



USING FLAXSEED, YEAST EXTRACT AND PSYLLIUM AS NEW STRUCTURING AGENTS IN GLUTEN-FREE BREAD: QUALITY CHARACTERISTICS

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Abstract: Research into alternative hydrocolloids that can provide the necessary network structure for gluten-free bread production is ongoing. The aim of this study was to use alternative natural additives as gum substitutes in the production of gluten-free bread and to determine their effect on the quality characteristics of gluten-free bread. Yeast extract, flaxseed flour, and psyllium husk powder were used as gum substitutes in different proportions in the formulation. The formulations were determined using the complex lattice mixture design method. The physical, chemical, functional, textural, and sensory properties of gluten-free breads were determined. The use of ingredients alone has a negative effect on the physical and sensory properties of bread. Their use in mixtures improves the chemical, functional, and sensory properties of bread. Yeast extract increases the total antioxidant capacity and the phenolic content. However, it reduces the overall liking score. Psyllium husk powder increases the moisture content of bread and reduces baking losses. Consumers are seeking natural alternatives to products manufactured using chemical agents for both health and sensory reasons. Yeast extract, flaxseed flour, and psyllium husk powder are important alternatives to meet this demand.

Keywords: Bread, Gluten-free, Mixture design

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1. Introduction

Celiac disease is an important disease characterised by hypersensitivity to gluten proteins found in some cereals, with lesions localised in the intestine (Iversen and Sollid, 2023). The prevalence of celiac disease in North America and Europe (Finland, Germany, Italy, and the UK) is around 1%. Furthermore, the prevalence of celiac disease has increased in recent years (Mustalahti et al., 2010). It is predicted that this increase in prevalence is not only due to the rise in testing facilities but also to the loss of tolerance to gluten because of environmental factors (Lebwohl and Rubio-Tapia, 2021). There is no known cure for coeliac disease, which has become one of the most important diseases of our time. It affects the body's systems and individuals with the disease must eat a gluten-free diet (Torbica et al., 2010). Most gluten-free consumers mention the lack of product variety and taste (Caio et al., 2019). These consumer demands are compelling researchers to increase the variety of gluten-free products and the use of alternative ingredients in products.

Yeast extract, a functional food source, is commercially available in various forms. It is an important product that stands out for its high-quality nutritional content and has

the potential to be used as a flavouring agent (Zhang et al., 2019). Flaxseed (*Linum usitatissimum* L.) is widely produced in the Eastern Mediterranean region as a valuable commercial product thanks to its oily seed and high fiber content. The history of flaxseed uses dates to 5000 BC (Bernacchia et al., 2014). The use of flaxseed dates to 5000 BC (Bernacchia et al., 2014). Flaxseed is an important crop with a high nutritional content (30% protein, 25% dietary fibre, and 23% polyunsaturated fatty acids, B group vitamins and minerals) (Bernacchia et al., 2014). Psyllium husk powder is an important product recommended for consumption by the US Food and Drug Administration as a high soluble and insoluble fibre ingredient with a high arabinoxylan content (over 60%) (Franco et al., 2020). There are studies showing the positive effects of psyllium on health. It is also reported that psyllium has the potential to be used in various products such as bread, biscuits, and cakes due to its functional properties (Franco et al., 2020; Bartkiene et al., 2023; Wojciechowicz-Budzisz et al., 2023; Warsito et al., 2025).

Water-soluble polysaccharides such as hydrocolloids are used to form a stable network structure in products such as gluten-free bread and cakes (Sahin et al., 2020).



Sodium alginate, HPMC, guar, xanthan, and locust bean gum are the most used hydrocolloids for this purpose. Studies using different hydrocolloids to improve the rheological, physico-chemical, textural, and quality properties of gluten-free breads and cakes are available in the literature. Basil, sage, cress, and balangu seeds, xanthan, guar and carrageenan gums (Salehi, 2019), fenugreek gum (Roberts et al., 2012), okra gum (Alamri, 2014), tara gum (Vidaurre-Ruiz et al., 2019), psyllium husk (Fratelli et al., 2021) and flaxseed (Cakmak et al., 2021) have been tested in gluten-free products. It was found that there were limited studies on the use of yeast extract, psyllium husk, and flaxseed in gluten-free products. The aim of this study was to replace commercial hydrocolloids with different proportions of psyllium husk powder, flaxseed flour, and yeast extract in the production of gluten-free bread and investigate their effects on quality characteristics. To this end, 10 different mixtures were developed, and gluten-free bread was produced. The study is expected to make a significant contribution to the literature on the use of natural hydrocolloids in gluten-free bread.

