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Fiber Power: Enhancing Quality, Nutrition, and Antioxidant Boost in Rye Bread with Ground Psyllium Fiber (Mixture of *Plantago psyllium* Seeds and *Plantago ovata* Husk) †

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Abstract: The aim of the study was to determine the influence of different share (0/100, 5/95, 10/90 and 15/85 ratios) of ground psyllium fiber—mixture of 80% psyllium seeds (*Plantago psyllium*) and 20% psyllium husk (*Plantago ovata Forsk*) on the quality characteristics, chemical composition, total polyphenolic content (TPC), and antioxidant activity of rye bread. The study was conducted with rye flour type 580 and 720 and two dough preparation methods (single-phase, two-phase). Notably, the results indicated that a 10% share of psyllium fiber can be considered as a potentially beneficial functional ingredient, promoting health benefits, without negatively affecting the physical and sensory qualities of rye bread.

Keywords: psyllium; dietary fiber; rye bread; quality and nutritional value; antioxidant activity

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1. Introduction

The modern consumption model contributes to the rise of civilization diseases, notably obesity. These ailments stem from diets high in processed, low-fiber foods offering excessive empty calories. Advanced economies show growing interest in functional foods, rich in nutrients for health benefits. Such foods contain compounds like essential fatty acids, fiber, and vitamins, guarding against illnesses [1]. The World Health Organization (WHO) recommends 20–40 g of daily dietary fiber, yet we usually consume just 15 g. To bolster fiber content, a commercial mixture of psyllium fiber (PF) was created, combining 80% psyllium seeds and 20% psyllium husk. The 4:1 ratio of these elements yielded optimal soluble and insoluble fractions, enhancing satiety [2].

Psyllium, a term referring to husk, seeds, and plants of the genus *Plantago*, possesses valuable properties. Psyllium seeds contain high fiber, protein, and compounds like sterols and aucubin. They aid digestion, improve peristalsis, and impact cholesterol levels. Plantago ovata husk, rich in soluble fiber and mucus, offers a strong laxative effect. Both contribute to intestinal health [3]. PF could aid weight loss and enhance blood lipid profiles. By merging the advantages of Plantago psyllium whole seeds and Plantago ovata husk, a blend of psyllium fiber can offer a more all-encompassing strategy for supplementing fiber. This approach caters to various digestive issues and presents a wide array of benefits to support digestive health in a comprehensive manner.

Rye (*Secale cereale* L.) is the second most important cereal, next to wheat, used for the preparation of bread [4]. Rye bread is made with the dough first acidified. Sourdough rye bread undergoes lactic acid fermentation involving bacteria and yeast, yielding a distinct texture and aroma. The introduction of starter cultures has improved production efficiency, nutritional content, and sensory qualities [5]. Compared to wheat bread, which contains a similar amount of available carbohydrates, rye bread reduces the demand for insulin production more effectively, has a beneficial impact on glucose levels within the human body, and exhibits higher antioxidative activity [4].

While Psyllium's health effects are studied, few explore its incorporation into food products, particularly rye bread. This research aimed to assess how varying psyllium fiber amounts—mixture of psyllium seeds—80% and psyllium husk—20%, affect quality, nutrition, and antioxidant activity in rye bread (RB) baked with different rye flours (RF), using single-phase (1F) and two-phase methods (2F).

2. Materials and Methods

2.1. Materials

The study was conducted with RF type 580 and type 720 (GoodMills Polska Ltd., Poland) and psyllium fiber (PF) (80% psyllium seeds (*Plantago psyllium*) and 20% psyllium husk (*Plantago ovata Forsk*)) (Agnex, Białystok, Poland). PF was grinded using a laboratory hammer mill type KT 120. Compressed yeast and commercial freeze-dried Saf Levain LV2 starter cultures were supplied by Lesaffre Bio-Corporation Inc. (Poland). Light rye sourdough in paste was supplied by Uldo Polska company (Wrocław, Poland). Other ingredients were purchased from a local store.

