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RESEARCH ARTICLE

Comparative Evaluation of Textural and Sensory Characteristics of Sourdough Bread Produced Using Botanical Water from Different Raisin Varieties

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ABSTRACT
This study evaluated the effects of botanical water from various raisin varieties on the sensory and textural qualities of sourdough bread. Black, green, and yellow raisins were used to make botanical water, which was then used as a natural fermentation medium. Conventional sourdough was used as the control. Hardness, cohesiveness, springiness, gumminess, chewiness, fracture force, adhesiveness, and stiffness were all measured by texture analysis. Fifty-five untrained panelists used a five-point hedonic scale to rate sensory acceptance. Significant differences were noted in hardness, springiness, gumminess, and stiffness; however, other textural parameters showed no significant variation. Hardness, gumminess, springiness, and stiffness values were highest in sourdough made with yellow raisin botanical water, while the control had the lowest hardness. The sourdough samples stayed within the acceptable range in the sensory evaluation, but the control sample scored highest for color, texture, and overall acceptability. Among the botanical water treatments, green raisin sourdough was the most well-liked. According to the findings, raisin botanical water has an impact on bread structure and fermentation behavior, resulting in quantifiable texture changes and mild variations in sensory perception. Therefore, it is possible to use botanical water from raisins as a natural fermentation medium for making sourdough bread without experiencing severe sensory rejection.

KEYWORDS: *Botanical water, Raisin variety, Sourdough bread, Texture profile, Sensory acceptance*

Introduction

In recent years, bread consumption in Indonesia has grown significantly, reflecting changes in dietary habits and food systems. Bread is a staple food in Indonesian cuisine, as evidenced by the country's average weekly consumption of 1.129 ounces (32 grams) per person in 2020 (Adhamatika *et al.*, 2022). Numerous socioeconomic factors, such as urbanization, market accessibility, and changing consumer preferences, are probably to blame for this increase. Urbanization is one of the main causes of Indonesia's growing bread consumption. Traditional diets that prioritized rice and other staples are gradually being replaced by processed foods like bread as cities grow and modern lifestyles take hold. Dietary patterns have shifted toward ready-to-eat items due to the emergence of bakery chains and the expanding market for convenience foods (Nugroho & Sihite, 2020).

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Sourdough bread offers health benefits because of its distinct fermentation process. The properties of lactic acid bacteria and wild yeast positively impact the bread's nutritional quality. Sourdough fermentation improves the digestibility of nutrients like proteins and dietary fibers (D'Amico *et al.*, 2023; Fernández-Peláez *et al.*, 2020), and increases essential minerals and vitamins. This process also reduces anti-nutrients such as phytic acid, which can inhibit mineral absorption *(*D'Amico *et al., 2023;* Sakandar *et al.*, 2019).

Raisins, or dried grapes, are not only tasty but also high in nutrition, providing numerous health benefits. They include natural sugars, fiber, vitamins, and minerals, which provide fast energy and several health benefits. Raisins are categorized into numerous sorts based on the grape variety utilized and the drying procedure. The most common varieties include black raisins, which are made from black grapes and high in antioxidants; green raisins (Sultanas), which are light-colored, made from green grapes, and known for their sweet taste and chewy texture; and yellow raisins, which are often made from golden grapes and have flavors that vary depending on how they are dried.

Raisins have become a potential ingredient for producing botanical water sourdough, providing multiple benefits related to fermentation (Palla *et al.*, 2020; Tieking *et al.*, 2003), flavor enhancement (Palla *et al.*, 2020), nutritional improvements (Palla *et al.*, 2020; Zotta *et al.*, 2009), and microbial diversity (Lau *et al.*, 2024; Zotta *et al.*, 2009). Using raisins in the sourdough process can significantly enhance the bread's sensory properties and health benefits.