2. Materials and Methods

2.1. Materials

Flaxseed flour, psyllium husk powder, and rice flour were obtained from Ingro Gıda (Karaman, Türkiye), yeast extract was obtained from Alfasol (Kimbiotek A.Ş., İstanbul, Türkiye), and other raw materials used in production were obtained from the local market (Tokat, Türkiye). All raw materials were stored at +4 °C until use. All other chemicals used in the present study were purchased from Sigma Chemical Company (MO, USA), Merck KGaA (Germany), or Alfa Aesar GmbH & Co KG (Germany).

2.2. Gluten-Free Bread Making

In this study, formulations were produced by selecting the "mixture design" parameters in the "Minitab 22" program in order to determine the effect of the mixture prepared with yeast extract, flaxseed flour, and psyllium powder added as an alternative to gums on bread properties. Yeast extract, flaxseed flour, and psyllium husk powder were added between 0-19.8 g. The 11 different bread formulations are shown in Table 1. The parameters used in the mixture design are shown in Table 2.

Table 1. Formulations/recipes to be used in gluten-free bread production (g)

Formulation Values of Control Bread and Gluten-Free Breads											
Raw Materials	Control (C)	Trial 1 (D1)	Trial 2 (D2)	Trial 3 (D3)	Trial 4 (D4)	Trial 5 (D5)	Trial 6 (D6)	Trial 7 (D7)	Trial 8 (D8)	Trial 9 (D9)	Trial 10 (D10)
Gluten Free Wheat Starch	195	195	195	195	195	195	195	195	195	195	195
Rice Flour	107	107	107	107	107	107	107	107	107	107	107
Corn starch	30	30	30	30	30	30	30	30	30	30	30
Potato Starch	15	15	15	15	15	15	15	15	15	15	15
Milk Powder	5	5	5	5	5	5	5	5	5	5	5
Maltodextrin	5	5	5	5	5	5	5	5	5	5	5
Sugar	10	10	10	10	10	10	10	10	10	10	10
Salt	5	5	5	5	5	5	5	5	5	5	5
Egg White Powder	1	1	1	1	1	1	1	1	1	1	1
Hydroxy Propyl Methyl Cellulose (HPMC)	0.50	0	0	0	0	0	0	0	0	0	0
Guar Gam	1	0	0	0	0	0	0	0	0	0	0
Xanthan Gum	0.50	0	0	0	0	0	0	0	0	0	0
Yeast Extract	0	19.8	0	0	9.9	9.9	0	6.6	13.2	3.3	3.3
Flaxseed Flour	0	0	19.8	0	9.9	0	9.9	6.6	3.3	13.2	3.3
Psyllium Husk Powder	0	0	0	19.8	0	9.9	9.9	6.6	3.3	3.3	13.2
Calcium Propionate	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sodium Bicarbonate	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Sodium Acid Pyrophosphate	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Liquid Yeast	30	30	30	30	30	30	30	30	30	30	30
Olive Oil	20	20	20	20	20	20	20	20	20	20	20
Water	110 mL	80 mL	90 mL	160 mL	85 mL	125 mL	135 mL	120 mL	85 mL	110 mL	100 mL
Pre-sourdough	120	120	120	120	120	120	120	120	120	120	120

Table 2. Components of formulations based on experimental design (g)

Formulation Code	Yeast Extract (g)	Flaxseed Flour (g)	Psyllium Husk Powder (g)
1	19.8	0.0	0.0
2	0.0	19.8	0.0
3	0.0	0.0	19.8
4	9.9	9.9	0.0
5	9.9	0.0	9.9
6	0.0	9.9	9.9
7	6.6	6.6	6.6
8	13.2	3.3	3.3
9	3.3	13.2	3.3
10	3.3	3.3	13.2

