Food and Nutrition Sciences, 2025, 16(8), 954-975
https://www.scirp.org/journal/fns
ISSN Online: 2157-9458
ISSN Print: 2157-944X

Xylanase Production from Fruit and Vegetable Waste Using *Aspergillus brasiliensis* and Its Application in Cookie Production

Timar Petros Menbere*, Joseph Wafula Matofari, John Masani Nduko

Department of Dairy and Food Science and Technology, Egerton University, Egerton, Kenya
Email: *petertimar42@gmail.com, jmatofari@gmail.com, jnduko@egerton.ac.ke

How to cite this paper: Menbere, T.P., Matofari, J.W. and Nduko, J.M. (2025) Xylanase Production from Fruit and Vegetable Waste Using *Aspergillus brasiliensis* and Its Application in Cookie Production. *Food and Nutrition Sciences*, **16**, 954-975.
https://doi.org/10.4236/fns.2025.168055

Received: May 29, 2025
Accepted: August 22, 2025
Published: August 25, 2025

Abstract

This study assessed the potential of using fruit and vegetable waste, including banana and mango peels and carrot pomace, to produce xylanase enzymes via solid-state fermentation with *Aspergillus brasiliensis*. Fruit and vegetable waste was collected from Nakuru city, dried for 24 hours at 70˚C, then ground into 0.5 mm powder. Box-Behnken Design (BBD) was employed to optimize fermentation parameters, where pH levels were adjusted to 4.0, 5.0, and 6.0. The substrates were inoculated with 1×10^6 spores/mL of *Aspergillus brasiliensis* and then incubated at 25˚C, 30˚C, and 35˚C for a duration of 96, 120, and 144 hours in triplicate. *Aspergillus brasiliensis* produced xylanase, which is indicated by a clear zone around a sample hole in a medium containing xylan. Data analysis using Minitab and SAS 9.4, with significance levels set at $p < 0.05$, revealed that pH and cultivation time significantly influenced enzyme activity, whereas temperature did not. Optimal conditions for maximal enzyme activity were pH 4.2, a cultivation time of 100.9 hours, and a temperature of 25˚C. Interaction effects between pH and time impacted enzyme activity. Further evaluation included the effects of enzyme concentrations (ranging from 0 to 1500 IU) on various properties of cookies. Xylanase treatments significantly affected cookie texture, with reductions in hardness and increased fracturability, diameter, and thickness with increasing enzyme concentration. Changes in color and viscosity were noted, although Farinograph properties remained relatively unaffected. Changes in time and temperature, depending on enzyme concentration, had notable effects on the onset of gelatinization, maximum viscosity, and end of the cooling period. Consumer acceptability scores indicated high ratings for cookies treated with xylanase, reflecting positive perceptions of the product. This study highlights the potential of utilizing fruit and vegetable waste for xylanase production, with promising implications for waste utilization and food processing.

Keywords

Solid-State Fermentation, Xylanase, *Aspergillus brasiliensis*, Fruit and Vegetable Waste, Cookie Production

1. Introduction

Fruit and vegetable waste (FVW) represents a significant portion of the total global food waste, estimated at 1.3 billion metric tons, with FVW alone accounting for up to 60% of this total [1]-[3]. This waste stream primarily comprises seeds, skins, rinds, and pomace, which are rich sources of bioactive compounds such as carotenoids, polyphenols, dietary fibers, vitamins, enzymes, and oils [3] [4]. The depletion of these nutrients not only worsens food insecurity but also poses environmental risks due to wasteful resource use.

Banana peels, often discarded or used as animal feed, contain a composition rich in starch (3.5% - 6.3%), ash content (9% - 11%), crude protein (5.5% - 7.87%), crude fat (2.24% - 11.6%), and carbohydrates (59.51% - 76.58%), including polysaccharides such as hemicellulose [5] [6]. Despite concerns about their high tannin levels for animal consumption, the nutritive value of banana peels suggests potential applications beyond mere feedstock. Solid-state fermentation offers a promising approach to utilizing banana peels as a substrate for the production of cellulolytic and hemicellulolytic enzymes, thereby providing a more valuable use for this waste material [5].

Mango peels and stones, which account for 35% - 60% of the total fruit weight, are significant waste products in the mango processing industry. The composition of mango peel varies depending on factors such as cultivar, ripening stage, soil, and climate conditions, with moisture content ranging from 62% to 83%, carbohydrates (>70%), total dietary fiber (35.5% - 78.3%), protein (1.5% - 6.6%), and other bioactive compounds such as gallic acid, ferulic acid, and catechin [7]. Currently discarded as waste, mango peel waste contributes to environmental pollution and serves as a breeding ground for undesirable bacteria and pests. The utilization of mango peel waste for extracting bioactive components could effectively address these issues [8].

Carrot pomace, a by-product of carrot juice extraction, constitutes 30% - 50% of the residual carrot material during production. Despite being commonly used as feed or manure, carrot pomace contains valuable vitamins, minerals, and dietary fiber, with a fiber composition of 3.88% pectin, 12.3% hemicellulose, 51.6% cellulose, and 32.1% lignin [9] [10]. Adopting a circular economy approach, which emphasizes reducing, recycling, reusing, recovering, and restoring, can unlock the potential of these waste products, thereby contributing to sustainable development and effective waste management [2] [11] [12].

