Food Technology Research Journal, Vol. 9, issue 1, 41-58, 2025

FTRJ

Germinated Radish Seed Powder as a Functional Ingredient in Toast: Effects on Product Quality and Obesity-Linked Metabolic Health in Rats

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Original Article

Article information
Received 08/08/2025
Revised 09/09/2025
Accepted 11/09/2025
Published 13/08/2025
Available online
14/09/2025

Keywords:
Germinated radish seeds, Functional foods, Obesity, Nutritional quality, Metabolic health

ABSTRACT

This study investigated the nutritional, functional, rheological, sensory, and therapeutic effects of incorporating germinated radish seed powder (GRS) into toast formulations and its potential impact on metabolic health in obese rats. Wheat flour (72% extraction) was partially replaced with GRS at levels of 3%, 6%, 9%, and 12%. Proximate analysis showed that GRS contained substantially higher protein (32.50%), crude fat (12.30%), crude fiber (22.00%), and ash (9.00%) than wheat flour, in addition to elevated antioxidant activity (87% DPPH inhibition), total phenols (26mg GAE/g), and flavonoids (17mg QE/g). Rheological assessment revealed that GRS substitution reduced water absorption and dough extensibility, while improving dough stability and elasticity. Sensory evaluation demonstrated that lower substitution levels (3–6%) maintained high overall acceptability, whereas higher levels enhanced texture but negatively influenced flavor and appearance. Nutritional analysis of GRS-enriched toast indicated increased protein, fiber, and mineral contents, coupled with reduced available carbohydrates and caloric values. In vivo experiments showed that obese rats consuming GRS-enriched diets exhibited dose-dependent improvements in metabolic health, including significant reductions in blood glucose, total cholesterol, triglycerides, LDL, VLDL, total lipids, and liver enzymes (AST, ALT, ALP), along with increased HDL levels. Notably, the 12% substitution group achieved biochemical parameters comparable to those of the non-obese control group. Overall, the findings highlight GRS as a nutrient dense functional ingredient capable of improving bakery product quality while exerting hypoglycemic, hypolipidemic, and hepatoprotective effects, suggesting its potential role in managing obesity-associated metabolic disorders.

1. Introduction

Obesity is a complex, multifactorial condition that currently affects more than one-third of the global population (AMA adopts 2013; Ng et al., 2013; Hamano et al., 2017 Abarca-Gómez et al., 2017and Saleem et al., 2023). In Egypt, its prevalence among adults has reached approximately 40% (Aboulghate et al., 2021). It is recognized as a major risk factor for numerous chronic diseases, including type 2 diabetes, hypertension, cardiovascular disorders, liver diseases, and certain cancers, imposing substantial clinical and economic burdens on both individuals and society. Autophagy, a key cellular degradation pathway, is responsible for eliminating excess nutrients, toxic protein aggregates, damaged organelles, and invading pathogens. Under obesity-related conditions characterized by lipotoxic, proteotoxic, and oxidative stresses autophagy plays a critical role in maintaining physiological balance.

Journal website: https://ftrj.journals.ekb.eg/
Published by Food Technology Research Institute, ARC
https://10.21608/ftrj.2025.414142.1180

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However, obesity and its associated stressors can impair autophagic activity through multiple mechanisms, thereby aggravating metabolic complications. Notably, the transition from an adaptive to a maladaptive autophagic response has been linked to the progression of several diseases, particularly obesity. Interestingly, in certain contexts, selective inhibition of autophagy may produce beneficial effects, by mitigating some of the harmful consequences of obesity (Namkoong et al., 2018; Saleem et al., 2023). Cruciferous vegetables widely are cultivated and consumed worldwide, and numerous epidemiological studies and meta-analyses have confirmed their protective role against chronic diseases and cancers (Li et al., 2022). In addition to their characteristic glucosinolates (GLSs), these vegetables are rich in polyphenols, carotenoids, and vitamin C which act synergistically as anti-inflammatory and antioxidant agents (Šamec et al., 2017). Sprouted vegetables have recently attracted growing interest, particularly among health conscious consumers (Francis et al., 2022). Compared with mature plants, sprouts may contain two to ten times more phytochemicals (Choe et al., 2018) and are ready for harvest within 5–10 days (Moreno et al., 2006). The health-promoting potential of edible seeds has also been widely reported (Kakkar et al., 2023). While wheat has been extensively studied (Chen et al., 2017; Tian et al., 2019), less attention has been given to other seeds such as buckwheat, broccoli, radish, alfalfa, and brown rice (Pajak et al., 2014; Thakur et al., 2021; Wunthunyarat et al., 2020). Germination generally increases antioxidants and vitamins, though in radish seeds it may reduce sugars and some specialized metabolites such as GLSs (Liu et al., 2022; Gamba et al., 2021). These findings highlight the importance of both seeds and sprouts as research targets. *Raphanus sativus* L. (radish) has gained popularity in its sprout form due to its enhanced nutrient profile compared with the mature plant (Manivannan et al., 2019; Gamba et al., 2021). Dried radish seeds (RS, *Raphani Semen*, known as Lai Fu-zi in Chinese) are listed in the Chinese Pharmacopoeia and have long been used both as food and as traditional medicine for the treating of indigestion, abdominal distension, constipation, shortness of breath, and cough (Jacky, 2023). In India, RS has traditionally been applied to relieve asthma and other respiratory disorders, showing notable anti-inflammatory and antioxidant effects (Aruna et al., 2012). Both radish seeds and sprouts are versatile in culinary applications sprouts are commonly consumed raw, sautéed, added to salads, or soups whereas seeds are less frequently eaten directly. Thus, both forms represent valuable functional foods with significant health-promoting potential. Previous studies have examined glucosinolates (GLSs), total phenols (TP), vitamin, and antioxidant activity in radish seeds and sprouts. However, the mechanisms driving changes in these compounds during germination remain unclear and no standard germination conditions or analytical methods have been established. Phytochemical composition and antioxidant capacity vary widely depending on factors, such as light exposure, germination duration, and seed treatments (Hanlon and Barnes, 2011; Baenas et al., 2012; Kyriacou et al., 2019; Liu et al., 2022; Bowen-Forbes et al., 2023; Tilahun et al., 2023; Šola et al., 2024). GLSs are characteristic compounds of cruciferous vegetables with diverse bioactivities, including antioxidant, anti-inflammatory, anti-diabetic, neuroprotective, cholesterol-lowering, and anticancer effects (Alloggia et al., 2023). This suggests that radish seeds may offer nutritional value comparable to sprouts. Yet, no comprehensive study has directly compared their functional properties. Such comparisons would provide valuable insights for guiding dietary choices.

The aim of this study was to investigate the potential of germinated radish seed powder (GRS) as a functional ingredient in pan bread by evaluating its effects on nutritional composition, rheological properties, sensory characteristics, and product quality. In addition, the study assessed the therapeutic potential of GRS-enriched bread through in vivo experiments in obese rats, focusing on its impact on glucose regulation, lipid profile, and liver function.

2. Materials and Methods

Raw materials

Wheat flour (72% extraction) was obtained from the North Cairo Flour Mills Company, Egypt. Radish seeds were supplied by the Agricultural Research Center, Giza, Egypt.

Shortening, table salt (sodium chloride), and sugar (sucrose) were purchased were from the local market.

