18 ± 0,78^{1}	2,18 ± 0,787^{1}	2,00 ± 0,68^{1}	1,93 ± 0,76^{1}
Aroma	2,82 ± 1,03^{2}	2,45 ± 0,81^{1,2}	2,58 ± 1,03^{1,2}	2,18 ± 0,78^{1}	2,38 ± 0,93^{1}
Taste	2,78 ± 0,83^{3}	2,25 ± 0,74^{1,2}	2,50 ± 0,99^{2}	2,13 ± 0,79^{1,2}	1,98 ± 0,83^{1}
Texture	2,75 ± 0,90^{2}	2,35 ± 0,80^{1}	2,33 ± 0,83^{1}	2,25 ± 0,87^{1}	2,03 ± 0,89^{1}
Overall	2,65 ± 0,74^{3}	2,18 ± 0,81^{2,3}	2,40 ± 1,0^{3}	2,1 ± 0,78^{1,2}	1,98 ± 0,86^{1}

Notes: Different superscript numbers in the same row indicate significant differences (α = 5%).

The incorporation of psyllium husk and chia seed into gluten-free bread formulations significantly influences the aroma parameters, as demonstrated by various studies. The sensory analysis of gluten-free bread often reveals that the addition of these ingredients can enhance the overall aroma profile, which is critical for consumer acceptance. In this study, the best aroma rating preferred by panelists was gluten-free bread with Formulation 1 using only psyllium husk. Psyllium husk can improve bread's volume and crumb structure, which in turn affects aroma perception (Fratelli *et al.*, 2021; Ren *et al.*, 2020). The balance of moisture and the physical properties of the bread are crucial for the release of volatile compounds that contribute to aroma (Fratelli *et al.*, 2021). Moreover, research indicates that the presence of certain compounds, such as pyrazines and other Maillard reaction products, can significantly enhance the aroma of gluten-free bread (Pico *et al.*, 2018). The unique composition of psyllium husk not only contributes to texture and moisture retention but also plays a pivotal role in the development of a more complex aroma profile, which is often lacking in traditional gluten-free formulations (Iwamura *et al.*, 2022).

The incorporation of psyllium husk in gluten-free bread formulations has been shown to significantly enhance sensory attributes, particularly taste. This improvement can be attributed to several interrelated factors, including the functional properties of psyllium, its impact on the dough matrix, and the overall sensory profile of the final product. In this study, gluten-free bread Formulation 1 with only psyllium husk, had the best taste rating. Moreover, the sensory acceptability of gluten-free bread enriched with psyllium husk has been positively received by both celiac and non-celiac consumers. Research by Torres-Pérez *et al.* (2024) highlighted that gluten-free products formulated with psyllium were well-received in sensory tests, indicating a favorable perception of taste and texture. In addition, the flavor profile of gluten-free bread can be influenced by the presence of psyllium. The mucilage produced by psyllium when hydrated can interact with other ingredients, potentially enhancing the overall flavor complexity of the bread

(Ren *et al.*, 2020). This interaction may help mask some of the off-flavors commonly associated with gluten-free products, leading to a more palatable end product.

For texture parameters, gluten-free bread with Formulation 1 received the highest rating preferred by panelists. The incorporation of psyllium husk into gluten-free bread formulations has been shown to significantly enhance the textural properties of the final product, which is often a critical factor in sensory analysis. Studies have demonstrated that the addition of psyllium husk leads to a reduction in dough hardness and an increase in elasticity, which are crucial parameters for achieving a desirable bread texture (Ren *et al.*, 2020; Filipčev *et al.*, 2021). For instance, Ren *et al.* (2020) highlighted that psyllium husk enhances the viscoelastic nature of the gluten-free dough, resulting in improved texture and sensory attributes compared to other hydrocolloids like methylcellulose. Moreover, the presence of psyllium husk has been linked to a decrease in the staling rate of gluten-free bread. This is particularly important as staling can adversely affect the texture and overall acceptability of bread over time. Filipčev *et al.* (2021) reported that psyllium not only improved moisture retention in gluten-free bread but also contributed to a more favorable crumb texture, which is often preferred in sensory evaluations. This is corroborated by the findings of Bak *et al.*, who noted that the use of psyllium husk in bread formulations resulted in improved quality characteristics, including texture and chewiness (Bak *et al.*, 2023).