Using diverse raisin varieties as components in botanical water sourdough is an intriguing opportunity to increase the sensory and textural features of sourdough bread. While previous research has focused on how different grains and sourdough fermentation procedures affect bread quality (Liu *et al.*, 2024), few studies have investigated the specific effects of various raisin kinds in this context. There is scant research on how different sourdough ingredients affect textural qualities. For example, Škrobot *et al.* (2022) looked at the differences in dough properties and baking results between ancient and modern wheat varieties but did not address the impact of raisin additives. Investigating how certain compounds in raisins—like sugars, acids, and phytochemicals—interact with the enzyme activity in sourdough could provide valuable insights. Additionally, the texture profiles resulting from adding raisins to sourdough merit thorough analysis since they could affect the bread's volume, elasticity, and crumb structure.

Different raisin varieties can shape the initial microbial inoculum and substrate landscape for sourdough fermentation, thereby altering community dynamics and metabolite production that drive bread quality (Liu et al., 2024; Watanabe & Hashimoto, 2023). Also, raisin-derived matrices can modulate fermentation pace and acidification through changes in available sugars, oligosaccharides (prebiotic potential), and microbial interactions (probiotics/synbiotics) (A.S. et al., 2019; Liu et al., 2024). Sourdough fermentation reports where substrate microbial ecology and metabolite production influence fermentation kinetics and aroma compound formation (Facco Stefanello et al., 2019; Liu et al., 2024; Walker et al., 2009).

Current methods for evaluating sensory attributes and analyzing bread products mostly focus on flour and fermentation types, ignoring the subtle effects of fruit additions, particularly raisins. Zolfaghari *et al.* (2017) discovered that varied fermentation processes considerably alter bread flavor and texture. However, the specific taste properties given by different raisin kinds during sourdough fermentation have not been widely investigated. Therefore, this research aims to compare the textural and sensory qualities of sourdough bread made with botanical water from different raisin varieties (black, green, and yellow).

Material and Method

Materials or Respondents

The main materials used in this study included bread-making ingredients such as dried raisins (black, green, and yellow), white wheat flour (Cakra Kembar®, Indonesia), whole wheat flour (Nourish®, Indonesia), water, salt (Dolphin®, Indonesia), instant yeast (Saf-Instant Gold®, Lesaffre, France), and honey (NN®, Indonesia).

Instrumentation

The primary equipment used in this study included bread production machines and analytical tools. Bread-making was conducted using a standing mixer (Sinmag B-10, Sinmag Equipment Corp., Taiwan), an oven (Mitochiba MO-888), and standard baking pans. Texture analysis was done using a Texture Analyzer (Lloyd TA Plus, AMETEK Lloyd Instruments Ltd., UK).

Moisture Content Analysis

Moisture content analysis was carried out with moisture analyzer. The moisture analyzer was turned on and an empty aluminum pan was placed inside it. A total of 1 gram of encapsulant was placed on the aluminum pan of moisture analyzer.

Preparation of Botanical Water

Botanical water was made using the method described by Baker (2020), with slight modifications adapting to the use of dried raisins as the starting material. The dried raisins were carefully washed to remove any surface contaminants. Following rinsing, the raisins were placed in a sterilized glass jar filled to the capacity with water to prevent air exposure and mold danger. The water-to-raisin ratio was maintained at 2:1 (v/w).

The jar was firmly sealed and let to ferment at room temperature. Every two days, the mixture was gently mixed to liberate the gasses created by fermentation. Botanical water was ready when visible bubbles developed on the liquid surface and a clear fizzing sound, comparable to that of a carbonated drink, was heard when the jar was opened.

To test its readiness for use as a sourdough starter, an equal amount of botanical water and flour were mixed and let to remain at room temperature for several hours. If the mixture swelled and bubbled on the surface, botanical water was deemed adequate as a natural leavening ingredient for sourdough fermentation. The control was created using the traditional way of producing sourdough without botanical water. As a control, a sourdough starter was prepared using the same procedure, but the botanical water was replaced with sterile water.