Xylan is a key part of hemicellulose and the second most common natural polysaccharide in the world; it offers a promising stream for valorizing FVW. Comprising different monosaccharides and organic acids linked by glycosidic and ester bonds, xylan can serve as a substrate for microbial xylanase production. Filamentous fungi, such as *Aspergillus sp.* and *Trichoderma sp.*, are commonly employed for industrial-scale xylanase production due to their high extracellular enzyme production capacity [13] [14]. Solid-state fermentation proves advantageous in this context, offering better adaptation to the medium, higher enzyme production, reduced bacterial contamination, and the possibility of obtaining concentrated enzymes with minimal water usage [2].

The purpose of this study was to assess the potential of fruit and vegetable waste, specifically banana peel, mango peel, and carrot pomace, for the production of commercially valuable products, including xylanase enzymes, through solid-state fermentation. This approach aligns with the principles of a circular economy, contributing to sustainable development and effective waste management.

2. Materials and Methods

2.1. Study Area

The optimization of parameters for xylanase enzyme production was conducted in various laboratories. The Microbiology and Chemistry Laboratory at Egerton University's Njoro main campus was used for substrate preparation and solid-state fermentation. Enzyme activity was assessed using spectrophotometry in the Biotechnology Laboratory at Egerton University. Additionally, cookie baking and consumer tests were conducted at the Kenya Industrial Research and Development Institute (KIRDI) in Nairobi, Kenya.

2.2. Sampling Site

Banana and mango peels were sourced from the local fresh market in Nakuru City, while carrot pomace was obtained from Orchard Juice Ltd. in Nakuru City. All samples were transported to Egerton University for further analysis.

2.3. Substrate Preparation

Carrot pomace, mango peel (MP), and banana peel (BP) were cleaned with distilled water, oven-dried at 70˚C for 24 hours, and then milled into a powdery form with a particle size of 0.5 mm. The powdered substrates were stored in polythene bags for future use [3] [14].

2.4. Optimization of Enzyme Production under Solid-State Fermentation

The *Aspergillus brasiliensis* EGER23 strain, which was previously isolated [3], was sub-cultured on PDA media for seven days to prepare a fresh inoculum. Banana and mango peels, along with carrot pomace, were homogeneously blended. Twenty-five grams (25 g) of the blended mixture were transferred to each of the three (3) 500 mL Erlenmeyer flasks, and each flask was moistened with 10 mL of the basal salt solution and trace metal solution. The composition of the basal salt solution was (g/L): NaCl, 30.00; KCl, 0.75; $MgSO_4$, 7.00; NH_4Cl, 0.5; K_2HPO_4, 2.5; KH_2PO_4, 0.5. The moisture content was adjusted to 80% using distilled water. The blended mixtures in the three flasks were autoclaved at 121˚C for 15 minutes. The flasks were then cooled to room temperature, and the inoculum was added at a concentration of 1×10^6 spores/ml. The flasks were shaken thoroughly to mix the inoculum with the mixtures and then incubated at various temperatures (25˚C, 30˚C, and 35˚C) and pH levels (4.0, 5.0, and 6.0) for different durations (96 hours, 120 hours, and 144 hours) as per [15]. Following incubation, the mixture was filtered using a sterile muslin cloth to separate the extract and residue. The extract was further filtered using a 0.45 μm syringe filter to obtain the crude xylanase enzyme.

2.5. Determination of Enzyme Activity

To confirm the presence of xylanase enzyme in the crude extract, a 2% substrate solution of xylan was incorporated into agar media, autoclaved at 120˚C for 15 minutes, poured into plates, and left to cool to room temperature. Three uniform holes of 5 mm were made in each plate, with two holes filled with the crude extract and one with sterile distilled water as a control. The clearance zone around the holes was used to indicate the presence of xylanase enzyme in the extract [14]. Subsequently, xylanase activity was measured by incubating different concentrations (known amounts) of the substrate solution with the crude enzyme solution at 37˚C for 60 minutes (**Table 1**). The substrate solution was composed of 2% artificial xylan in 0.1 M sodium phosphate buffer. The released reducing sugars were measured using the 3,5-dinitrosalicylic acid (DNS) method, and enzyme activity was determined at 540 nm using a spectrophotometer, where one μmole/min of enzyme activity is equal to micromoles of product produced per minute [16].

Table 1. Concentration of substrate vs. crude enzyme.

Substrate concentration	Crude enzyme concentration	Total volume
0.3 ml	0.7 ml	1 ml
0.6 ml	0.4 ml	1 ml
0.9 ml	0.1 ml	1 ml

According to **Table 1**, the known concentration is used to estimate the unknown enzyme activity from the x-y graph, based on the enzyme activity formula in Equation (1) [17].

$$\text{Xylanase activity } (\mu\text{mol/min}) = S \times 1000/(T \times W_m) \tag{1}$$

where S is the amount of xylose (μg) corresponding to the measured absorbance on the standard curve; 1000 is the conversion factor between mg and μg; T is the reaction time (which is 60 min in this case); and W_m is the molecular weight of xylose (150.13 g/mol).

2.6. Protein Assay

The protein content of the culture supernatants was assessed using Bovine Serum Albumin (BSA) as a standard reference [18].