Germination red radish seeds

Radish seeds were first cleaned to remove broken or damaged seeds. Approximately 5,000g of seeds were soaked in 50L of tap water at room temperature for 12h. After soaking, the water was discarded, and the seeds were rinsed every 8h for 6 days to promote germination. The sprouts were then thoroughly washed, sun-dried for 3 days, and milled into a fine powder. The procedure followed the method described by Tork (2017).

Chemical composition analysis of the raw materials and their blend

Proximate composition including crude protein, crude lipids, ash, crude fiber, and available carbohydrates was determined the raw materials and their blends according to AOAC (2012). Mineral content was analyzed from diluted ash solutions using an atomic absorption spectrophotometer (Perkin-Elmer 3300), following AOAC (2012) procedures.

Determination of soluble and insoluble dietary fiber

Soluble and insoluble dietary fiber contents were measured following the method of Asp et al. (1983).

Baking experiment of toast bread

Bread preparation followed the method of El-Hadidy and El-Dreny (2020). The formula, based on flour weight at 14% moisture, included flour (100g), salt (2g), and fresh compressed yeast (1.5g). Wheat flour was partially substituted with germinated radish seed powder (GRS) at 3%, 6%, 9%, and 12%. Flours or blends were first mixed for 1 min. in a farinograph bowl. Salt and yeast were dissolved separately in water and then incorporated. The required water amount was determined according to farinograph absorption. Dough was mixed for 5 min., placed into baking pans, and fermented at 30°C with 80–90% relative humidity. After the first fermentation (45 min.), the dough was remixed and subjected to a second fermentation (45 min). Baking was performed at 220°C for 45 min. for each 400g dough portion, with steam injected into the oven to prevent excessive crust drying.

Table 1. Toast bread constituents

Ingredients (g)	Control	B3	B6	B9	B12
WF	100	97	94	91	88
GRS	--	3	6	9	12
Sugar	5	5	5	5	5
Butter	3	3	3	3	3
Salt	2	2	2	2	2
Yeast	1.5	1.5	1.5	1.5	1.5
Fresh egg	24	24	24	24	24

Control Toast bread =100% wheat flour (72% extraction rate)
B3 Toast bread = 3% Germinated radish seeds+97% wheat flour (72% extraction rate)
B6 Toast bread = 6% Germinated radish seeds+94%wheat flour (72% extraction rate)
B9 Toast bread = 9% Germinated radish seeds+91%wheat flour (72% extraction rate)
B12 Toast bread = 12% Germinated radish seeds+88%wheat flour (72%extraction rate)

Sensory evaluation of toast bread

Sensory evaluation of toast bread was conducted by 20 panelists from the staff of Sakha Food Technology Research Laboratory., Agric. Res. Center, Egypt. Panelists assessed crust color, taste, odor, crumb grain, appearance, texture, and overall acceptability following the method of Kramer and Twigg (1974). All attributes were scored using a 9-point hedonic scale as described by Larmond (1997).

Color evaluation

The color of toast bread at different substitution levels was measured using a Hunter Lab Colorimeter (Mini Scan XE Plus, Reston, VA) following the method of Gallegos-Infante et al. (2010). Color values were expressed as L* (lightness; 0 = black, 100 = white), a* (−a* = green, +a* = red), and b* (−b* = blue, +b* = yellow).

Biological experiments

Animal feeding

This study utilized 30 adult male albino rats (195 ±5g) from the Food Technology Research Institute in Giza, Egypt. After a 10-day acclimatization under standard conditions, the rats were fed a uniform basal diet (Table 2) containing 4% salt and 1% vitamin mixtures, with ad libitum access to tap water.

Table 2. Composition of experimental diets

Ingredients	Normal G1	HFD G2	HFD 3% GRS G3	HFD 6% GRS G4	HFD 9% GRS G5	HFD 12% G6
Casein	20	20	20	20	20	20
Salt mixture	3.5	3.5	3.5	3.5	3.5	3.5
Vitamin mixture	1	1	1	1	1	1
Cellulose	5	5	5	5	5	5
Corn starch	65	60	57	54	51	48
Corn oil	5	5	5	5	5	5
Coconut oil	--	15	15	15	15	15
DL-methionine	0.3	0.3	0.3	0.3	0.3	0.3
Cholic acid	0.2	0.2	0.2	0.2	0.2	0.2
Cholesterol	--	1	1	1	1	1
GRS	---	---	3	6	9	12

American Institute of Nutrition (AIN) 1993 G diets (Abdalla et al., 2021).
G1: fed on the basal diet (negative control).
G2: obese rats fed on basal diet (Positive control).
G3: obese rats were fed on 3% germinated radish seeds powder.
G4: obese rats were fed on 6% germinated radish seeds powder.
G5: obese rats were fed on 9% germinated radish seeds powder.
G6: obese rats were fed on 12% germinated radish seeds powder

Design of experiment

Thirty adult male albino rats (195±5g) were obtained from the Animal House of the Agricultural Research Center, Giza, Egypt. Animals were acclimatized for 10 days under standard laboratory conditions (22±2°C, 12 h light/dark cycle) with free access to food and water. After acclimatization, rats were randomly assigned into six groups (n = 5 each): Normal control (NC): fed a standard diet, Obese control (OC): fed a high-fat diet (HFD), HFD+3% GRS: obese rats fed HFD containing 3% germinated radish seed powder, HFD+6% GRS: obese rats fed HFD containing 6% GRS, HFD+9% GRS: obese rats fed HFD containing 9% GRS, HFD+12% GRS: obese rats fed HFD containing 12% GRS, Diets were formulated according to AIN-93 guidelines and administered for 8 weeks. Body weight and feed intake were recorded weekly. At the end of the feeding period, rats were fasted overnight, anesthetized, and blood samples were collected from the retro-orbital plexus. Serum was separated for biochemical analysis, including glucose, lipid profile (total cholesterol, triglycerides, HDL, LDL, VLDL), and liver enzymes (AST, ALT, ALP).

Blood sampling

After the induction of injury in the obese rats and at the end of the experimental period, blood samples were obtained from the lateral tail vein following a 12 -hour fast. Using micro-capillary glass tubes, blood was collected into dry, clean centrifuge tubes and allowed to clot in a water bath at 37°C for 30 minutes, according to the method described by El-Hadidy and Boriy (2024). The samples were then centrifuged at 3000 rpm for 10 minutes to separate the serum. A portion of the serum was immediately used for glucose determination. The remainder was carefully transferred into clearly labeled, fit-for-purpose plastic tubes and stored frozen at -18°C until the analysis of the remaining biochemical parameters.

Biochemical analysis and enzymes assays

Determination of serum glucose

Blood glucose measurement

Blood glucose levels were measured in serum using a commercial kit (Spain React Company, Spain) according to the method of Trinder (1969).

Serum lipid analysis

Serum lipid profiles were determined using established methods. Total lipids were estimated by Knight et al. (1972), and triglycerides were determined according to Fassati and Prencipe (1982). Total cholesterol and high density lipoprotein (HDL) cholesterol were assayed using the method described by

Allain (1974). Very-low-density lipoprotein (VLDL) and low-density lipoprotein (LDL) cholesterol levels were calculated using the following equations:

VLDL (mg/dL) = Triglycerides / 5

LDL (mg/dL) = Total cholesterol - (HDL + VLDL)

as described by Lee and Nieman (1996).