2.1.1. Dough Formulations and Bread Baking

Rye bread (RB) was baked with the single-stage (1F) and two-phase (2F) method. In the both methods PF was used to prepare blends with RF in 0/100, 5/95, 10/90 and 15/85 ratios. The control sample was 100% RB. In the direct method (1F) the dough was prepared using 250 g of RF or RF/PF blend, yeasts—1.0 g/100 g of flour, salt—1.5 g/100 g of flour, light rye sourdough in paste—5.0 g/100 g of flour in Sigma mixer S 300 (Brabender farinograph) by adding water at a temperature of 30 °C, until the consistency of the dough was 250±20 FU. The obtained dough was placed in metal baking pans greased with oil. The dough fermented for 90 min (temperature of 30 °C, relative humidity 85%). Afterward, the dough was manually degassed and left for final fermentation. In the two-phase (2F) method, acid was first prepared by fermenting a mixture of RF (50% from the recipe) with water and the addition of 0.5% LV2 starter cultures for 18 h at 28–29 °C at a yield of 180 phase. The dough was prepared using previously made acid with pH = 4.0–4.2 (containing 50% of flour from the recipe), 50% of flour from a recipe for 250 g of flour or a RF-F blend, yeasts—1.0 g/100 g of flour, salt—1.5 g/100 g of flour, the amount of water at a temperature of 30 °C needed to obtain a dough with a consistency of 250 ± 20 FU (farinographic units). Fermentation was carried out at the temperature of 30 °C until oven maturity was obtained. The bread was baked in two replications in a GT 800 electric furnace (IBIS, Szubin, Poland), at a temperature of 250 °C for 30 min, with steaming in the first 3 min of baking. After baking, loaves were sprinkled with water and left at the room temperature to cool down. Each sample of bread after 24 h was freeze-dried and milled.

2.2. Methods

2.2.1. Bread Characteristic

After 24 h the bread was evaluated in terms of specific volume, porosity of the crumb acc. Mohs's scale, crust and crumb color and texture profile analysis (TPA). After cooling, breads were weighed to determine overbake in respect of the weight of flour used for baking. Bread volume was assessed by millet displacement method using the SA-WY bread volumeter (ZBPP, Bydgoszcz, Poland), and expressed in cm^3 per 1 g of bread. Analyses were performed at least in duplicate. Breads' crust and crumb color was measured with Minolta Colorimeter (CR-400/410, Konica Minolta, Japan). Five different points of the slice (crumb) and loaf surface (crust) with L*, a* and b* values were measured. The texture of the crumb was determined 24 h after baking. The loaves were cut into slices 13 mm thick, cylindrical samples with a diameter of 17 mm were punched from the center and the TPA test was performed in a ZWICK ROELL texturometer (Z010, Zwick Roell, Germany). The crumb sample was compressed twice with a 30 mm diameter pin to 40% of the depth. The measurement was performed in 8 replications on samples from the middle parts of the bread.

2.2.2. Chemical Composition of Breads

Breads were determined for: moisture—with the AACC Approved Method 44–15.02 [6], total protein content—with the Kjeldahl method using a Foss Tecator Kjeltec 2400 analyzer (Foss, Hilleroed, Denmark) (N × 5.7), ash content—with the AACC Method 46.11A, and total dietary fiber content (TDF)—acc. to AOAC Method 985.29 [7] using total dietary fiber assay kits TDF-100A-1KT and TDF-C10 (Sigma-Aldrich, Saint Louis, MO, USA). The samples were analyzed at least in duplicate, and the results are expressed on a dry matter (d.m.) basis.