2.7. Enzyme Effects on Farinograph Properties of the Wheat Flour

Whole wheat was procured from a local market in Nairobi (Nyamakima), sorted, washed, and oven-dried at 70˚C for 24 hours. The wheat was milled using a Brabender model 880101.003 miller in the Food and Innovation Laboratory at the Kenya Industrial Research and Development Institute (KIRDI) in Nairobi. The enzyme with the highest activity was applied at varying dosages (0, 250, 500, 750, 1000, and 1500 IU) to evaluate its effects on the Farinograph properties of the flour. The concentrations (0, 250, 500, 750, 1000, 1500 IU) were selected to cover a wide spectrum of enzyme activity levels, and they increased in regular increments (250 IU), enabling a systematic investigation of how increasing enzyme dosage influences the dough properties measured by the Farinograph-AT (AACC 54-21) [19].

2.8. Viscograph Properties

The Brabender Viscograph-E was utilized to assess the effect of the enzyme on the onset of gelatinization, highest gelatinization temperature, viscosity during holding, and viscosity at the end of cooling, following AACC method number 22-10 [20].

2.9. Cookie Baking and Analysis

Cookies were baked following AACC Method No. 10-54 with slight modifications [21]. The ingredients included shortening, salt, sugar, baking powder, flour, and milk powder. A mixture of 500 g of milled wheat flour, 200 g of sugar, 5.4 g of baking powder, 143 g of fat, 2.3 g of salt, and a milk powder solution made by dissolving 17.5 g of milk powder in 50 mL of water was prepared. The ingredients were mixed at a regular speed of 63 rpm for 7 minutes, rolled to a thickness of 0.2 cm, and manually shaped into cookies with a diameter of 6.5 cm using a cookie cutter. The cookies were baked at 182˚C for 15 minutes, then left to cool and packed for analysis and sensory evaluation.

2.9.1. Textural Properties

The TA.XT.plus Texture Analyzer was used to measure the hardness and fracturability of the cookies. The diameter and thickness of the cookies were measured manually using a caliper [22].

2.9.2. Calorimeter

The values for a (position of the color on the green (−) to red axis (+)), b (position of the color on the blue (−) to yellow (+) axis), and L* (the lightness of the color, where 0 = black, 100 = white) of the cookies were measured using a colorimeter

(Chroma Meter CR-400) in three replications according to AACC Method No. 14.22.02 [23].

2.9.3. Sensory Analysis

Consumer acceptance was conducted at KIRDI after 24 hours of baking, using a 7-point hedonic scale to assess the product's properties [24]. The panelists were BSc Food Science students from universities in the Nairobi area, undertaking internships at KIRDI at the time of the evaluation. The panel comprised 15 males and 15 females, and all participants were over 18 years of age.

2.10. Experimental Design

The response surface methodology-based Box-Behnken design (BBD) was used to collect data for optimizing the three parameters for enzyme production: pH (4, 5, 6), time (96, 120, 144 hours), and temperature (25˚C, 30˚C, 35˚C). These were the independent variables, and enzyme activity was the dependent variable [18].

2.11. Data Analysis

Minitab software was used to analyze the data for optimization, and the results were described statistically using a second-order polynomial regression model.

The statistical model (second-order polynomial equation) is as shown in Equation (2):

$$\begin{aligned} Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 \\ + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 \end{aligned} \tag{2}$$

where Y is the response (enzyme activity in μmol/min), μmol.

β_0 is the model intercept.

X_1, X_2 and X_3 are independent factors under study (temperature, pH, and time), and

β_1, β_2, and β_3 are linear coefficients.

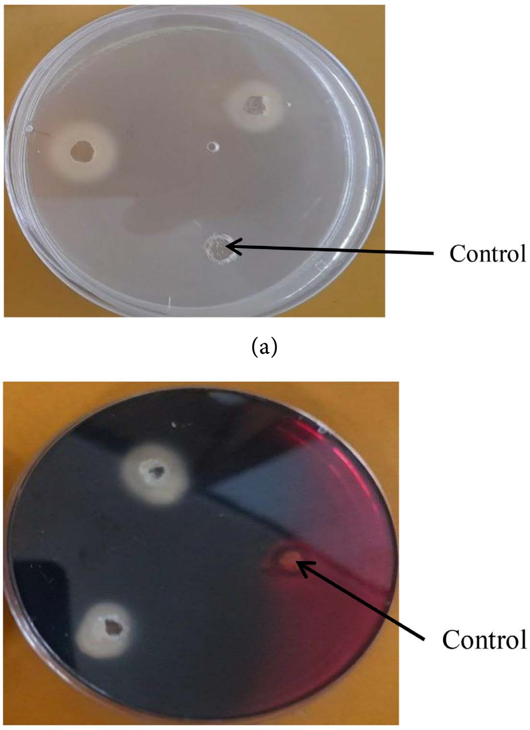
SAS 9.4 was used to analyze the data from the texture analyzer, colorimeter, Farinograph, and Viscograph. Each experiment was conducted in triplicate, and the level of significance was determined by the analysis of variance technique (ANOVA) at $p < 0.05$. Mean differences were explained using Tukey.