Liver function assays

Liver enzyme activities were determined as follows: aspartate aminotransferase (AST) by Henry (1974), alanine aminotransferase (ALT) by Varley et al. (1980), and alkaline phosphatase (ALP) by Rosalki and Foo (1984).

Statistical analysis

Data are presented as mean ± standard deviation (S.D.). Statistical analyses were performed using SPSS-PC software (version 26.0). Differences between groups were assessed by one-way analysis of variance (ANOVA).

3.Results and Discussion

Chemical analysis of wheat flour and germinated radish seeds

Table 3 presents a comparative analysis of the chemical composition of wheat flour and germinated radish seeds, highlighting the significant nutritional enhancements resulting from germination. Wheat flour, a common staple, exhibited a higher moisture content (14.00%) than the germinated radish seeds (7.00%), a factor that may influence product shelf life and microbial stability. The germination process markedly increased the nutritional value of the radish seeds. Their crude protein content (32.50%) was substantially higher than that of wheat flour (12.20%), positioning them as a superior plant-based protein source. Similarly, the crude fat (12.30%) and crude fiber (22.00%) contents in the germinated seeds far exceeded those in wheat flour (1.75% and 0.85%, respectively), indicating a greater potential to provide essential fatty acids and promote digestive health. The ash content, an indicator of total mineral content, was also significantly greater in the germinated seeds (9.00%) than in wheat flour (0.65%), suggesting a richer micronutrient profile. Conversely, wheat flour contained a much higher proportion of available carbohydrates (84.55%) compared to germinated radish seeds (24.20%), consistent with its primary role as an energy-dense staple. Despite this difference, the energy value of wheat flour (412.60 kcal/100g) was only moderately higher than that of the germinated seeds (344.40 kcal/100g), which can be attributed to the latter's higher protein and fat content. Overall, germinated radish seeds offer a more nutrient-dense profile, establishing them as a valuable functional ingredient for enhancing the nutritional quality of food products. They are particularly suited for high-protein, high-fiber formulations aimed at managing metabolic disorders or improving overall health. These findings align with previous research (El-Dreny and EL-Hadidy, 2018; El-Dreny, 2019; Tork et al., 2019; El-Hadidy, 2020; Abd Allah and Abd-Elrahman, 2021; Hanafi, 2025; EL-Hadidy et al., 2025).

Table 3. Chemical analysis of wheat flour and germinated radish seeds

Components	Wheat flour	Germinated radish seeds
Moisture%	14.00^{a}±0.35	7.00^{b}±0.10
Crude protein%	12.20^{b}±0.25	32.50^{a}±0.20
Crude fat%	1.75^{b}±0.01	12.30^{a}±0.05
Crude fiber%	0.85^{b}±0.02	22.00^{a}±0.10
Ash%	0.65^{b}±0.01	9.00^{a}±0.05
Available Carbohydrates%	84.55^{a}±0.15	24.20^{b}±0.10
Energy (K/100cal)	412.60^{a}±0.20	344.40^{b}±0.25

Each value was an average of three determination ± standard deviation.
Different letters indicate to significant differences between groups in the same column (p≤0.05)

Phytochemicals of wheat flour and germinated radish seeds

As shown in Table 4, a significant difference exists in the dietary fiber content between wheat flour and germinated radish seeds. Wheat flour contains a low total dietary fiber content of 0.85g/100g dry weight (DW), comprising 0.35g of soluble fiber and 0.50g of insoluble fiber.

In contrast, germinated radish seeds provide a remarkably higher total of 22g/100g DW, which includes 7g of soluble fiber and 15g of insoluble fiber. This dramatic increase indicates that germination transforms radish seeds into a rich source of functional dietary fiber. Soluble fiber aids in lowering blood cholesterol and regulating glucose levels by forming viscous gels in the digestive tract, while insoluble fiber enhances gastrointestinal health by promoting bowel regularity. The high fiber content suggests strong potential for germinated radish seeds as a functional food ingredient aimed at improving digestive health, supporting weight management, and reducing the risk of chronic diseases such as diabetes and cardiovascular disease. Overall, their incorporation into food products can significantly enhance the dietary fiber profile and associated health benefits compared to conventional wheat flour.

Antioxidant Parameters

The antioxidant parameters of wheat flour (72% extraction) and germinated radish seeds also exhibit a substantial difference, highlighting the superior antioxidant potential of the germinated seeds. Germinated radish seeds recorded a markedly higher total phenolic content (26mg GAE/g) compared to wheat flour (0.75mg GAE/g). Similarly, the total flavonoid content was significantly greater in the seeds (17mg QE/g) than in the flour (0.23mg QE/g). As these phytochemicals are known for potent free radical scavenging, the antioxidant activity measured by DPPH radical inhibition was consequently far greater in the germinated seeds (87%) than in wheat flour (11%). This dramatic improvement is attributed to the germination process, which activates metabolic pathways that synthesize phenolic compounds and flavonoids. Therefore, incorporating germinated radish seed powder into food formulations could significantly elevate their antioxidant capacity and functional value. These findings on both fiber and antioxidant content align with previous research (El-Dreny and El-Hadidy, 2018; El-Dreny, 2019; Tork et al., 2019; El-Hadidy, 2020; Abd Allah and Abd-Elrahman, 2021; Hanafi, 2025; EL-Hadidy et al., 2025).

Table 4. Phytochemicals of wheat flour and germinated radish seeds

Component (g/100g DW)	Wheat flour	Germinated radish seeds
Total dietary fiber	0.85	22
Soluble fiber	0.35	7
Insoluble fiber	0.50	15
Antioxidants parameters		
Total phenols (mg GAE/g)	0.75	26
Total flavonoids (mg QE/g)	0.23	17
Antioxidant activity (DPPH)	11	87

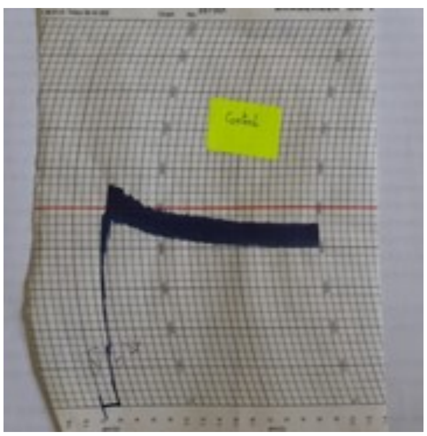
Farinograph parameters dough enrichment with germinated radish seeds

Table 5 and Figure 1 present the Farinograph parameters for dough enriched with varying levels of germinated radish seed powder, demonstrating its significant impact on dough rheology. The control dough (100% wheat flour) exhibited a water absorption of 63.20%, with an arrival time of 1.0 minute, a dough development time of 1.5 minutes, stability of 2.5 minutes, and a degree of softening of 70 B.U. The incorporation of germinated radish seeds led to several key changes: Water absorption gradually decreased to 60.8% at the 12% substitution level. This reduction is likely attributed to the seeds' lower starch content and higher levels of fat and fiber, which possess different water-binding capacities than wheat gluten and starch (Shaban et al., 2023). Dough development time increased from 1.5 minutes (control) to 3.5 minutes at 9% substitution, indicating a slower formation of the gluten network. Dough stability substantially improved, peaking at 8.0 minutes with a 3% substitution a significant increase from the control's 2.5 minutes and remained high (7.0–7.5 minutes) at higher levels. This suggests that the seed's protein and fiber components enhance the dough's strength and tolerance to mixing. Conversely, the degree of softening increased significantly, from 70 B.U. in the control to 150 B.U. at 9% substitution.