2.2.3. Determination of Total Polyphenolic Content (TPC) and Antioxidant Activity

The total polyphenolic content (TPC) of the bread samples was determined using the Folin–Ciocalteu spectrophotometric method [8]. The absorbance at 765 nm was measured after 1 h, using the UV-2401 PC spectrophotometer (Shimadzu, Kyoto, Japan). The results were expressed as mg of gallic acid equivalents (GAE) per 100 g of dry bread (mg GAE/100g d.m.). The ABTS and FRAP methods were applied in our studies as reported by Re et al. [9] and Benzie et al. [10]. The absorbance was measured at 734 nm and 593 nm using the UV-2401 PC spectrophotometer (Shimadzu, Kyoto, Japan). The results of antiradical capacity and reducing power were expressed as Trolox equivalents in μmol per 100 g of dry sample (μM TE/100 g d.m.). Data were expressed as the mean value for three measurements.

2.3. Statistic Analysis

The results presented are mean values ± standard deviation (SD). Statistical analysis such as three-way ANOVA were analysed using Statistica 13.3 (StatSoft, Kraków, Poland). Significant differences ($p \leq 0.05$) between the mean values were determined using the Duncan's Multiple Range Test.

3. Results and Discussion

3.1. The Quality Traits and Nutritional Content of Breads

The quality features of the bread are directly influenced by the raw materials used, including additional ones, production parameters and the way of carrying out the dough.

The quality traits and nutritional content of RB enriched with PF are presented in Table 1.

Table 1. The quality traits and nutritional content of rye bread enriched with PF.

		Specific Volume [cm^3/g]	Over-Bake [%]	Porosity of the Crumb	Total Protein Content [g/100 g d.m.]	Ash [g/100 g d.m.]	TDF [g/100 g d.m.]
Rye flour type	**580**	2.59 ± 0.13 a	63.9 ± 1.9 a	6.9 ± 0.9 b	6.45 ± 0.80 b	0.76 ± 0.16 b	11.71 ± 1.87 b
	720	2.52 ± 0.36 a	66.8 ± 1.3 a	7.8 ± 1.4 a	11.17 ± 0.54 a	0.92 ± 0.15 a	16.50 ± 1.16 a
Baking method	**1F**	2.70 ± 0.23 a	72.6 ± 1.6 a	6.9 ± 1.2 b	8.90 ± 1.62 a	0.85 ± 0.19 a	14.67 ± 1.72 a
	2F	2.41 ± 0.23 b	58.1 ± 8.8 b	7.8 ± 1.3 a	8.72 ± 1.43 b	0.83 ± 0.16 a	13.54 ± 1.63 b
Share of PF [%]	**0**	2.68 ± 0.27 a	59.4 ± 1.7 b	7.1 ± 1.2 ab	7.97 ± 1.73 d	0.65 ± 0.09 d	8.89 ± 1.60 d
	5	2.62 ± 0.30 a	62.1 ± 1.6 ab	6.8 ± 1.5 b	8.53 ± 1.58 c	0.78 ± 0.12 c	12.62 ± 1.69 c
	10	2.50 ± 0.25 b	68.2 ± 1.3 ab	7.9 ± 0.8a	9.09 ± 1.48 b	0.89 ± 0.12 b	15.92 ± 1.01 b
	15	2.42 ± 0.20 b	71.8 ± 1.04 a	7.6 ± 1.5 a	9.66 ± 1.32 a	1.04 ± 0.10 a	18.98 ± 1.58 a

Values are expressed as the mean (n = 2) ± standard deviation. Mean values bearing different letters in the same row denote statistical difference (a > b > c … etc.). PF—psyllium fiber, 1F—one-phase baking method. 2F—two-phase baking method.