The formulations in Table 1 were used in the production of gluten-free bread. First, a pre-sourdough was prepared. Buckwheat flour (225 g), rice flour (40 g), ground flaxseed flour (25 g), and chickpea flour (25 g) were combined and mixed with 1110 mL of water and kept at +4 °C for 16 hours (Köse, 2021). This prepared sourdough was used for bread production. The powdered raw materials of the mixtures were weighed according to the recipes given in Table 1 and mixed in a mixer (Kitchen Aid, USA) in the 2nd stage. Olive oil was added in the 1st minute, liquid yeast in the 2nd minute, pre-sourdough in the 3rd minute, and water in the 4th minute of the mixing process, and the mixing process was continued for a total of 10 minutes at two levels. 150±1 g of the mixture was weighed into bread pans (10 × 13 × 5 cm). The dough in the molds was fermented in an oven at 35±1 °C and 90% relative humidity for 20 min. The breads were baked in pre-oiled special bread pans in a convection steam oven at 230±5 °C and 60% relative humidity (Kromlux KKFE/10, Turkey) for 20 min. They were cooled for two hours after baking, packed in polyethylene bags, and used for the analysis.

2.3. Physical Analysis

The weights (g) and heights (cm) of all the bread were measured. AACC Standard Method No. 10-05.01 (AACC, 2004) was used to determine their volumes. The baking loss value of the samples was determined by the ratio of the weight of the baked bread to the dough weight. The specific volume of the bread was calculated in mL/g using equation 1 below (Araki et al., 2009).

$$\text{Specific Volume} = \frac{\text{Volume of bread (mL)}}{\text{Weight of bread (g)}} \quad (1)$$

2.4. Chemical Analysis

The moisture (AACC Standard Method No. 44-01.01) and ash content (AACC Standard Method No. 08-01.01) of the breads were determined (AACC, 2004). The color of the crumb and crust of the bread samples was measured with a colorimeter (Minolta

Inc., CR300, Tokyo, Japan) using the Hunter L*, a*, and b* color scales. The ΔE value was calculated according to equation 2.

$$\Delta E = [(L - L_{ref})^2 + (a - a_{ref})^2 + (b - b_{ref})^2]^{1/2} \quad (2)$$

2.5. Texture Analysis

Hardness measurements of the breads were determined in N/cm² at 0, 24, 48 and 72 hours using a texture analyser (Zwick Z0.5, Germany) according to Aydin (1991). Measurements were taken using a round head with a diameter of 2 cm and an indentation depth of 10 mm. The operating conditions of the texture analyser are as follows: V_{test}: 35.0 mm/min, V_{return}: 500 mm/min, V_{pos1}: 500 mm/min, V_{pos2}: 10 mm/min, L_{max}: 10 mm, Fv 0.1 N

2.6. Total Phenolic Content and Antioxidant Capacity Analysis

To determine the functional properties of gluten-free breads (total phenolic content and total antioxidant capacity), extracts were obtained using the extraction method described by Eberhardt et al. (2000). The total phenolic content of the obtained extracts was determined using the Folin-Ciocalteu method (Singleton and Rossi, 1965), while the total antioxidant capacity was determined using the FRAP (Benzie and Strain, 1996) and DPPH (Brand-Williams et al., 1995) methods.

2.7. Sensory Analysis

The sensory evaluation of gluten-free breads was conducted using a 5-point hedonic scale. Twelve semi-trained panelists (4 women, 8 men) aged 25-55 were asked to rate the breads on shape and symmetry, crust and crumb color, crumb structure, aroma, crumb texture, taste, and flavor on a scale from 1 (very poor) to 5 (very good) (Yildirim and Arici, 2019). The sensory evaluation was conducted in the food engineering department laboratory at Tokat Gaziosmanpaşa University.

2.7.1. Statement of Informed consent

Panelists taking part in the sensory analysis were given a 'Free and Informed Consent Statement' which covered the nature of the research, the research participants, the people involved in the research, the risks and inconveniences. Following the explanations, participants were asked to freely give their consent to participate in this research. All panelists were informed and volunteered to participate. The panelists signed the consent form.