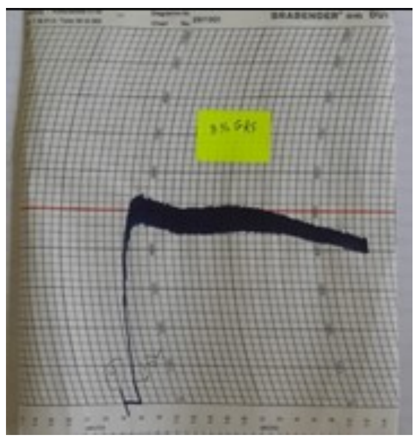
This indicates that while the dough is more stable, it also becomes softer and less elastic, likely due to gluten dilution and physical interference from fiber. In summary, enriching dough with germinated radish seeds alters its farinographic properties by reducing water absorption, extending development time, and improving stability. These changes indicate potential functional benefits for bakery applications requiring stronger dough, though formulation adjustments may be necessary to mitigate reduced elasticity and maintain optimal handling and baking quality.

Table 5. Farinograph parameters dough enrichment with germinated radish seeds

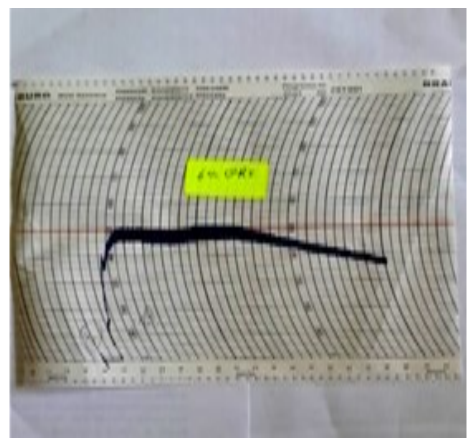
Samples	Water absorption (%)	Arrival time (min)	Dough development (min)	Stability (min)	Degree of softening (B.U)
Control	63.20	1.0	1.5	2.5	70
3% Germinated radish seeds	62.6	1.0	1.5	8.0	70
6% Germinated radish seeds	62.0	1.5	2.5	7.0	110
9% Germinated radish seeds	61.8	2.0	3.5	7.0	150
12% Germinated radish seeds	60.8	1.0	2.0	7.5	130



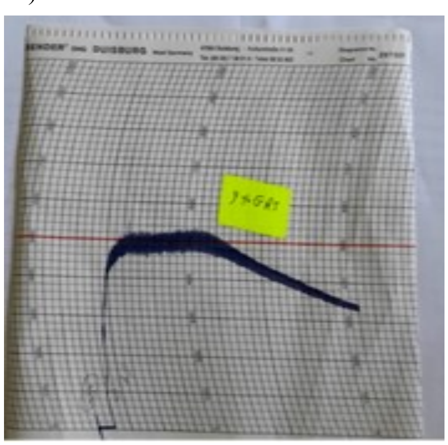
Control Toast bread =100% wheat flour (72% extraction rate)



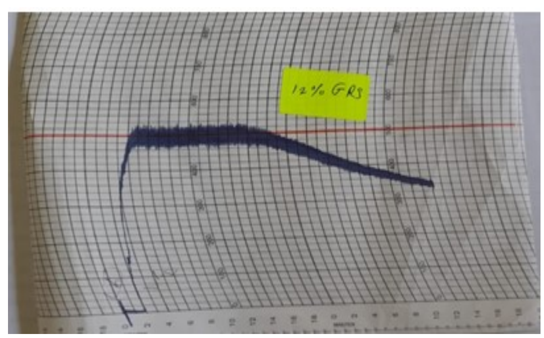
97% wheat flour + 3% GRS



94%wheat flour +6% GRS



91%wheat flour + 9% GRS



88%wheat flour + 12% GRS

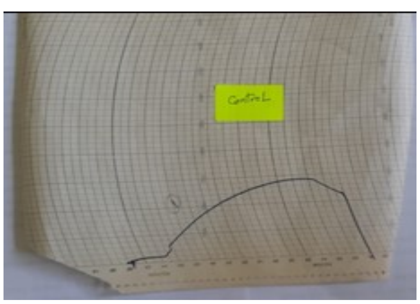
Figure 1. Farinograph parameters dough enrichment with germinated radish seeds

Extensograph parameters dough enrichment with germinated radish seeds

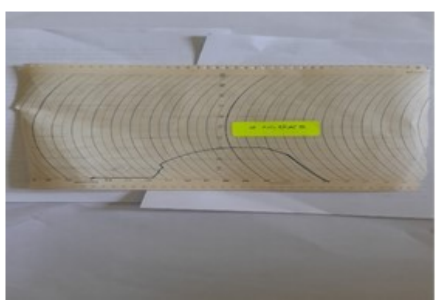
Table 6 and Figure 2 illustrate the impact of germinated radish seed enrichment on the extensograph properties of wheat flour dough, providing insight into its strength, resistance to extension, and potential baking performance. The control dough (100% wheat flour) exhibited an elasticity (resistance) of 280 B.U, extensibility of 130 mm, a proportional number (P.N) of 2.15, and an energy of 67 cm². The incorporation of germinated radish seeds resulted in the following key changes: Elasticity (Resistance) significantly increased, reaching 340 B.U at the 12% substitution level. This suggests the dough became stronger and more resistant to stretching, likely due to the reinforcing effect of the seed's high fiber and protein content on the dough matrix. Extensibility decreased from 130 mm to 80 mm at the 12% level, indicating a reduction in the dough's ability to stretch. This is likely caused by gluten dilution and physical interference from fiber, which may impair gas retention during fermentation. The Proportional Number (P.N), representing the ratio of resistance to extensibility, increased markedly from 2.15 to 4.25. This confirms a fundamental shift towards a stiffer, stronger, but less extensible dough. Energy, denoting the overall workability and strength of the dough, decreased with seed addition up to 6% and remained below the control value (67 cm²) even with a slight recovery at 12% (52 cm²). This indicates a general reduction in dough strength. In summary, the enrichment with germinated radish seeds alters dough rheology by increasing its resistance and stiffness while reducing its extensibility and overall energy. These modifications could enhance dough stability but may adversely affect the volume and texture of baked goods that require high extensibility, such as pan bread (Shaban et al., 2023). Consequently, optimizing processing techniques or formulations is recommended to mitigate these effects in specific bakery applications.