3. Results and Discussion

3.1. Xylanase Production by *Aspergillus brasiliensis* EGER23

The study aimed to evaluate the potential of fruit and vegetable waste, including banana peel, mango peel, and carrot pomace, for the production of xylanase enzymes using *Aspergillus brasiliensis* (formerly known as *Aspergillus niger*) through solid-state fermentation [18]. Xylanases are enzymes that hydrolyze beta-1,4-xylan, a major component of plant cell walls, into xylose [14] [25]. In food processing, xylanases improve wheat dough and baked products. They are also used in the extraction of coffee, plant oils, and starch and for the clarification of juices

[26]. Xylanases are generally produced using substrates that are rich in xylan [27]. To produce the enzyme in large quantities, the choice of substrate and production conditions is important. In this study, fruit and vegetable waste was used as the substrate. Firstly, the ability of *Aspergillus brasiliensis* isolate to produce xylanases was evaluated. The crude enzyme extracts degraded xylan in the media, indicated by the clear zone around the sample hole, unlike the case of distilled water used as a control, where there was no clear zone. The observation was done within 24 hours. This reaffirmed the presence of xylanase enzyme in the crude extract (**Figure 1**). This result was in line with other studies that have demonstrated the utility of *Aspergillus* strains in the production of xylanases [25] [26].



(a)

(b)

Figure 1. Xylan-containing samples were incubated with crude extract and sterilized distilled water (as a control) for 24 hours. (a) Clear zones before Congo red staining; (b) Clear zones after Congo red staining.

3.2. Optimization of Parameters for the Production of the Xylanase Enzyme with Maximum Activity

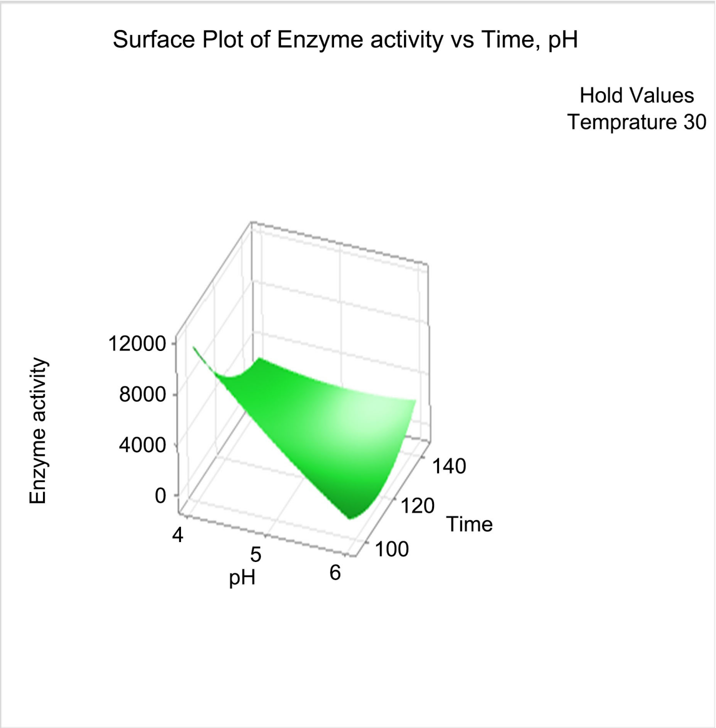
Industrial enzymes are mostly produced through the fermentation process, and therefore optimizing the fermentation conditions is important for the growth of the organism and the production of the target enzyme [28]. **Table 2** presents a response surface ANOVA for the optimization of three factors (pH, time, and temperature) on enzyme activity using a Box-Behnken design (BBD). The "Model F-value" (3.56) and p-value (0.006) indicate that the overall model was statistically significant ($p < 0.05$), meaning that it adequately explains the relationship between the factors and enzyme activity. The variable parameters of 25˚C, 30˚C, and 35˚C, pH levels of 4.0, 5.0, and 6.0, and different cultivation durations of 96 hrs, 120 hrs, and 144 hrs were used. For the main effects, the linear pH and cultivation time terms had a significant impact (p = 0.003 and 0.032, respectively) on enzyme activity, suggesting that altering the pH level and cultivation time could significantly affect enzyme activity. This is further supported by the high F-values (10.88 and 5.16, respectively). However, the linear temperature term was not statistically significant (p = 0.430), suggesting that within the tested range, temperature did not significantly affect enzyme activity. The response surface optimization regression model (**Table 3**) and surface plots (**Figure 2**) provided further insights into the relationship between the independent variables and the xylanase activities. There was a negative linear effect of pH of cultivation of *A. brasiliensis* on enzyme activity, where an increase in pH value resulted in a decrease in enzyme activity, which conforms to the findings of xylanase activity reported by [27], where it was demonstrated that xylanases from *A. niger* had the highest activity for cells cultivated at a pH of 4.0 - 5.0, and the activity reduced with an increase in pH value. In our study, the highest enzyme activity was observed in cells cultivated at a lower pH of 4.2, which conforms to the acidic nature of xylanases [16] [29]. However, the lowest pH evaluated in this study was 4.0, which suggests that the optimal cultivation pH of the xylanase enzyme-producing organisms may not have been assessed.

Table 2. Response surface ANOVA for the optimization of pH, time, and temperature on enzyme activity.