2.8. Statistical Analysis

The analysis of variance (ANOVA) of the results was performed using the IBM SPSS Statistics V21.0 statistical program (SPSS, Inc., Chicago, IL, USA). The Duncan multiple comparison test was employed to evaluate the differences between groups with a 95% confidence interval.

3. Results and Discussion

The results of physical and chemical analyses of gluten-free breads produced by adding alternative hydrocolloids are shown in Table 3. It was determined that the moisture content of the gluten-free breads varied

between 25.41-35.81%, and the bread made with the D3 formulation had the highest moisture value at 35.81% moisture value and the bread made with the D1 formulation had the lowest moisture value of 25.41%. It is predicted that the high moisture content is due to the use of psyllium husk powder in the structure. A study by Sabanis et al. (2009) reported that the moisture content of gluten-free breads containing fibre additives was between 47.42% and 53.34%. Another study reported that the moisture content of gluten-free bread is 56% (Bernardi et al., 2010).

It was determined that ash values varied between 1.14 and 1.54 %. The ash values of the samples increased as flaxseed flour was added to the gluten-free breads. It was determined that the bread made with the D10 formulation had the highest baking loss value at 15.10%, and the bread made with the D5 formulation had the lowest baking loss value at 10.74%. When the height values of the breads produced were analyzed, it was determined that the addition of flaxseed flour decreased the height values. It is a linear model that best describes the specific volume of bread. The specific volume values of the samples varied between 3.23 and 4.4 cm³/g.

Color is one of the most important physical features that consumers pay attention to when buying bread. Physicochemical properties such as baking conditions, temperature, heat transfer mode, relative humidity, amino acid, water content of dough, pH, and presence of

reducing sugars are the parameters that affect color values (Esteller and Lannes, 2008). The crust and crumb colour values of the gluten-free breads are shown in Table 4. It was found that the crust colours of the breads varied between 45.76-73.74, 4.13-14.20 and 24.75-39.29 for L*, a*, b* respectively. The L* value decreased more, and the crust color became darker in the samples to which yeast extract was added at a higher rate in the production of gluten-free bread (D1, D4, D5, and D8). In the breads where flaxseed and psyllium husk powder were mainly added, the L* value was closer to that of the control sample. Similarly, the a* value increased in the samples with more yeast extract (D1, D4, D5), whereas the increase in the a* value was limited in the samples with psyllium and flaxseed. The lowest b* value of the crust of the bread samples was found in D3, and the highest value was found in the sample coded D1.

The crust appearance of gluten-free breads is shown in Figure 1. In the ΔE value, which expresses the total colour change in the samples, D2, D3 and D6 coded breads had a total colour value closer to the control, while the sample coded D1 showed the most different colour value. The crumb colours of the breads varied between 55.81-77.62, (-0.52)-3.10 and 13.87-20.06 for L*, a* and b* respectively. In the production of gluten-free bread, the L* value decreased more, and the internal color became darker in the samples to which yeast extract and flaxseed were added at a higher rate (D1, D2, D4).

Table 3. Results of physical and chemical analyses of gluten-free bread

	Moisture (%)	Ash (%)	Baking Loss	Height Values	Specific Volume
C	30.85±2.48 ^{bc}	1.15±0.06 ^e	19.59±0.55 ^{bc}	53.0±0.6 ^a	3.92
D1	25.41±0.11 ^f	1.38±0.01 ^d	20.05±0.48 ^b	46.0±0.3 ^b	3.91
D2	28.80±0.29 ^c	1.36±0.09 ^d	18.27±0.76 ^c	40.0±0.9 ^d	3.48
D3	35.81±1.79 ^a	1.14±0.02 ^e	19.58±0.65 ^{bc}	40.0±0.4 ^d	3.85
D4	26.99±0.11 ^e	1.51±0.03 ^a	20.22±0.63 ^{ab}	46.5±0.8 ^b	3.87
D5	33.31±0.75 ^b	1.43±0.02 ^c	16.99±0.52 ^d	40.0±0.6 ^d	3.75
D6	29.70±0.12 ^c	1.38±0.03	18.65±0.53 ^c	39.0±0.2 ^e	3.67
D7	29.75±2.54 ^c	1.54±0.02 ^a	19.40±0.94 ^{bc}	45.5±0.5 ^c	3.75
D8	27.98±0.06 ^d	1.49±0.01 ^b	19.98±0.65 ^{bc}	44.0±0.4 ^d	3.86
D9	27.64±0.11 ^d	1.47±0.03 ^b	18.73±0.59 ^c	46.0±0.3 ^b	3.66
D10	32.29±0.25 ^b	1.38±0.01 ^d	21.16±0.71 ^a	46.5±0.9 ^b	3.75

The different letters indicate statistical differences at the P<0.05 level of the samples in the same column.