Table 6. Extensograph parameters dough enrichment with germinated radish seeds

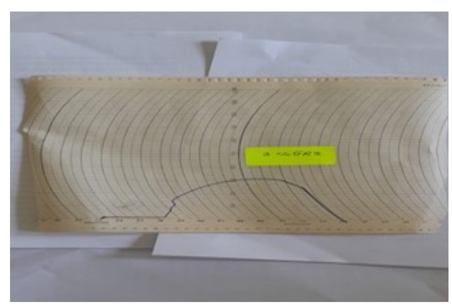
Samples	Elasticity (B.U)	Extensibility (mm)	P. N	Energy (cm^2)
Control	280	130	2.15	67
3% Germinated radish seeds	320	90	3.56	45
6% Germinated radish seeds	300	95	3.16	42
9% Germinated radish seeds	330	95	3.47	46
12% Germinated radish seeds	340	80	4.25	52



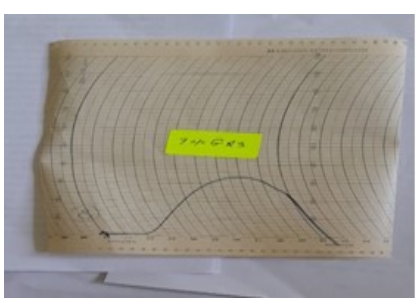
Control wheat flour (72% extraction rate)



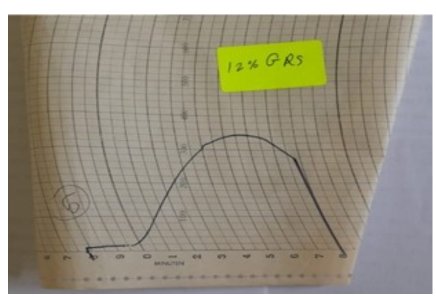
97% wheat flour + 3% GRS



94%wheat flour +6% GRS



91%wheat flour + 9% GRS



88%wheat flour + 12% GRS

Figure 2. Extensograph parameters dough enrichment with germinated radish seeds

Sensory characteristics of toast enrichment with germinated radish seeds

The sensory evaluation results presented in Table 7 show that incorporating germinated radish seed (GRS) powder into toast formulations significantly influenced consumer-perceived quality attributes. The control sample consistently received the highest scores across all parameters, including crust color (8.70), crumb grain (8.90), crumb texture (8.75), odor (8.80), taste (8.50), appearance (8.60), and overall acceptability (8.85), indicating excellent sensory quality. Substitution with 3% GRS (B3) maintained relatively high acceptability, with only a slight decline in all attributes compared to the control, suggesting that low levels of enrichment did not adversely affect consumer preference. At 6% substitution (B6), further reductions in scores were observed, particularly in crust color, odor, and taste, though crumb texture remained relatively acceptable, reflecting a modest impact on overall quality. Higher inclusion levels (9% and 12%) resulted in more pronounced declines across all sensory attributes, with significant decreases in taste, odor, and overall acceptability, likely due to the stronger flavor and darker color imparted by GRS, as well as possible textural changes. Overall, the findings indicate that GRS can be successfully incorporated into toast at levels of 3–6% without compromising consumer acceptability, whereas higher levels may be less preferred due to negative effects on flavor, appearance, and overall eating quality.

Table 7. Sensory characteristics of toast enrichment with germinated radish seeds

Samples	Crust color (9)	Crumb grain (9)	Crumb texture (9)	Odor (9)	Taste (9)	Appearance (9)	Overall acceptability (9)
Control	$8.70^{a}\pm0.15$	$8.90^{a}\pm0.09$	$8.75^{a}\pm0.15$	$8.80^{a}\pm0.20$	$8.50^{a}\pm0.10$	$8.60^{a}\pm0.15$	$8.85^{a}\pm0.25$
B3	$8.10^{b}\pm0.13$	$8.20^{b}\pm0.10$	$8.40^{b}\pm0.20$	$8.00^{b}\pm0.15$	$8.10^{b}\pm0.15$	$8.00^{b}\pm0.10$	$8.10^{b}\pm0.20$
B6	$7.50^{c}\pm0.16$	$7.80^{c}\pm0.15$	$8.00^{c}\pm0.18$	$7.50^{c}\pm0.10$	$7.30^{c}\pm0.14$	$7.60^{c}\pm0.20$	$7.50^{c}\pm0.15$
B9	$7.20^{d}\pm0.14$	$7.10^{d}\pm0.20$	$7.60^{d}\pm0.15$	$7.00^{d}\pm0.12$	$7.00^{d}\pm0.16$	$7.00^{d}\pm0.25$	$6.50^{d}\pm0.15$
B12	$6.90^{e}\pm0.12$	$6.80^{e}\pm0.25$	$6.50^{e}\pm0.25$	$6.00^{e}\pm0.15$	$6.30^{e}\pm0.20$	$6.00^{e}\pm0.10$	$6.00^{e}\pm0.20$

Each value was an average of three determination ± standard deviation.
Different letters indicate to significant differences between groups in the same column($p\leq0.05$)
Control Toast bread =100% wheat flour (72% extraction rate)
B3 Toast bread = 3% Germinated radish seeds+97% wheat flour (72% extraction rate)
B6 Toast bread = 6% Germinated radish seeds+97%wheat flour (72% extraction rate)
B9 Toast bread = 9% Germinated radish seeds+97%wheat flour (72% extraction rate)

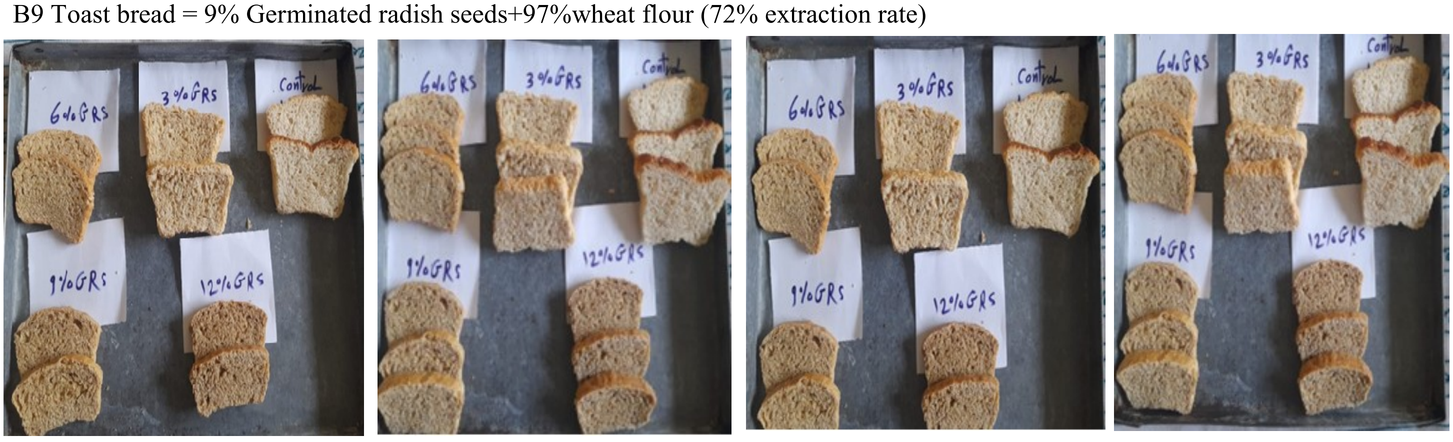


Figure 3: Toast bread at different ratios of germinated radish seeds

Chemical of toast enrichment with germinated radish seeds

The chemical composition of toast supplemented with germinated radish seeds (GRS) demonstrated a progressive enhancement in nutritional value with increasing substitution levels (Table 8). Crude protein content increased significantly from 13.28% in the control to 15.32% in the B12 sample, directly reflecting the high protein contribution of GRS. Concurrently, fat, crude fiber, and ash contents also showed consistent rises, achieving their highest values in the B12 formulation (7.67%, 2.92%, and

1.71%, respectively). This trend indicates a substantial improvement in nutritional density. Conversely, the available carbohydrate content exhibited a steady decline from 78.56% (control) to 72.38% (B12). This reduction is nutritionally advantageous as it may lower the product's glycemic impact. Consequently, the energy value showed a slight but consistent decrease from 436.42 kcal/100 g to 429.37 kcal/100 g, primarily attributable to the lower carbohydrate content. Among the enriched samples, the B3 and B6 formulations presented a balanced nutrient profile, offering improved protein and fiber content without a drastic compromise on available carbohydrates or energy value. In summary, the incorporation of germinated radish seeds effectively boosts the protein, fiber, and mineral content of toast. This enrichment strategy offers functional benefits for developing healthier baked goods, with optimal balance achieved at moderate (3–6%) substitution levels.