Preparation of Sourdough Bread

The sourdough bread formulation was adapted from the White Bread recipe provided by Forkish (2022). The dough formulation is shown in Table 1. The weight of the sourdough starter indicated in this table applies uniformly to both the control and all treatment groups.

Table 1. Formulation of sourdough bread.

Ingredients	Control (g)	Percentage (%)	Sourdough Bread (g)	Percentage (%)
White wheat flour	280	100	280	100
Whole wheat flour	20	7.14	20	7.14

Water	70	17.5	70	17.5
Salt	8	2,85	8	2.85
Honey	15	3.75	15	3.75
Sourdough starter	150	53.57	150	53.57

Dough preparation began by mixing the dry and wet ingredients (omitting salt and butter) in a planetary mixer at 148 rpm for 5 minutes, ensuring complete sugar dissolution and uniform distribution. Once homogeneous, butter and salt were added, and the mixture was kneaded at 307 rpm for 2 minutes to develop a cohesive dough structure. Bulk fermentation was then carried out in a basin at 30 ± 1 ˚C with a relative humidity (R.H.) of 75 ± 2% for 180 minutes. Afterwards, the fermented dough was divided into 250 g segments, manually formed into oval loaves (dimensions of ~12 × 7 × 5 cm), and positioned on silicone baking mats. The loaves underwent a 360-minute final proofing phase under the same climatic conditions (30 ± 1 ˚C, 75 ± 2% R.H.) until their volume had approximately doubled. The proofed dough was baked at 180 ˚C for 30 minutes in a gas convection oven to achieve a target internal temperature of 90 ± 1 ˚C. Prior to subsequent analyses, the baked sourdough breads were allowed to cool on racks for roughly one hour to reach room temperature (25 ˚C).

Physical Analysis

Physical properties were evaluated through Texture Profile Analysis (TPA) using a Texture Analyzer (Lloyd TA Plus, AMETEK Lloyd Instruments Ltd., UK) following the procedure described by Kulthe *et al.*, (2014). The textural parameters measured included hardness, cohesiveness, springiness, gumminess, chewiness, fracture force, adhesiveness, and stiffness. Measurements were performed on bread samples at room temperature, and each treatment was analyzed in triplicates to ensure data reliability.

Sensory Analysis

Sensory evaluation was conducted using a consumer acceptance test based on a hedonic rating scale, following the method described by (Meilgaard *et al.*, 2007). The evaluated parameters included color, taste, texture, and overall acceptability. A five-point hedonic scale was applied, where 1 = dislike very much and 5 = like very much. The sensory test involved 55 untrained panelists. The inclusion criteria required panelists to be adults (including university students) of all genders who consume bread on a daily basis. Smokers were excluded from the study to prevent any compromised sensory perception. Samples were presented in randomized order to minimize bias, and water was provided for palate cleansing between samples.

Statistical Analysis

All data obtained from physical and sensory analyses were statistically evaluated using Analysis of Variance (ANOVA) at a significance level of $\alpha = 0.05$ to determine the effect of raisin variety on the measured parameters. When significant differences were detected, Duncan's Multiple Range Test (DMRT) at $\alpha = 0.05$ was performed to identify differences among treatment means. In cases where only two groups were compared, an independent sample t-test was applied. All statistical analyses were performed using IBM SPSS Statistics version 29 (IBM Corp., Armonk, NY, USA).

Results and Discussion

Texture Analysis

Texture analysis serves as an essential tool in the food industry to evaluate product quality, understand consumer preferences, and support product development. In this study, the textural properties of sourdough bread were evaluated using the following parameters: hardness, cohesiveness, springiness, gumminess, chewiness, fracture force, adhesiveness, and stiffness.

Based on one-way ANOVA analysis ($\alpha = 0.05$), significant differences among formulations were observed in hardness, springiness, gumminess, and stiffness, whereas no significant differences were found in cohesiveness, chewiness, fracture force, and adhesiveness. The results of the significantly different parameters are presented in Table 2.

Table 2. Texture profile analysis results.