It was found that the type of RF had no effect on specific volume and overbake, while for porosity of the crumb (7.8 ± 1.4 points), total protein (11.17 ± 0.54 g/100 g d.m.), ash (0.92 ± 0.15 g/100 g d.m.) and TDF (16.50 ± 1.16 g/100 g d.m.), higher values were recorded for bread baked with RF type 720 than 580 (respectively 6.9 ± 0.9 points; 6.45 ± 0.80 g/100 g d.m.; 0.76 ± 0.16 g/100 g d.m.; 11.71 ± 1.87 g/100 g d.m.). Using the 1F baking method, higher values for specific volume (2.70 ± 0.23 cm^3/g), overbake (72.6 ± 1.6%), total protein (8.90 ± 1.62 g/100 g d.m.) and TDF (14.67 ± 1.72 g/100 g d.m.) were obtained than with the 2F method. Only the porosity of the 2F breads (7.8 ± 1.3 points) was rated higher than for the 1F breads (6.9 ± 1.2 points). Along with the increasing share of PF, the values of all features increased, except for specific volume, where higher values were recorded for the control bread—2.68 ± 0.27 cm^3/g and with a 5% share of PF (2.62 ± 0.30 cm^3/g) than with the 10 and 15% share of PF (respectively 2.50 ± 0.25 cm^3/g and 2.42 ± 0.20 cm^3/g).

3.2. Total Polyphenolic Content (TPC) and Antioxidant Activity

The TPC and the antioxidant activity of breads are presented in Table 2. It was found that the 720 type RF bread had a higher TPC (101.7 ± 0.92 mg GAE/100 g d.m.), antioxidant capacity (254.6 ± 1.3 μmol TE/100 g d.m.) and reducing power (903.4 ± 1.54 μmol TE/100 g d.m.) than RF type 580 (respectively 41.5 ± 0.95 mg GAE/100 g d.m., 226.8 ± 1.1 μmol TE/100 g d.m., 586.1±1.49 μmol TE/100 g d.m.). The dough preparation method had no effect on ABTS. In the case of TPC and FRAP, a higher value was obtained for the 2F method (78.2 ± 1.38 mg GAE/100 g d.m., 872.4 ± 1.66 μmol TE/100 g d.m.).

Table 2. Total polyphenolic content (TPC) and Antioxidant Activity of rye bread enriched with PF.

		TPC [mg GAE/100 g d.m.]	ABTS [μM TE/100 g d.m.]	FRAP [μM TE/100 g d.m.]
Rye flour type	**580**	41.5 ± 0.95 b	226.8 ± 1.1 b	586.1 ± 1.49 b
	720	101.07 ± 0.92 a	254.6 ± 1.3 a	903.4 ± 1.54 a
Baking method	**1F**	65.0 ± 1.12 b	236.3 ± 1.1 a	617.1 ± 1.38 b
	2F	78.2 ± 1.38 a	245.1 ± 1.2 a	872.4 ± 1.66 a
Share of PF [%]	**0**	35.5 ± 0.89 d	176.9 ± 1.7 c	437.2 ± 1.4 d
	5	58.4 ± 0.90 c	239.1 ± 1.5 b	601.9 ± 1.39 c
	10	83.4 ± 1.25 b	243.5 ± 1.1 b	890.5 ± 1.56 b
	15	109.1 ± 1.31 a	311.6 ± 1.1 a	1049.5 ± 2.46 a

Values are expressed as the mean (n = 2) ± standard deviation. Mean values bearing different letters in the same row denote statistical difference (a > b > c … etc.). PF—psyllium fiber, 1F—one-phase baking method. 2F—two-phase baking method.

In the study of Konopka et al. [11] high polyphenols content of rye flour decreased significantly during bread making process (fermentation and baking), while the total antioxidant activity (both ABTS and FRAP) increased significantly during baking. Pejcz et al. [12] observed that breads produced by the single-phase method had higher polyphenols content and ABTS antioxidant activity, possibly due to the higher acidity and composition of baking acid paste. Michalska et al. [13] explained that the baking process influences the overall antioxidant activity of rye bread by the formation of Maillard compounds during baking (antioxidants—melanoidins). In our study, with the increasing amount of PF in the bread, the antioxidant activity and the TPC increased.