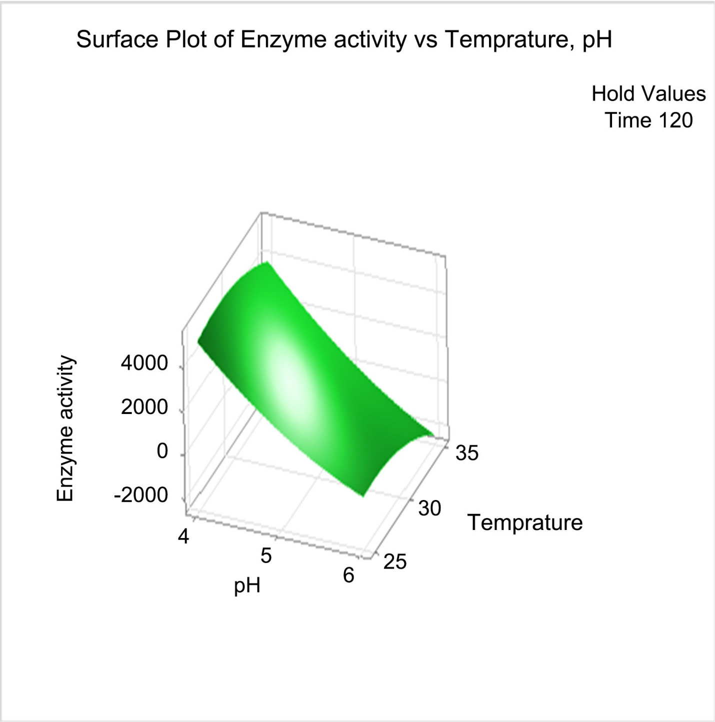
Source	DF	Adj SS	Adj MS	F-Value	p-Value
Model	9	463,783,128	51,531,459	3.56	0.006
Linear	3	226,877,740	75,625,913	5.22	0.006
pH	1	157,560,176	157,560,176	10.88	0.003
Time	1	74,708,336	74,708,336	5.16	0.032
Temperature	1	9,309,622	9,309,622	0.64	0.430
Square	3	47,765,616	15,921,872	1.10	0.368
pH*pH	1	2,498,599	2,498,599	0.17	0.681
Time*Time	1	32,059,301	32,059,301	2.21	0.149
Temperature*Temperature	1	3,297,468	3,297,468	0.23	0.637
2-Way Interaction	3	95,955,675	31,985,225	2.21	0.112
pH*Time	1	87,673,267	87,673,267	6.06	0.021
pH*Temperature	1	386,127	386,127	0.03	0.872
Time*Temperature	1	10,883,041	10,883,041	0.75	0.394
Error	25	361,882,766	14,475,311		
Lack-of-Fit	4	41,466,063	10,366,516	0.68	0.614
Pure Error	21	320,416,703	15,257,938		
Total	34	825,665,894			

Table 3. Response surface optimization regression model.

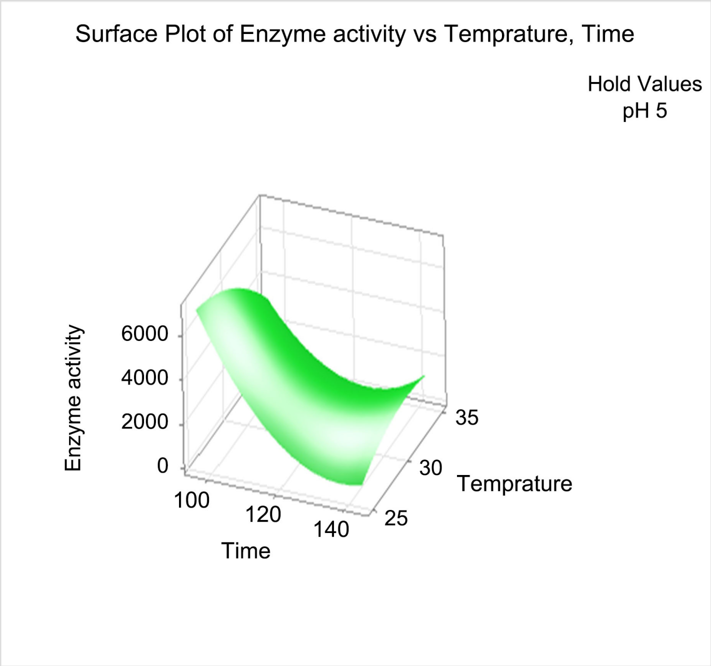
Enzyme activity	=	Enzyme activity = 167,719 − 20,680·pH − 1807·Time + 563·Temperature + 585·pH^2 + 3.67·Time^2 − 27.9·Temperature^2 + 110.4·pH·Time − 42·pH·Temperature + 9.7·Time·Temperature



(a)



(b)



(c)

Figure 2. Surface plots of the effects of temperature (a), time (b), and pH (c) on xylanase activity.