Formulation	Hardness	Springiness	Gumminess	Stiffness
F0	163.08 ± 7.98^{1}	6.79 ± 0.24^{1}	10.86 ± 3.00^{1}	0.02 ± 0.00^{1}
F1	210.51 ± 30.51^{2}	5.01 ± 1.03^{1}	5.39 ± 4.08^{2}	$0.04 \pm 0.00^{1,2}$
F2	286.85 ± 17.03^{3}	5.56 ± 0.36^{1}	20.2 ± 0.81^{3}	0.04 ± 0.01^{2}
F3	355.72 ± 28.16^{4}	13.45 ± 2.80^{2}	25.4 ± 1.25^{4}	0.12 ± 0.02^{3}

Remarks: Different superscript numbers within the same column indicate significant differences at α = 0.05 (F0 = control sourdough prepared using the conventional method without botanical water; F1 = sourdough with black raisin botanical water; F2 = sourdough with green raisin botanical water; F3 = sourdough with yellow raisin botanical water).

Hardness is an important quality attribute that determines consumer acceptance. It reflects bread crumbs' resistance to deformation. In this investigation, the control formulation (F0) had the lowest hardness rating, whereas sourdough bread made with yellow raisin starting had the highest hardness (F3). The minerals, sugars, and organic acids in the botanical fluids generated from raisins have a considerable influence on the hardness of sourdough bread. The sugar content of black, green, and yellow raisins varies, as does the quantity of phenolic compounds and other phytochemicals. This diversity has an impact on fermentation dynamics, resulting in variable acid profiles that may cause changes in dough behavior and, as a result, ultimate bread hardness (Roby *et al.*, 2020).

The differences in hardness among sourdough formulations F1 (black raisin), F2 (green raisin), and F3 (yellow raisin) might be indirectly influenced by the intrinsic composition of the raisins used. Although specific chemical components were not measured in the present study, previous literature indicates that raisins are generally rich in phenolic compounds (Kelebek *et al.*, 2013; Habibi *et al.*, 2018). It is hypothesized that the presence of such compounds, which are known for their antioxidant and antimicrobial activities, could potentially influence microbial dynamics during fermentation. This variation in microbial activity might, in turn, contribute to the observed differences in bread texture. However, further studies incorporating comprehensive chemical analyses are required to confirm this relationship.

The fermentation process in sourdough is complex and can be influenced by the properties of the botanical water used. Although microbiological profiles (such as yeast and lactic acid bacteria counts) and acidity parameters (pH and Total Titratable Acidity) were not evaluated in the present study, existing literature extensively reports that botanical waters typically harbor varying populations of lactic acid bacteria and wild yeast. According to previous studies, these microorganisms can produce varying quantities of organic acids, including acetic and lactic acid, during fermentation. Increased acetic acid generation has been reported to result in tougher bread due to a stronger gluten network and altered starch behavior during retrogradation (Codină *et al.*, 2021). While our study did not measure these specific metabolites, the observed textural changes align with the findings of Roby *et al.*, (2020) who connected bread hardness with the type of organic acids produced. Nevertheless, further investigations incorporating comprehensive microbiological and physicochemical analyses are necessary to validate these fermentation mechanisms in the current formulations.

Springiness is the capacity of a bread crumb to regain its original shape following compression. In this trial, F3 (yellow raisin sourdough) demonstrated much higher springiness than the other formulations. This variation could be attributed to changes in microbial composition inside the sourdough starter, namely the balance of LAB and Saccharomyces cerevisiae, which effects gas generation, gluten network growth, and crumb flexibility (Supasil *et al.*, 2022). Formulations F1 and F2 did not differ significantly from the control (F0), probably due to similar microbial dominance patterns, with Saccharomyces cerevisiae populations being higher than LAB, resulting in equivalent structural properties.