Table 4. Crust and crumb colour values of gluten-free breads

	Crust				Crumb			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
C	64.89±1.03 ^c	4.13±1.05 ^f	32.74±0.94 ^d	-	61.28±1.10 ^d	-0.52±0.17 ^h	13.87±0.37 ^e	-
D1	45.76±1.73 ^g	14.20±0.21 ^a	39.29±1.09 ^a	22.62±1.31	55.81±1.89	1.38±0.18 ^g	20.03±0.98 ^a	8.80±1.50
D2	57.76±1.59 ^e	5.57±1.35 ^e	31.25±1.35 ^e	7.66±5.53	56.16±0.51 ^f	2.66±0.19 ^c	15.64±0.55 ^d	6.62±2.75
D3	63.46±1.26 ^{cd}	4.38±0.22 ^f	24.75±2.16	8.23±2.07	61.23±1.45 ^d	2.89±0.19 ^b	14.56±0.85	3.78±0.58
D4	53.21±0.46 ^f	11.16±0.95 ^c	37.70±1.42 ^b	14.77±3.85	58.38±1.28 ^e	2.19±0.08 ^e	17.61±0.52 ^c	6.46±2.06
D5	55.13±1.98 ^e	11.33±0.56 ^c	37.41±0.67 ^b	13.06±1.56	65.25±1.92 ^c	1.79±0.08 ^f	18.95±0.52 ^b	6.99±1.25
D6	64.59±1.26 ^c	5.22±0.89 ^e	29.61±0.11 ^f	4.30±1.23	64.31±1.21 ^c	2.44±0.08 ^d	15.80±0.45 ^d	5.02±0.93
D7	68.10±0.63 ^b	12.47±1.75 ^b	36.77±0.38 ^b	10.44±0.82	75.89±2.02 ^b	2.95±0.13 ^b	18.47±0.45 ^b	15.72±1.96
D8	62.48±0.50 ^d	10.43±2.97 ^c	36.32±0.97 ^b	12.42±1.37	76.50±1.86 ^a	2.65±0.25 ^c	20.06±0.94 ^a	16.78±1.47
D9	73.74±1.91 ^a	9.02±0.93 ^d	34.43±0.20 ^c	10.97±2.35	74.38±1.24 ^b	2.84±0.24 ^b	17.71±0.57 ^c	14.15±1.88
D10	69.91±1.05 ^b	10.86±1.18 ^c	36.72±0.99 ^b	10.03±2.08	77.62±0.80 ^a	3.10±0.18 ^a	17.65±0.46 ^c	17.16±0.72

The different letters indicate statistical differences at the P<0.05 level of the samples in the same column.