Similar to pH, cultivation time exhibited a negative linear effect on enzyme activity, whereby increasing cultivation time of *Aspergillus brasiliensis* decreased the xylanase activity. Previous research by [17] [30]. demonstrated that peak xylanase activity was achieved after 72 hours (3 days) of incubation when producing xylanases using *A. niger*. This level of activity remained stable for up to 6 days before showing signs of decrease. The observed stabilization in enzyme activity over time could be attributed to the depletion of nutrients in the fermentation medium, which can affect the physiology of the organisms [31]. Similar results with shorter cultivation periods have been reported in other species such as *Aspergillus fumigatus* and *Aspergillus flavus*, while longer cultivation periods have been observed in strains of *Rhizopus oryzae* and *Aspergillus fumigatus* [28] [32]. Our findings suggest that shorter cultivation periods may be ideal for industrial production, offering advantages such as minimizing contamination risks and enhancing process economy [33]. There was no significant effect of temperature on enzyme activity that could be attributed to the interactive relationship between pH and time, where the overall impact of temperature becomes less pronounced in the presence of other optimized conditions. Furthermore, pH and time can significantly influence the growth and metabolism of *Aspergillus brasiliensis*. While the selected temperature might fall within the optimal range for growth and enzyme production, it suggests that the chosen temperature was either within the microorganisms’ adaptable limits or within the optimum conditions for their growth and enzyme production. However, our optimum temperature giving maximum activity was 25˚C (**Figure 3**). This conforms to the results of [27], who obtained the highest xylanase activity at 25˚C, and the enzyme activity kept decreasing with an increase in temperature up to 60˚C as a result of protein denaturation.

For the interaction effects, the pH-time interaction term was significant ($p = 0.021$), implying that the combined effect of pH and time on enzyme activity was not merely additive. Instead, they could have a synergistic or antagonistic effect depending on the specific combination of pH and time chosen. However, none of the other two-way interaction terms (pH-temperature, time-temperature) were statistically significant ($p > 0.05$), suggesting that the combined effects of these factors on enzyme activity were likely additive within the tested range. The lack-of-fit F-value (0.68) and p-value (0.614) indicate that the model adequately fit the data, and there was no evidence of unusual curvature in the response surface. None of the individual factors (pH, time, or temperature) exhibited a significant quadratic effect on enzyme activity within the tested range. As illustrated in **Figure 3**, the results show that optimizing parameters greatly increases the chance of exceeding 10,000 µmole/min enzyme activity. The calculated probability of reaching the minimum activity level is 99.98% by setting the pH to 4.2, the time to 100.9 hours, and the temperature at 25˚C (optimum conditions).

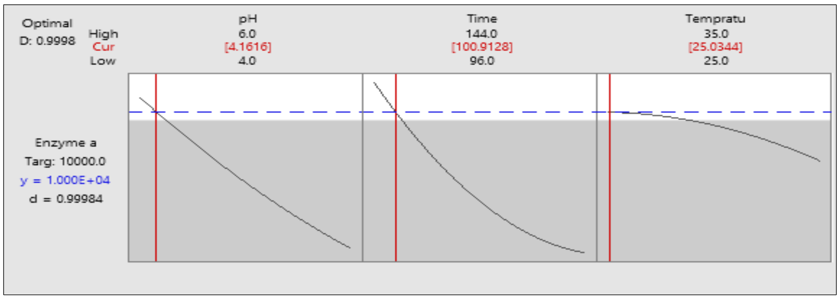


Figure 3. Optimal pH, time, and temperature for xylanase activity above 10,000 µmole/min.

3.3. Effect of Xylanase Concentration on the Farinograph Properties of Wheat Flour

Table 4 shows the results of the Farinograph properties of wheat flour treated with different enzyme concentrations. The mean squares for "Treatment" were not statistically significant for any of the Farinograph properties, suggesting that the different enzyme concentrations did not significantly affect the water absorption capacity (WAC), stability, breakdown, development time, or Farinograph quality time (FQN) of the wheat flour. For replicates and Error, the mean squares for replicates were generally similar to those for "Error" for most properties, indicating that the replicates were consistent, and the experimental error might have been relatively high for some properties. The R^2 values for all properties were moderate (ranging from 0.23 to 0.61), indicating that the replicates and error explain a significant portion of the variance in the measurements. For water absorption capacity (WAC), there was no statistically significant difference in WAC across all enzyme concentrations except at 1500 IU. The dough appeared to absorb a similar amount of water regardless of enzyme treatment. Both stability and breakdown showed a slight decrease with increasing enzyme concentration (from 0 to 750 IU). At higher concentrations (1000 and 1500 IU), the values stabilized, suggesting that the enzymes might have weakened the dough structure initially, but the effect plateaued at higher concentrations. There were no statistically significant differences observed in development time across all concentrations. FQN showed a significant decrease at 750 IU compared to the control (0 IU). However, the values recovered somewhat at higher concentrations. This suggests that the enzyme treatment might negatively affect dough quality at a specific concentration but does not have a consistent impact across the entire range. Our results are similar to [34]. who reported that adding xylanase into the flour had no significant influence on the farinographic properties of the dough.

Table 4. Farinograph properties of wheat flour treated with xylanase at different concentrations.