Then, for the overall parameter in this study, gluten-free bread with Formulation 1 also had the highest rating preferred by panelists (can be seen in Picture 2). The use of psyllium husk in gluten-free bread formulations has garnered significant attention due to its ability to enhance the sensory qualities and overall acceptability of the final product. Sensory analysis conducted by various researchers indicates that gluten-free bread incorporating psyllium husk consistently receives higher ratings from panelists compared to other formulations lacking this ingredient. This phenomenon can be attributed to several key factors related to the physical and chemical properties of psyllium. Furthermore, the sensory attributes of gluten-free bread enriched with psyllium husk have been positively correlated with consumer preferences. Studies have demonstrated that panelists frequently rate gluten-free bread containing psyllium higher in terms of overall acceptability, flavor, and texture compared to those made with other hydrocolloids or without any additives (Garcia dos Santos *et al.*, 2021; Torres-Pérez *et al.*, 2024). The unique combination of improved moisture retention, enhanced texture, and the ability to prolong freshness contributes to the favorable sensory profile of psyllium-enriched gluten-free bread.

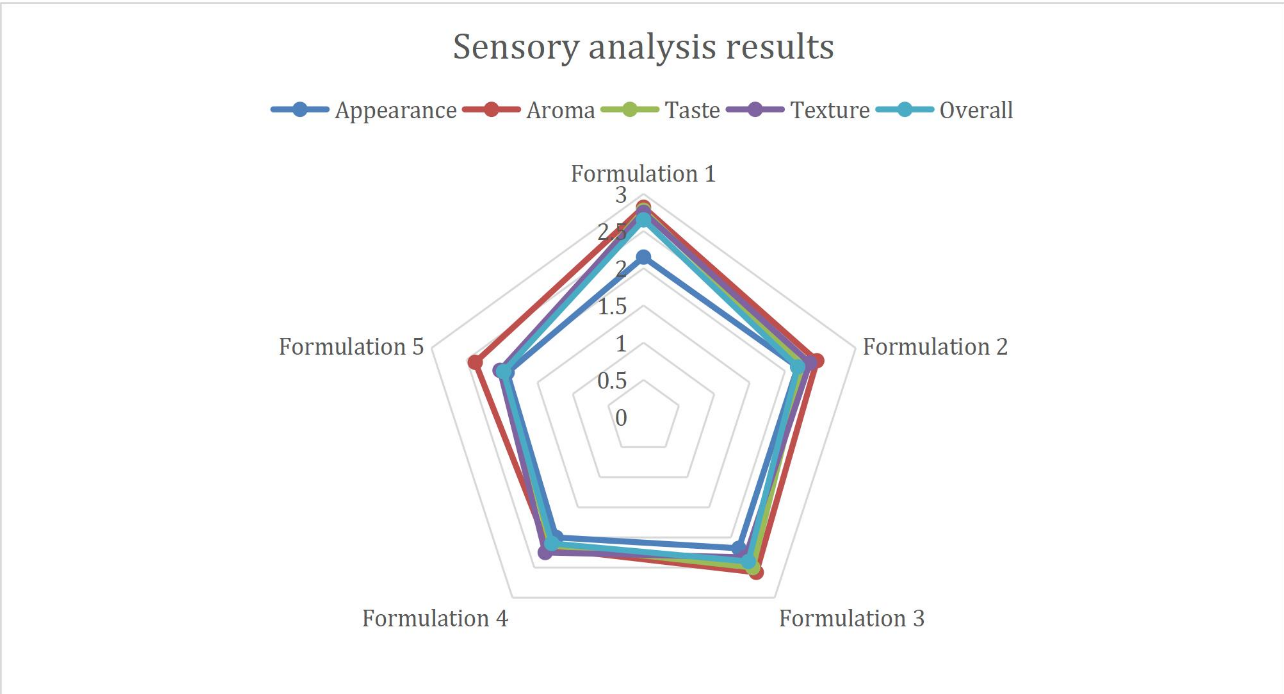

Figure 2. Sensory analysis results

CONCLUSION

The incorporation of psyllium husk and chia seed affects the physical and sensory characteristics of gluten-free bread. For physical characteristics, psyllium husk and chia seed incorporation affect springiness index, chewiness, adhesive force, and adhesiveness parameters in gluten-free bread, while for sensory characteristics several parameters have significant differences, namely aroma, taste, texture, and overall parameter, meanwhile, appearance parameter has no significant difference. For the overall parameter, gluten-free bread with only psyllium husk (Formulation 1) received the highest rating preferred by the panelist.

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