Gumminess is the energy required to breakdown semi-solid food before swallowing, and it is closely related to hardness, cohesiveness, and chewiness (Kaur et al., 2022). Higher gumminess values are related with a sticky and dense crumb structure, which may negatively impact consumer perception (Mizrahi, 2012). In this study, F1 exhibited the lowest gumminess value, whereas F3 showed the highest. The presence of sourdough and extended fermentation time can increase certain textural parameters, including gumminess (Codină *et al.*, 2021). The present findings are consistent with this trend, except for F1, which showed lower gumminess than the control.

The stiffness of F2 and F3 differed significantly from that of the control (F0). Stiffness measures the structural rigidity of the bread crumb and is controlled by fermentation kinetics and microbial metabolites. In sourdough systems, LAB can create exopolysaccharides (EPS), which affect dough rheology and crumb structure (Tamani *et al.*, 2013). Microbial enzymes, organic acids, and gluten proteins may interact, resulting in increased structural rigidity in sourdough bread (Sidari *et al.*, 2020). These biochemical and rheological alterations are most likely responsible for the increased stiffness values found in various sourdough formulations.

Sensory Analysis

Sensory evaluation was conducted using a five-point hedonic scale to assess color, taste, aroma, texture, and overall acceptability of sourdough bread produced with different raisin-derived botanical waters. The results of sensory analysis are presented in Table 3.

Table 3. Sensory analysis results.

Parameter	Mean Hedonic Score of Samples			
	F0	F1	F2	F3
Color	4.02 ± 0.747^{1}	3.62 ± 0.860^{1}	3.77 ± 0.800^{1}	3.66 ± 0.876^{1}
Taste	3.64 ± 0.982^{1}	3.55 ± 0.867^{1}	3.72 ± 0.948^{1}	3.45 ± 0.952^{1}
Aroma	3.47 ± 0.932^{1}	3.49 ± 0.750^{1}	3.66 ± 0.919^{1}	3.55 ± 0.748^{1}
Texture	3.81 ± 0.856^{2}	3.23 ± 0.974^{1}	3.30 ± 1.030^{1}	3.25 ± 1.054^{1}
Overall	3.81 ± 0.833^{1}	3.68 ± 0.779^{1}	3.66 ± 0.807^{1}	3.47 ± 0.868^{1}

Remarks: Different superscript numbers within the same column indicate significant differences at α = 0.05 (F0 = control sourdough prepared using the conventional method without botanical water; F1 = sourdough with black raisin botanical water; F2 = sourdough with green raisin botanical water; F3 = sourdough with yellow raisin botanical water).

The control sample (F0) earned the highest color score (4.02), while the sourdough samples scored somewhat lower (3.62-3.77). The darker crumb and crust color observed in sourdough bread may be ascribed to prolonged fermentation, which intensifies the Maillard reaction due to greater availability of reducing sugars and amino acids. The use of raisin botanical fluids (from black, green, and yellow raisins) not only adds flavor but also introduces phenolic chemicals that aid in pigment production, which may explain the darker hue found in sourdough samples (Papadaki *et al.*, 2021). Phenolic chemicals are known to improve color by participating in oxidative processes and complex formation, which might contribute to dough browning during baking (Sabanis *et al.*, 2009). The incorporation of these natural extracts allows for not only functional improvements, but also visual appeal in the finished product, as evidenced by their minor inclusion in the overall color enhancement. Although the color of sourdough samples was slightly less preferred than the control, the scores remained within the acceptable range, indicating that the visual appearance was still positively perceived.

Taste scores ranged from 3.45 to 3.72, with F2 (green raisin sourdough) showing the highest acceptance. The somewhat lower scores in sourdough samples compared to the control group could be attributed to the synthesis of organic acids (lactic and acetic acids) during fermentation, which contribute to a mild sour flavor. These acids are known to give sourdough bread a moderate sour flavor, which is an important aspect of its sensory profile (De Luca *et al.*, 2021; Fulea Fekensa, 2021). Studies indicate that lactic acid concentration yields distinct sensory attributes in bread, affecting consumer acceptance based on the balance of sourness and sweetness (Manshur *et al.*, 2023; Math *et al.*, 2014).