Conc. (IU)	WAC	Stability	Breakdown	Dev. time	FQN
0	63.70 ± 0.15^{a}	5.31 ± 0.01^{a}	7.03 ± 0.02^{a}	3.27 ± 0.07^{a}	66.67 ± 0.88^{a}
250	63.47 ± 0.03^{a}	5.26 ± 0.10^{a}	6.21 ± 0.02^{b}	3.27 ± 0.03^{a}	63.67 ± 0.33^{abc}
500	63.40 ± 0.10^{a}	5.18 ± 0.10^{a}	6.30 ± 0.03^{b}	3.17 ± 0.01^{a}	65.00 ± 0.58^{ab}
750	63.70 ± 0.06^{a}	4.52 ± 0.00^{b}	5.78 ± 0.13^{c}	3.21 ± 0.08^{a}	61.00 ± 0.58^{c}
1000	63.20 ± 0.15^{a}	4.47 ± 0.05^{b}	6.20 ± 0.03^{b}	3.08 ± 0.01^{a}	63.33 ± 0.33^{abc}
1500	62.40 ± 0.12^{b}	4.46 ± 0.08^{b}	6.21 ± 0.05^{b}	3.08 ± 0.06^{a}	62.33 ± 1.45^{bc}

Values are means ± standard errors of triplicate measurements. Means with the same letter within the column are not significantly different at $p \leq 0.05$; Conc. = Concentration; Dev. Time = Development Time; FQN = Farinograph Quality Time; WAC = Water Absorption Capacity.

3.4. Effect of Xylanase on Viscograph Properties of Wheat Flour

Tables 5-7 present the effects of enzyme concentration (IU) on the pasting properties of the wheat samples, measured with a Viscograph. The data were categorized into three tables: viscosity (Table 5), time (Table 6), and temperature (Table 7). Compared to the control, there was a general trend of decreasing viscosity with increasing enzyme concentration (250 to 1500 IU) for most parameters in Table 5, including maximum viscosity, start of holding period, start of cooling period, end of cooling period, end of final holding period, breakdown, and setback. This suggests that the enzymes were influencing the rheological characteristics of the flour by breaking down xylan/polymers in the sample, leading to a reduction in its thickening ability. This finding aligns with previous studies that have demonstrated the xylanase's structural degradation of the dough leading to changes in viscosity [35]. Interestingly, the time parameters in Table 6 (beginning of gelatinization, maximum viscosity time, start of holding period, start of cooling period, end of cooling period, end of holding period, breakdown, and setback) exhibited minimal changes across all enzyme concentrations. This suggests that the xylanase action primarily targeted the structural components of the flour, leading to alterations in its rheological properties, rather than influencing the kinetics of the pasting process. These findings are consistent with studies that have reported minimal changes in pasting time parameters in response to enzymatic treatments [20]. The temperature values in Table 7 also showed minimal variation across enzyme concentrations, indicating that the enzymes did not significantly ($p \le 0.05$) alter the temperatures at which pasting transitions occurred. This suggests that the enzymatic treatment did not impact the thermal properties of the flour or induce changes in the temperature-dependent transitions during the pasting process. These findings provide valuable insights into the specific effects of enzyme concentration on the pasting properties of flour samples and highlight the potential for enzymatic treatments to modulate rheological characteristics without affecting pasting kinetics or thermal behavior.

Table 5. The impact of enzyme concentration on the viscosity of cookie flour at different evaluation points.

Conc. (IU)	Beginning of gelatinization	Maximum viscosity	Start of holding period	Start of the cooling period	End of the cooling period	End of the final holding period	Breakdown	Setback
0	14.00 ± 0.58^{a}	64.00 ± 3.61^{a}	60.33 ± 3.18^{a}	45.00 ± 2.31^{a}	162.00 ± 8.08^{a}	211.67 ± 14.24^{a}	19.00 ± 1.53^{a}	124.00 ± 6.56^{a}
250	14.00 ± 0.58^{a}	45.67 ± 2.03^{b}	40.00 ± 1.73^{b}	31.00 ± 1.53^{b}	118.00 ± 5.13^{b}	156.00 ± 6.08^{b}	15.00 ± 1.15^{ab}	82.67 ± 2.33^{ab}
500	14.00 ± 0.00^{a}	42.33 ± 1.76^{b}	37.67 ± 3.33^{b}	30.33 ± 1.20^{b}	110.67 ± 8.95^{b}	142.67 ± 11.89^{b}	12.67 ± 0.88^{ab}	78.67 ± 4.91^{ab}
750	14.00 ± 0.58^{a}	41.00 ± 2.65^{b}	36.00 ± 1.53^{b}	30.00 ± 1.53^{b}	110.00 ± 3.61^{b}	141.00 ± 3.79^{b}	12.67 ± 0.88^{ab}	78.00 ± 1.73^{ab}
1000	14.33 ± 0.33^{a}	40.00 ± 2.89^{b}	39.00 ± 2.08^{b}	29.00 ± 2.08^{b}	107.00 ± 4.73^{b}	135.33 ± 8.51^{b}	12.00 ± 1.53^{b}	76.00 ± 4.58^{ab}
1500	14.67 ± 0.33^{a}	37.00 ± 1.53^{b}	35.00 ± 1.53^{b}	27.00 ± 2.52^{b}	101.00 ± 3.51^{b}	128.00 ± 2.31^{b}	12.00 ± 1.53^{b}	50.33 ± 21.74^{b}

Values are means ± standard errors of triplicate measurements. Means with the same letter within the column are not significantly different at $p \le 0.05$.

Table 6. Change in time with varying enzyme concentrations at different Viscograph evaluation points.