Table 8. Chemical of toast enrichment with germinated radish seeds

Blends	Protein	Fat	Crude fiber	Ash	Available carbohydrates	Energy Value
Control	13.28^{e}±0.05	6.58^{e}±0.01	0.73^{e}±0.02	0.85^{e}±0.01	78.56^{a}±0.10	436.42^{a}±0.12
B3	13.88^{d}±0.06	6.85^{d}±0.03	1.28^{d}±0.01	1.06^{d}±0.02	76.93^{b}±0.15	434.66^{b}±0.15
B6	14.48^{c}±0.08	7.12^{c}±0.02	1.83^{c}±0.03	1.28^{c}±0.01	75.29^{c}±0.10	432.85^{c}±0.13
B9	15.08^{b}±0.05	7.40^{b}±0.01	2.37^{b}±0.02	1.49^{b}±0.01	73.66^{d}±0.20	431.17^{d}±0.10
B12	15.32^{a}±0.06	7.67^{a}±0.03	2.92^{a}±0.04	1.71^{a}±0.02	72.38^{e}±0.13	429.37^{e}±0.20

Each value was an average of three determination ± standard deviation.
Different letters indicate to significant differences between groups in the same column ($p \leq 0.05$)
Control Toast bread =100% wheat flour (72% extraction rate)
B3 Toast bread = 3% Germinated radish seeds+97% wheat flour (72% extraction rate)
B6 Toast bread = 6% Germinated radish seeds+94%wheat flour (72% extraction rate)
B9 Toast bread = 9% Germinated radish seeds+91%wheat flour (72% extraction rate)

Crumb color of toast enrichment with germinated radish seeds

Crumb color measurements (Table 9) demonstrated that enrichment with germinated radish seeds (GRS) significantly altered the color attributes of toast, with effects intensifying at higher substitution levels. The lightness value (L*) decreased progressively from 62.39 in the control to 53.73 in the B12 sample, indicating a darker crumb color. This is likely attributable to the natural pigments in GRS and enhanced Maillard browning reactions during baking (Mospah et al., 2023; Nassef et al., 2022). Conversely, both chromaticity values increased substantially. The redness (a) parameter rose markedly from 4.91 (control) to 12.59 (B12), indicating a shift toward a more reddish hue. Similarly, yellowness (b) increased significantly, reaching 28.47 in the B12 sample, which suggests a more intense golden-yellow coloration. Among the enriched samples, B6 exhibited a balanced color profile with a moderate reduction in lightness and attractive reddish-yellow tones. In contrast, B12 showed the most pronounced color shift. These alterations in crumb color, particularly the increased darkness at higher substitution levels, may influence consumer perception of the product's quality and freshness.

Impact of germinated radish seeds on blood glucose level of obese rats

Figure 4 illustrates the effect of germinated radish seed (GRS) supplementation on the blood glucose levels of obese rats over a five-week period. The normal control group (G1) maintained a glucose level of 100mg/dL. In contrast, the obese control group (G2) exhibited a significant elevation to 130 mg/dL, indicating the development of obesity-associated hyperglycemia. Dietary inclusion of germinated radish seeds resulted in a gradual, dose-dependent decrease in blood glucose levels. Rats supplemented with 3% GRS (G3) showed a slight reduction to 125mg/dL. Supplementation at 6% (G4) and 9% (G5) further lowered glucose levels to 120mg/dL and 118mg/dL, respectively. The most notable effect was observed in the group receiving 12% GRS (G6), which demonstrated a complete normalization of blood glucose to to 100 mg/dL, a value comparable to that of the normal control group. These results suggest that higher levels of germinated radish seed supplementation exert significant antihyperglycemic effects. This is potentially due to an increased presence of bioactive compounds such as antioxidants, fiber, and phytochemicals generated during germination, which may improve insulin sensitivity and regulate glucose metabolism in obese individuals (Abd Allah and Abd-Elrahman, 2021).

Table 9. Crumb color of toast enrichment with germinated radish seeds

Blends	Crumb color		
Parameters	*L**	*a**	*b**
Control	62.39[a]±0.15	4.91[e]±0.04	18.01[d]±0.12
B3	61.19[b]±0.10	5.74[c]±0.05	17.75[e]±0.06
B6	58.56[c]±0.12	6.33[b]±0.09	20.81[b]±0.15
B9	56.51[d]±0.13	05.18[d]±0.04	19.96[c]±0.13
B12	53.73[e]±0.20	12.59[a]±0.15	28.47[a]±0.30

Each value was an average of three determination ± standard deviation.
Different letters indicate to significant differences between groups in the same column(p≤0.05)
Control=100% wheat flour (72% extraction rate)
B3= 3% Germinated radish seeds+97% wheat flour (72% extraction rate)
B6= 3% Germinated radish seeds+94% wheat flour (72% extraction rate)
B9= 3% Germinated radish seeds+91%wheat flour (72% extraction rate)