The higher score in F2 suggests a more balanced acid–sweet profile, possibly due to differences in microbial activity and sugar metabolism in the green raisin starter. Sourdoughs, particularly F0 (control) and F2 (green raisin), produce higher organic acids due to their unique LAB activity. Green raisins' natural sugars may improve this balance, resulting in a sweeter character that could counteract excessive sourness, producing a higher acceptability score (Mantzourani *et al.*, 2024; Mietton *et al.*, 2022).

Aroma score scores were rather consistent across all formulations (3.47-3.66), demonstrating that the use of raisin-derived sourdough starters had no negative impact on olfactory acceptance. Fermentation metabolites such organic acids, alcohols, and esters are recognized to contribute to sourdough bread's unique scent. The comparable ratings indicate that these volatile chemicals were judged as pleasant and did not emit unpleasant scents.

The control sample (F0) had the highest texture like score (3.81), whereas the sourdough samples scored lower (3.23-3.30). This study is congruent with the instrumental texture analysis results, which showed that sourdough bread with raisins and botanical water had significantly higher hardness and stiffness values ($p<0.05$) ; and lower gumminess value ($p<0.05$). According to studies, consumers prefer softer textures since they are associated with improved palatability and comfort during eating experiences (Fulea Fekensa, 2021).

In contrast, the sourdough samples including raisins and botanical water had increased hardness and stiffness as evaluated by instrumental texture analysis, which likely reduced their overall sensory appeal. As a result, this solid texture may fail to match consumer expectations for bread, which are often linked with light, airy, and flexible qualities (Jamanca-Gonzales *et al.*, 2022; Rahardjo & Sihombing, 2023). Consumers prefer softer and more elastic crumb structures in sourdough bread, hence the stiffer texture of sourdough samples may have a lower sensory preference. Nonetheless, all sourdough samples fell within an acceptable hedonic range.

Overall acceptance scores ranged from 3.47 and 3.81. The control sample scored the highest, followed by F1 and F2, while F3 had the lowest overall approval. The lower score in F3 could be attributed to the increased hardness, gumminess, and stiffness values observed in the instrumental analysis, which most likely influenced panelist perception during consumption. Panelists generally approved all sourdough bread samples, albeit slightly lower marks compared to the control group. This suggests that raisin-derived botanical water can be employed as a natural fermentation medium without significantly altering sensory perception.

Conclusion

The addition of botanical water obtained from several raisin kinds has a substantial impact on the textural features of sourdough bread, including hardness, springiness, gumminess, and stiffness. Yellow raisin botanical water produced bread with the highest structural firmness and elasticity, while the conventional sourdough control exhibited the softest texture. Sensory evaluation revealed that all sourdough samples were generally satisfactory, with the control receiving the highest score for texture and overall enjoyment. Among the botanical water treatments, green raisin sourdough had the highest taste acceptance, indicating a better balance of acid and sweetness. The findings demonstrate that raisin botanical water can act as a natural fermentation medium, changing bread structure while retaining consumer appeal. Further optimization of fermentation conditions is recommended to improve crumb softness while preserving the functional and sensory advantages of raisin based sourdough.

Declaration of Generative AI

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) to improve language clarity and readability. Grammarly was used for grammar and spelling checks. All scientific content, experimental design, data analysis, and conclusions were developed by the authors. The authors reviewed and edited the output and take full responsibility for the accuracy and integrity of the manuscript.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Author Contributions

Monika Rahardjo conceived and designed the study and developed the methodology. Sekar Eka Wahyuningtyas conducted the experiment and performed the data collection. Monika wrote the manuscript. Monang Sihombing reviewed and edited the manuscript. All authors agreed to the final version of this manuscript.

Ethical Statement

This study involved sensory evaluation using untrained human panelists and posed minimal risk to participants. All panelists participated voluntarily and provided informed consent prior to the test. No personal or identifiable data were collected. The study was conducted in accordance with institutional guidelines for sensory evaluation.

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