3.3. Color of Crust and Crumb of Breads

The color parameters of the crust and crumb of RB enriched with PF are presented in Table 3. It was found that lighter color of the crust (L* = 35.11±1.30) and crumb (L* = 45.61 ± 1.62), a higher proportion of red (a* = 7.82 ± 1.94) and yellow (b* = 11.44 ± 1.45) color in the color of the crust was characteristic of bread baked with 580 type RF than with 720 type RF (respectively L* = 30.78 ± 1.33, L* = 40.62 ± 1.00, a* = 5.71 ± 1.84, b* = 4.91 ± 1.92).

Table 3. The color parameters of the crust and crumb of rye bread enriched with PF.

		The Crust Color			The Crumb Color		
		L*	**a***	**b***	**L***	**a***	**b***
Rye flour type	**580**	35.11 ± 1.30 a	7.82 ± 1.94 a	11.44 ± 1.45 a	45.61 ± 1.62 a	3.93 ± 0.36 a	11.42 ± 2.16 a
	720	30.78 ± 1.33 b	5.71 ± 1.84 b	4.91 ± 1.92 b	40.62 ± 1.00 b	4.05 ± 0.69 a	10.96 ± 2.84 a
Baking method	**1F**	31.21 ± 1.78 b	6.11 ± 1.44 b	7.68 ± 1.53 a	41.11 ± 1.47 b	4.26 ± 0.71 a	10.35 ± 1.59 b
	2F	34.68 ± 1.36 a	7.42 ± 1.62 a	8.68 ± 1.21 a	45.11 ± 1.16 a	3.72 ± 0.33 b	12.04 ± 1.30 a
Share of PF [%]	**0**	34.53 ± 1.66 a	8.69 ± 1.91 a	10.84 ± 1.40 a	55.05 ± 1.73 a	1.87 ± 0.27 b	18.69 ± 1.71 a
	5	34.52 ± 1.24 a	7.33 ± 1.55 b	10.30 ± 1.89 a	44.04 ± 1.43 b	4.61 ± 0.30 a	12.01 ± 1.30 b
	10	31.91 ± 1.41 ab	6.28 ± 1.54 c	7.39 ± 1.28 b	39.10 ± 1.78 c	4.72 ± 0.41 a	8.77 ± 1.14 c
	15	30.81 ± 1.38 b	4.77 ± 1.60 d	4.19 ± 0.74 c	34.26 ± 1.73 d	4.76 ± 0.86 a	5.29 ± 1.47 d

Values are expressed as the mean (n = 2) ± standard deviation. Mean values bearing different letters in the same row denote statistical difference (a > b > c … etc.). PF—psyllium fiber, 1F—one-phase baking method. 2F—two-phase baking method.

A lighter color of the crust (L* = 34.68 ± 1.36) and crumb (L* = 45.11 ± 1.16), a higher proportion of red (a* = 7.42 ± 1.62) in the color of the crust and yellow (b* = 12.04 ± 1.30) in the color of the crumb and a lower proportion of red in the color of the crumb (a* = 3.72 ± 0.33) were characterized by the bread obtained using the 2F method rather than the 1F method. With the increase in the share of PF in the breads, the color of the crust and crumb darkened, the share of red and yellow in the color of the crust and yellow in the color of the crumb decreased. The share of the red color in the crumb color for the control bread (a* = 1.87 ± 0.27) was lower than for PF-enriched breads (a* = 4.61 ± 0.30–4.76 ± 0.86). In Pejcz et al. [13] research, *Plantago* additives did not affect the brightness of the crust, while the increasing share of these additives contributed to the decrease in crumb brightness. These results agree with those of Ziemichód [15]. Pejcz et al. [14] and Ziemichód [15] made the same observations, like ours, regarding the influence of the used additives on the crumb a* and b* color factors. Similar to ours observations in the change of crumb color caused by the addition of Psyllium husk to biscuits were made by Beikzadeh et al. [16]. Aldughpassi et al. [17] stated that the addition of Psyllium husk to the wheat pita bread decreased the lightness and the b* value (yellowish color) and there was no change in the red color of crumb.