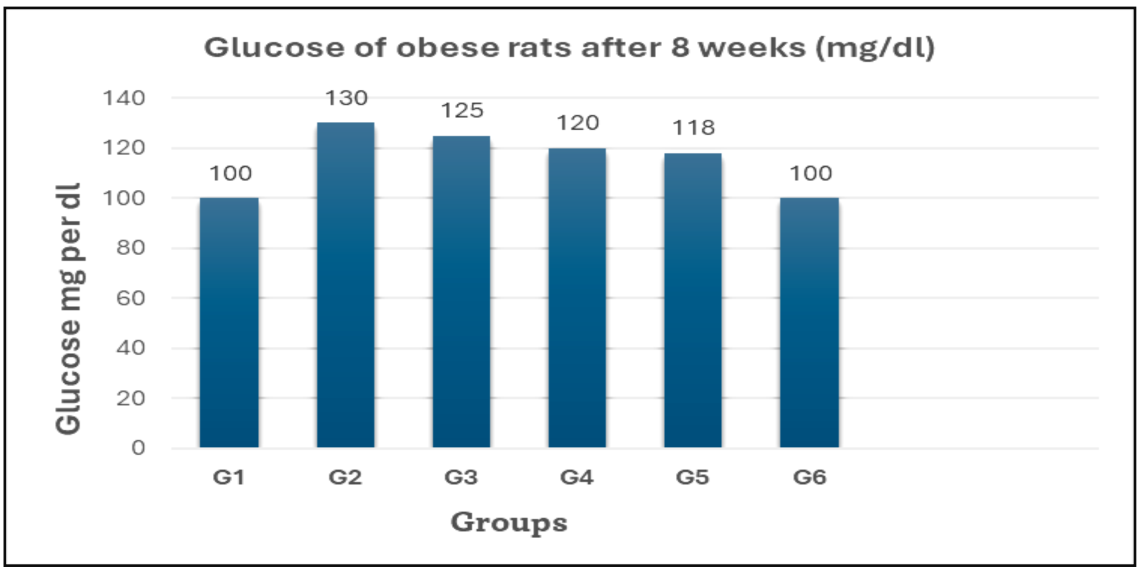


Figure 4. Impact of germinated radish seeds on blood glucose level of obese rats

Influence of germinated radish seeds on some lipid parameters of obese rats

Table 10 displays the impact of germinated radish seed (GRS) supplementation on the serum lipid profiles of obese rats following an 8-week experimental period. The parameters measured include total cholesterol, triglycerides, high-density lipoprotein (HDL), low-density lipoprotein (LDL), and very low density lipoprotein (VLDL). The normal control group exhibited an optimal lipid profile, with total cholesterol at 120 mg/dL, triglycerides at 130mg/dL, HDL at 58.00 mg/dL, LDL at 36.00mg/dL, and VLDL at 26.00mg/dL. In contrast, the obese control group displayed a significantly dysregulated profile characteristic of dyslipidemia, marked by elevated total cholesterol (280mg/dL), triglycerides (250mg/dL), LDL (199.80 mg/dL), and VLDL (50.00mg/dL), alongside a substantial reduction in HDL (30.20mg/dL). Higher supplementation levels of 6% and 9% resulted in further reductions in total cholesterol (230 and 195mg/dL), triglycerides (220 and 200 mg/dL), and LDL (147.92 and 111.00mg/dL), accompanied by increased HDL levels (38.00 and 44.00mg/dL). The most significant amelioration was observed at the

12% supplementation level, total cholesterol dropped to 180mg/dL, triglycerides to 195mg/dL, LDL to 91.00mg/dL, and VLDL to 39.00mg/dL, while HDL rose to 50.00mg/dL values that closely approach those of the normal control group. These results indicate that germinated radish seeds exert a potent hypolipidemic effect. This activity is likely attributable to their high content of dietary fiber, antioxidants (e.g., phenolics and flavonoids), and possibly phytosterols formed during germination. These bioactive compounds are known to improve lipid metabolism, enhance cholesterol excretion, and inhibit LDL oxidation. In summary, the findings demonstrate that germinated radish seed supplementation can effectively reverse dyslipidemia associated with obesity and support its potential use as a functional dietary ingredient for managing lipid disorders (Abd Allah and Abd-Elrahman, 2021; Abdelhameed and Bashandy, 2022).

Table 10. Influence of germinated radish seeds on some lipid parameters of obese rats

Groups	Total cholesterol (mg/dl)	Triglyceride (mg/dl)	HDL (mg/dl)	LDL (mg/dl)	VLDL (mg/dl)
Normal control (-)	120^{f}±2.20	130^{f}±1.30	58.00^{a}±0.60	36.00^{f}±0.90	26.00^{f}±0.90
Obese control (+)	280^{a}±3.50	250^{a}±3.00	30.20^{f}±0.30	199.80^{a}±2.90	50.00^{a}±1.30
3%Germinated radish seeds	260^{b} ±2.40	240^{b}±2.00	34.00^{e} ±0.20	178.00^{b} ±0.60	48.00^{b}±1.00
6% Germinated radish seeds	230^{c}±3.20	220^{c}±3.00	38.00^{d} ±0.40	147.92^{c} ±1.40	44. 08^{c}±1.00
9% Germinated radish seeds	195^{d}±1.90	200^{d}±2.50	44.00^{c} ±0.50	111.00^{d} ±1.20	40.00^{d}±1.10
12% Germinated radish seeds	180^{e}±2.50	195^{e}±1.60	50.00^{b}±0.40	91.00^{e} ±1.00	39.00^{e}±1.80

Each value was an average of five determination ± standard deviation.
Different letters indicate to significant differences between groups in the same column ($p \leq 0.05$)
G1: fed on the basal diet (negative control).
G2: obese rats fed on basal diet (Positive control).
G3: obese rats were fed on 3% germinated radish seeds powder.
G4: obese rats were fed on 6% germinated radish seeds powder.
G5: obese rats were fed on 9% germinated radish seeds powder.
G6: obese rats were fed on 12% germinated radish seeds powder

Influence of germinated radish seeds on total lipid of obese rats after 8 weeks

Figure 5 illustrates the effect of germinated radish seed (GRS) supplementation on total lipid concentrations in obese rats following an 8-week treatment period. The normal control group (G1) maintained a baseline total lipid concentration of 1.50 g/dL. In contrast, the obese control group (G2) exhibited a substantial increase to 4.50 g/dL, indicating the significant lipid accumulation characteristic of obesity. Supplementation with germinated radish seeds resulted in a progressive, dose-dependent reduction in total lipid levels: G3 (3% GRS): 4.00g/dL, G4 (6% GRS): 3.50 g/dL, G5 (9% GRS): 3.10g/dL. The most significant reduction was observed in group G6 (12% GRS), which achieved a total lipid level of 2.60 g/dL, a value that closely approaches the normal physiological range. These findings demonstrate that germinated radish seeds possess potent lipid-lowering properties. This effect is likely mediated by their enriched content of dietary fiber, phytosterols, and antioxidant compounds generated during germination. These bioactive components may act synergistically to enhance lipid metabolism, reduce intestinal fat absorption, and improve hepatic lipid regulation, thereby ameliorating obesity-related dyslipidemia (Abd Allah and Abd-Elrahman, 2021; Abdelhameed and Bashandy, 2022).

Effect of feeding germinated radish seeds on liver functions in obese rats

Table 11 presents the effect of germinated radish seed (GRS) supplementation on liver function markers aspartate aminotransferase (AST), alanine aminotransferase (ALT), and alkaline phosphatase (ALP) in obese rats after an 8-week period. The normal control group (G1) exhibited the lowest enzyme activities, with AST at 43.40U/L, ALT at 39.00U/L, and ALP at 75.50U/L, indicating healthy liver function.

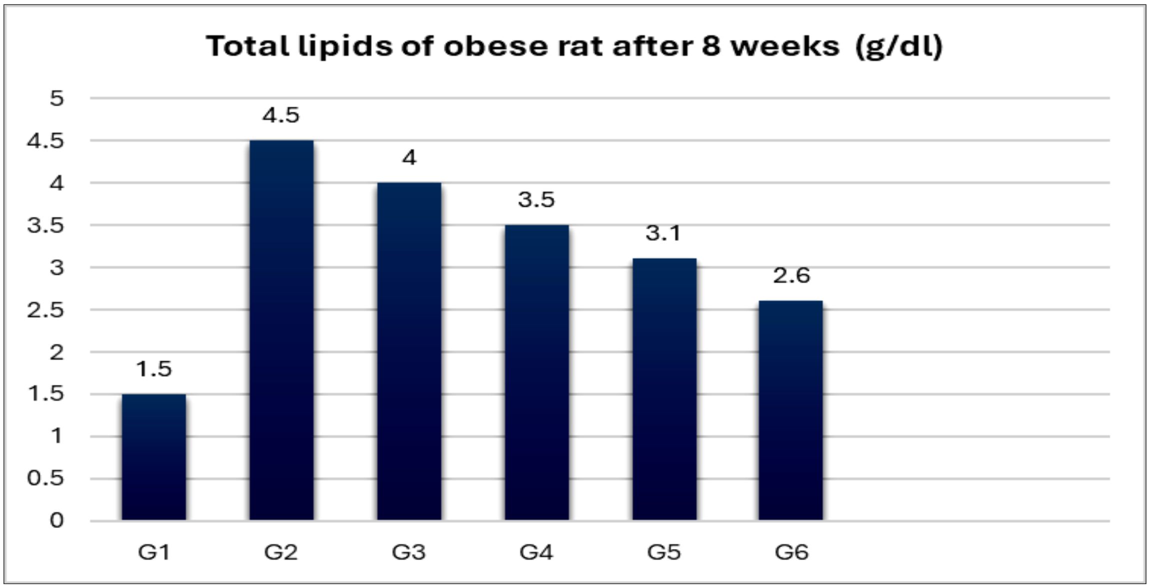


Figure 5. Influence of germinated radish seeds on total lipid of obese rats after 8 weeks