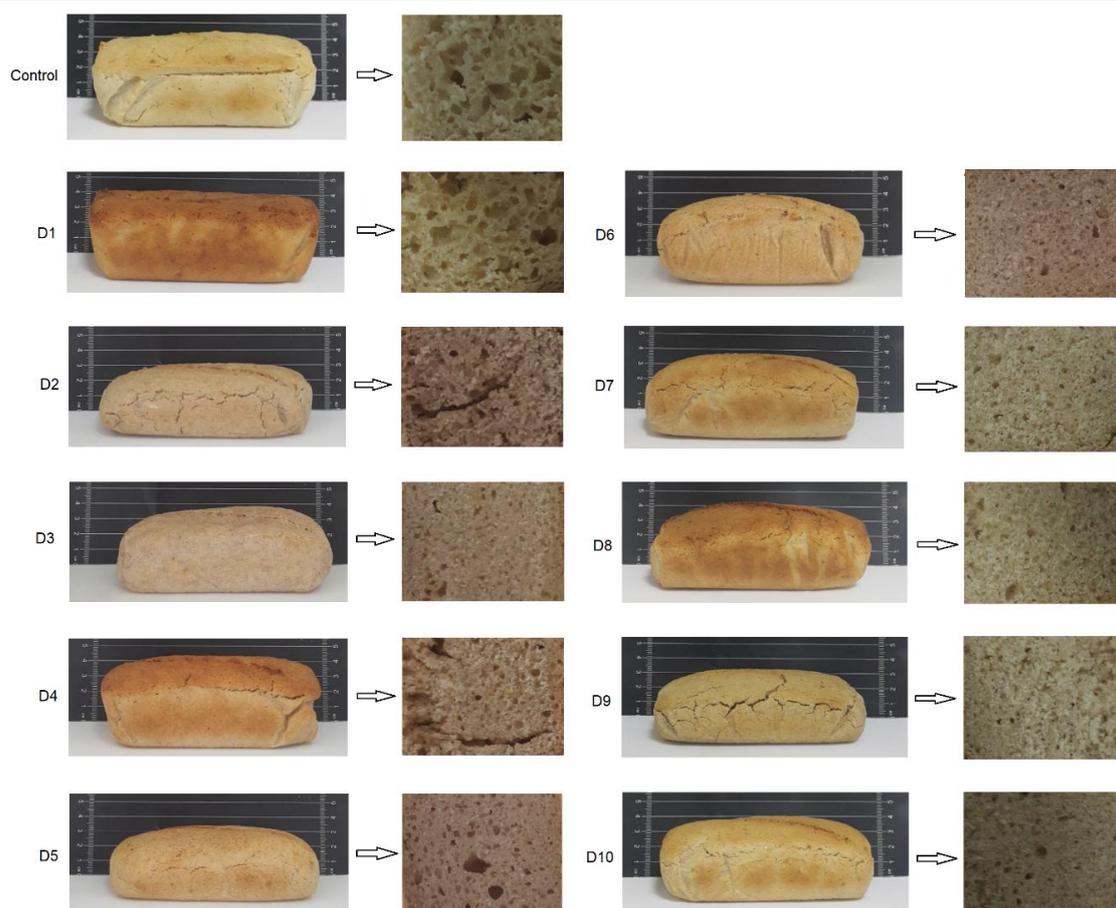


Figure 1. Crust and crumb structures of breads

In the breads where psyllium powder was the main ingredient, the L^* value was closer to that of the control sample. The samples in which three hydrocolloids were mixed in equal proportions (D7-D10) had the highest L^* . a^* increased more with the addition of yeast extract and flaxseed, whereas the increase in a^* was limited in the samples with psyllium. The crumb b^* value, which was 13.87 in the control bread, reached the highest value in the D1 and D8 samples to which yeast extract was added. The internal appearance of the gluten-free breads is shown in Figure 1. For the ΔE value, which expresses the total colour change of the samples, the bread coded D3 had the closest total colour value to the control, while the sample coded D10 had the most different colour value.

The total antioxidant capacity and total phenolic content of gluten-free breads are shown in Table 5. It was found that the DPPH, FRAP, and total phenolic content of the breads varied between 3460.50-3835.50 $\mu\text{g TE/g}$, 91.53-804.38 $\mu\text{g TE/g}$, and 253.54-1860.10 $\mu\text{g GAE/g}$, respectively. The order of effect of hydrocolloids in increasing the antioxidant capacity and total phenolic content of bread was yeast extract > flaxseed meal > psyllium husk powder. Table 6 shows the 3-day hardness values of gluten-free breads. It was found that the hardness values of the bread at the end of 0, 24, 48, and 72 hours varied between 10.48-34.75, 28.12-86.50, 43.50-95.93, and 57.55-127.57 N/cm^2 , respectively. While the hardness measured 2 hours after the oven exit

(0th hour) was 10.48 N/cm^2 in the control bread, it increased to 34.75 N/cm^2 (D2, D9) with the addition of flaxseed. At 24, 48, and 72 hours, a similar situation was observed, and flaxseed increased the hardness value of the bread. The use of psyllium husk powder, which has a high-water holding capacity, caused the internal structures of the breads to become firmer and softer (Figure 1).