3.4. Texture Profile Analysis (TPA)

The enrichment of RB with PF influenced the TPA parameters (Table 4). It was found that the type of RF had no effect only on the gumminess. Breads baked with 580 type RF were characterized by higher values of such parameters as: cohesiveness (0.71 ± 0.03), springiness (0.92 ± 0.02), chewiness (4.00 ± 0.44 N·mm) and lower hardness (5.88 ± 1.58 N) than those baked with RF type 720 (respectively 0.56 ± 0.06, 0.75 ± 0.08, 3.05 ± 0.52 N·mm and 7.54 ± 1.92 N).

Table 4. Parameters of the Instrumental Test of Texture Profile Analysis (TPA) of rye bread enriched with psyllium fiber.

		Hardness [N]	Cohesiveness	Springiness	Gumminess [N]	Chewiness [N·mm]
Rye flour type	**580**	5.88 ± 1.58 b	0.71 ± 0.03 a	0.92 ± 0.02 a	4.34 ± 0.50 a	4.00 ± 0.44 a
	720	7.54 ± 1.92 a	0.56 ± 0.06 b	0.75 ± 0.08 b	4.13 ± 0.45 a	3.05 ± 0.52 b
Baking method	**1F**	5.27 ± 1.79 b	0.66 ± 0.08 a	0.86 ± 0.07 a	3.40 ± 0.49 b	2.92 ± 0.48 b
	2F	8.15 ± 1.24 a	0.61 ± 0.09 b	0.81 ± 0.12 b	5.08 ± 0.44 a	4.14 ± 0.44 a
Share of PF [%]	**0**	6.83 ± 1.79 a	0.64 ± 0.05 a	0.85 ± 0.09 a	4.31 ± 0.58 ab	3.67 ± 0.36 a
	5	7.06 ± 1.84 a	0.64 ± 0.08 a	0.84 ± 0.09 ab	4.40 ± 0.45 a	3.69 ± 0.40 a
	10	6.43 ± 1.34 a	0.63 ± 0.11 a	0.83 ± 0.11 bc	4.30 ± 0.44 ab	3.53 ± 0.48 ab
	15	6.51 ± 1.19 a	0.63 ± 0.10 a	0.82 ± 0.11 c	3.96 ± 0.46 b	3.23 ± 0.43 b

Values are expressed as the mean (n = 2) ± standard deviation. Mean values bearing different letters in the same row denote statistical difference (a > b > c … etc.). PF—psyllium fiber, 1F—one-phase baking method. 2F—two-phase baking method.

Breads baked using the 1F method were characterized by higher cohesiveness (0.66 ± 0.08), springiness (0.86 ± 0.07) and lower hardness (5.27 ± 1.79 N), gumminess (3.40 ± 0.49 N) and chewiness (2.92 ± 0.48 N·mm) than those baked using the 2F method (respectively 0.61 ± 0.09, 0.81 ± 0.12, 8.15 ± 1.24 N, 5.08 ± 0.44 N, 4.14 ± 0.44 N·mm). The growing share of PF in bread did not affect hardness and cohesiveness, but caused a decrease in springiness and chewiness. In the case of gumminess, the highest value was obtained for bread with a 5% share of PF (4.40 ± 0.45 N) and the lowest—15% (3.96 ± 0.46 N).

4. Conclusions

Notably, the results indicated that a 10% share of psyllium fiber can be considered as a recommended share of this functional ingredient, promoting health benefits, without negatively affecting the physical and sensory qualities of rye bread. The psyllium fiber can be considered as a functional ingredient enhancing the nutritional value of rye bread without compromising its overall quality.

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