In contrast, the obese control group (G2) demonstrated significantly elevated levels of AST (75.50 U/L), ALT (85.10 U/L), and ALP (130.40 U/L), reflecting substantial liver stress or injury associated with obesity. Dietary inclusion of germinated radish seeds resulted in a clear, dose-dependent amelioration of these elevated biomarkers (Gouda and Hanafi, 2025). Enzyme activities decreased progressively with higher levels of supplementation: AST declined from 65.30 U/L (G3, 3% GRS) to 50.30U/L (G6, 12% GRS), ALT declined from 80.00U/L (G3) to 55.20 U/L (G6), ALP declined from 120.20U/L (G3) to 80.60 U/L (G6). The group receiving 12% supplementation (G6) displayed values closest to those of the normal control group, indicating a hepatoprotective or restorative effect. These improvements are likely attributable to the enhanced antioxidant content and bioactive compounds such as flavonoids, phenolics, and sulfur-containing compounds in germinated radish seeds, which help mitigate oxidative stress and inflammation in hepatic tissues (Gouda and Hanafi, 2025).

Table 11. Effect of feeding germinated radish seeds on liver functions in obese rats

Treatments	Groups	AST (GOT) (U/L)	ALT (GPT) (U/L)	ALP (U/L)
Normal control (-)	G1	43.40^{f}±1.50	39.00^{f}±1.40	75.50^{f}±1.00
Obese control (+)	G2	75.50^{a}±3.00	85.10^{a}±2.60	130.40^{a}±1.50
3% Germinated radish seeds	G3	65.30^{b}±2.50	80.00^{b}±2.00	120.20^{b}±1.50
6% Germinated radish seeds	G4	60.40^{c}±2.00	75.10^{c}±1.30	110.30^{c}±1.60
9% Germinated radish seeds	G5	55.50^{d}±1.60	63.40^{d}±1.25	98.40^{d}±1.40
12% Germinated radish seeds	G6	50.30^{e}±1.25	55.20^{e}±1.20	80.60^{e} ±1.50 -

Each value was an average of five determination ± standard deviation.
Different letters indicate to significant differences between groups in the same column($p \leq 0.05$)
G1: fed on the basal diet (negative control).
G2: obese rats fed on basal diet (Positive control).
G3: obese rats were fed on 3% germinated radish seeds powder.
G4: obese rats were fed on 6% germinated radish seeds powder.
G5: obese rats were fed on 9% germinated radish seeds powder.
G6: obese rats were fed on 12% germinated radish seeds powder

Effect of feeding germinated radish seeds on body weight gain (%), feed intake, and feed efficiency ratio of normal control and obese rats

Table 12 illustrates the effect of feeding germinated radish seeds (GRS) on body weight gain, feed intake, and feed efficiency ratio (FER) in normal and obese rats. The obese control group (G2) recorded the highest feed intake (23.33g/day; 1306.48g/56 days) and body weight gain (60.20 g; 31.10%), both significantly higher than those of the normal control group (G1). Supplementation with GRS at different levels (G3–G6) resulted in a gradual and significant reduction in feed intake, total feed consumed, and body weight gain compared with the obese control. At the highest supplementation level (12% GRS, G6), rats exhibited the lowest feed intake (21.80 g/day; 1220 g/56 days) and body weight gain (20.59g; 40.00%), approaching values closer to the normal control. Similarly, FER values were significantly improved in GRS-fed groups compared with the obese control, decreasing from 4.61 in G2 to 3.27 in G6, indicating enhanced efficiency of feed utilization. Notably, final body weights did not differ significantly among groups, suggesting that the observed effects were primarily due to moderated weight gain rather than drastic reductions in body mass. These findings highlight that GRS supplementation, particularly at higher levels, effectively controlled hyperphagia and excessive weight gain in obese rats, demonstrating its potential as a functional dietary intervention against obesity.

Table 12. Effect of feeding germinated radish seeds on body weight gain (%), feed intake, and feed efficiency ratio of normal control and obese rats

Groups	Diets	Initial weight (g)	Final weigh (g)	Gaining body weight (g)	Gaining body weight %	Total feed intake Per 56 days	feed intake (g/day)	(FER)
G1	Normal control (-)	192.30^{a} ±4.50	222.30^{f} ±2.50	30.00^{f} ±1.00	15.60^{f} ±0.92	1176^{f} ±2.80	21.00^{f} ±0.13	2.55^{f} ±0.01
G2	Obese control (+)	193.60^{a} ±5.00	253.80^{a} ±3.50	60.20^{a} ±2.10	31.10^{a} ±1.14	1306.48^{a} ±3.50	23.33^{a} ±0.16	4.61^{a} ±0.15
G3	3% Germinated radish seeds	195.50^{a} ±5.50	251.10^{b} ±1.90	55.60^{b} ±1.20	28.45^{b} ±1.20	1276^{b} ±5.40	22.80^{b} ±0.15	4.35^{d} ±0.10
G4	6% Germinated radish seeds	196.30^{a} ±4.60	246.10^{c} ±1.50	49.80^{c} ±1.09	25.37^{c} ±1.30	1248.80^{c} ±4.20	22.30^{c} ±0.10	3.99^{b} ±0.06
G5	9% Germinated radish seeds	197.40^{a} ±6.50	242.70^{d} ±2.00	45.30^{d} ±1.40	22.95^{d} ±1.15	1232^{d} ±2.50	22.00^{d} ±0.10	3.67^{c} ±0.04
G6	12% Germinated radish seeds	194.33^{a} ±4.10	234.33^{e} ±1.70	40.00^{e} ±1.30	20.59^{e} ±1.20	1220^{e} ±3.40	21.80^{e} ±0.12	3.27^{e} ±0.02

- FER=Food efficiency ratio
- Each value was an average of five determination ± standard deviation.
- Different letters indicate to significant differences between groups in the same column($p \leq 0.05$)

4. Conclusion

This study demonstrates, for the first time, the successful incorporation of germinated radish seed (GRS) powder into toast bread. Moderate substitution levels (3–6%) preserved sensory quality while enhancing nutritional value, whereas higher levels (9–12%) maximized antioxidant and therapeutic effects. In obese rats, GRS supplementation improved lipid profile, blood glucose, and liver function, indicating promising functional potential. While these findings highlight GRS as a novel ingredient for functional bakery products, further validation, particularly through human clinical trials and industrial-scale applications, is warranted to confirm its role in managing obesity-related disorders.

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