The sensory evaluation of the gluten-free breads, shape and symmetry, crust colour, crumb pore structure, crumbling, flavour and aroma, odour, and overall evaluation are shown in Table 7. In the evaluation of the shape and symmetry of the breads, it was found that the highest score was given to the D7 bread obtained by mixing the hydrocolloids in equal proportions, and the lowest score was given to the D3 sample with the addition of psyllium. Crust colour is one of the parameters that increases the attractiveness of bread and has the greatest influence on consumer preference. While the highest sensory score for crust colour was given to bread coded D4, the least liked bread in terms of crust colour was D3 bread with psyllium added. The crumb pore structure of breads is an important criterion for consumers who prefer breads with a homogeneous pore structure when sliced. The highest pore structure score was observed in the control bread, followed by breads coded D4 and D9.

Table 5. Total antioxidant capacity and phenolic content values of gluten-free breads

	DPPH ($\mu\text{g TE/g}$)	FRAP ($\mu\text{g TE/g}$)	Total phenolic content ($\mu\text{g GAE/g}$)
C	3460.50 \pm 34.03 ^g	91.53 \pm 3.93 ^h	253.54 \pm 12.45 ^h
D1	3535.50 \pm 25.00 ^f	804.38 \pm 39.73 ^a	1860.10 \pm 76.79 ^a
D2	3538.00 \pm 40.00 ^f	281.46 \pm 8.59 ^f	520.71 \pm 37.88 ^f
D3	3568.00 \pm 8.16 ^f	95.69 \pm 8.56 ^h	264.24 \pm 15.06 ^h
D4	3628.00 \pm 31.62 ^e	564.79 \pm 50.39 ^c	1141.92 \pm 82.33 ^c
D5	3685.50 \pm 23.63 ^d	422.71 \pm 28.74 ^d	1136.36 \pm 33.76 ^c
D6	3563.00 \pm 68.56 ^f	159.58 \pm 11.79	403.03 \pm 30.37 ^g
D7	3678.00 \pm 52.28 ^d	407.50 \pm 15.77 ^d	912.63 \pm 58.93 ^d
D8	3835.50 \pm 37.75 ^a	656.46 \pm 61.93 ^b	1402.02 \pm 26.88 ^b
D9	3735.50 \pm 15.00 ^c	391.87 \pm 24.38 ^e	761.11 \pm 33.90 ^e
D10	3780.50 \pm 12.58 ^b	231.46 \pm 19.06 ^g	876.77 \pm 44.55 ^d

The different letters indicate statistical differences at the P<0.05 level of the samples in the same column.

Table 6. Hardness values of gluten-free breads (N/cm²)

	0 h	24 h	48 h	72 h
C	10.48 \pm 0.55 ^h	37.85 \pm 4.86 ^f	58.36 \pm 7.20 ^e	67.46 \pm 11.27 ^f
D1	20.28 \pm 1.45 ^f	32.71 \pm 5.77 ^f	52.29 \pm 7.47 ^e	71.01 \pm 11.81 ^f
D2	35.90 \pm 0.89 ^a	86.50 \pm 6.29 ^a	95.93 \pm 5.08 ^a	115.15 \pm 6.45 ^b
D3	16.25 \pm 1.27 ^g	33.52 \pm 5.09 ^f	51.23 \pm 2.80 ^e	57.55 \pm 5.59 ^g
D4	30.12 \pm 0.97 ^c	28.12 \pm 6.94	43.50 \pm 6.24 ^f	85.80 \pm 0.73 ^e
D5	24.77 \pm 1.00 ^e	45.21 \pm 1.39 ^e	55.49 \pm 2.47 ^e	81.54 \pm 4.34 ^e
D6	31.92 \pm 0.69 ^b	66.19 \pm 2.12 ^c	76.94 \pm 3.39 ^c	106.20 \pm 0.41 ^c
D7	31.92 \pm 0.69 ^b	65.67 \pm 4.67 ^c	89.17 \pm 2.78 ^b	96.46 \pm 0.36 ^d
D8	26.70 \pm 0.68 ^d	56.39 \pm 4.29 ^d	90.79 \pm 5.64 ^a	104.19 \pm 2.55 ^c
D9	34.75 \pm 0.46 ^a	68.67 \pm 1.86 ^b	90.76 \pm 4.39 ^a	127.57 \pm 6.66 ^a
D10	27.75 \pm 0.73 ^d	55.95 \pm 4.94 ^d	64.26 \pm 3.69 ^d	75.99 \pm 0.00 ^f

The different letters indicate statistical differences at the P<0.05 level of the samples in the same column.

Table 7. Sensory analysis data of gluten-free breads

	Shape and Symmetry	Crust color	Crumb Pore Structure	Crumble	Taste and aroma	Smell	General Taste
C	3.83	3.50	4.08	3.75	3.25	3.83	3.58
D1	3.75	3.58	3.25	3.00	2.00	2.42	2.50
D2	3.58	2.58	3.33	3.58	3.58	3.67	3.58
D3	3.17	2.58	2.83	4.08	4.17	4.08	3.92
D4	3.75	3.83	3.92	3.83	3.67	3.83	3.83
D5	3.58	3.00	3.00	4.17	3.50	3.58	3.58
D6	3.75	3.33	3.33	4.33	4.17	4.00	4.25
D7	4.25	3.67	3.67	3.75	3.33	3.92	3.67
D8	3.42	3.42	3.17	2.75	2.75	3.17	3.00
D9	4.00	3.58	3.92	3.17	4.08	3.75	3.83
D10	3.92	2.83	3.42	4.17	4.00	3.75	4.00

The addition of psyllium resulted in a very dense pore structure and a doughy internal structure. The main problem with gluten-free products, such as bread and cakes, is that their internal structure tends to crumble. Hydrocolloids are used to eliminate or reduce this problem. It has been found that breads made with psyllium (D3, D5, and D6) have higher crumbling scores due to the fact that psyllium has a higher water retention capacity than other hydrocolloids. While the taste and odour score was 3.25 in the control bread, the lowest score was found in the D1 sample to which yeast extract was added and the highest score was found in the D3, D6

and D10 samples to which psyllium was added. It was found that the excessive addition of yeast extract caused unwanted odour in the breads, and this situation reduced the odour score. The intense odour of the yeast extract affected both the odour score and the overall taste score. The samples coded D6, D10, and D3 had the highest overall palatability score.

4. Conclusion

In the study, in order to produce gluten-free bread, three different natural flour mixtures were used with gum substitute and, at the same time, to impart the

physicochemical properties of gluten to bread dough. In order to observe the effects of yeast extract, flaxseed flour, and psyllium powder mixtures as gum substitutes, the formulation was created by selecting the “Mixture Designing” parameters. In the study, gluten-free bread was produced using three different natural hydrocolloids instead of commercial hydrocolloids. The physical, chemical, functional, and sensory properties of the breads produced were determined. Psyllium increased the moisture content of the bread and gave it a softer texture. At the same time, it reduced the baking loss of bread. The addition of flaxseed flour reduced the rise of the breads and caused a decrease in the specific volume values. Yeast extract reduced the L* values of the breads and darkened the crust colour. Yeast extract improved the DPPH, FRAP, and total antioxidant capacity of gluten-free breads. The softest breads were those with psyllium powder. The strong odour of the yeast extract reduced the sensory acceptability of the bread. This study shows that yeast extract, flaxseed flour, and psyllium husk powder can be used as natural hydrocolloids in the production of gluten-free bread. They were found to increase the functional content of the bread and make it healthier by replacing commercial gums.

Author Contributions

The percentages of the authors’ contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	H.A.K.	A.C.	C.K.
C	30	50	20
D	50	50	
S			100
DCP	60	40	
DAI	30	70	
L	80	20	
W	50	50	
CR		50	50
SR		100	

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Panelists taking part in the sensory analysis were given a 'Free and Informed Consent Statement' which covered the nature of the research, the research participants, the people involved in the research, the risks and inconveniences. Following the explanations, participants were asked to freely give their consent to participate in this research. All panelists were informed and volunteered to participate. The panelists signed the consent form.

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