Conc. (IU)	Beginning of gelatinization	Maximum viscosity	Start of holding period	Start of the cooling period	End of the cooling period	End of the final holding period	Breakdown	Setback
0	28.79 ± 0.64^{b}	39.60 ± 0.03^{a}	42.00 ± 0.00^{a}	57.00 ± 0.00^{a}	99.00 ± 0.00^{a}	114.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
250	30.12 ± 0.69^{ab}	39.56 ± 0.13^{a}	42.00 ± 0.00^{a}	57.00 ± 0.00^{a}	99.00 ± 0.00^{a}	114.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
500	30.51 ± 0.54^{ab}	39.50 ± 0.04^{ab}	42.00 ± 0.00^{a}	57.00 ± 0.00^{a}	99.00 ± 0.00^{a}	114.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
750	30.81 ± 0.55^{ab}	39.45 ± 0.04^{ab}	42.00 ± 0.00^{a}	57.00 ± 0.00^{a}	99.00 ± 0.00^{a}	114.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
1000	31.26 ± 0.63^{ab}	39.38 ± 0.03^{ab}	42.00 ± 0.00^{a}	57.00 ± 0.00^{a}	99.00 ± 0.00^{a}	114.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
1500	31.71 ± 0.11^{a}	39.24 ± 0.02^{b}	42.00 ± 0.00^{a}	57.00 ± 0.00^{a}	99.00 ± 0.00^{a}	114.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}

Values are means ± standard errors of triplicate measurements. Means with the same letter within the column are not significantly different at $p \le 0.05$.

Table 7. Changes in temperature following increased enzyme concentration at various Viscograph evaluation points.

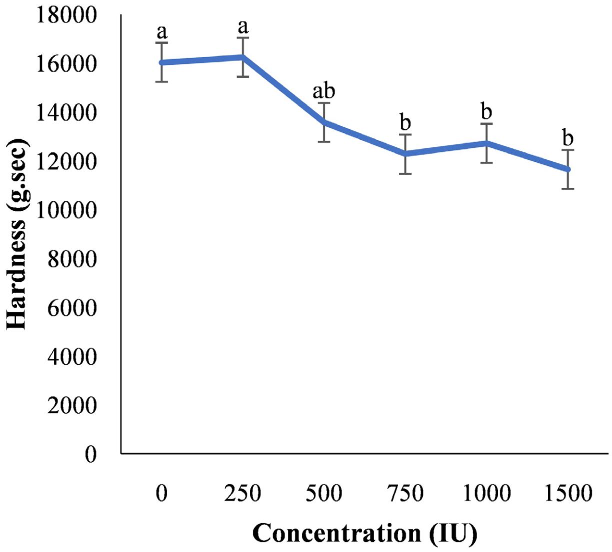
Conc. (IU)	Beginning of gelatinization	Maximum viscosity	Start of holding period	Start of the cooling period	End of cooling period	End of the final holding period	Breakdown	Setback
0	72.57 ± 0.99^{b}	89.20 ± 0.06^{a}	93.00 ± 0.00^{a}	93.00 ± 0.00^{a}	32.57 ± 0.03^{a}	30.10 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
250	75.10 ± 1.01^{ab}	89.13 ± 0.09^{a}	92.90 ± 0.06^{a}	93.00 ± 0.00^{a}	32.47 ± 0.03^{ab}	30.10 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
500	75.80 ± 0.81^{ab}	89.13 ± 0.24^{a}	92.90 ± 0.06^{a}	93.00 ± 0.00^{a}	32.43 ± 0.03^{abc}	30.10 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
750	76.57 ± 0.97^{a}	89.07 ± 0.03^{a}	92.83 ± 0.03^{a}	93.00 ± 0.00^{a}	32.43 ± 0.03^{abc}	30.07 ± 0.03^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
1000	76.80 ± 0.57^{a}	88.87 ± 0.09^{a}	92.77 ± 0.09^{a}	92.90 ± 0.06^{a}	32.40 ± 0.06^{bc}	30.07 ± 0.03^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
1500	77.33 ± 0.12^{a}	88.70 ± 0.12^{a}	92.77 ± 0.03^{a}	92.90 ± 0.06^{a}	32.30 ± 0.00^{c}	30.07 ± 0.03^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}

Values are means ± standard errors of triplicate measurements. Means with the same letter within the column are not significantly different at $p \le 0.05$.

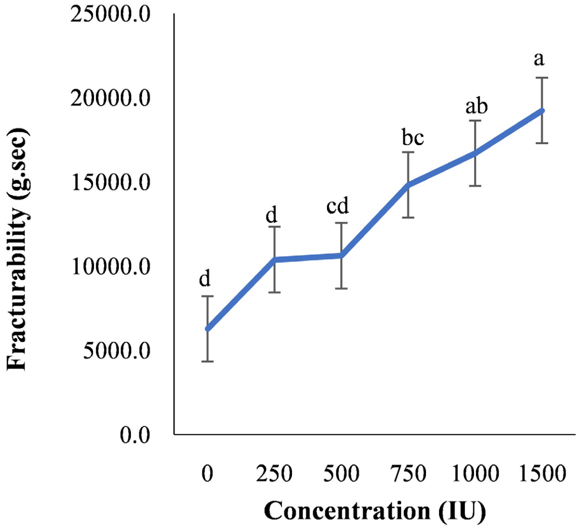
3.5. Effect of Xylanase on Properties of Cookies

3.5.1. Textural Properties

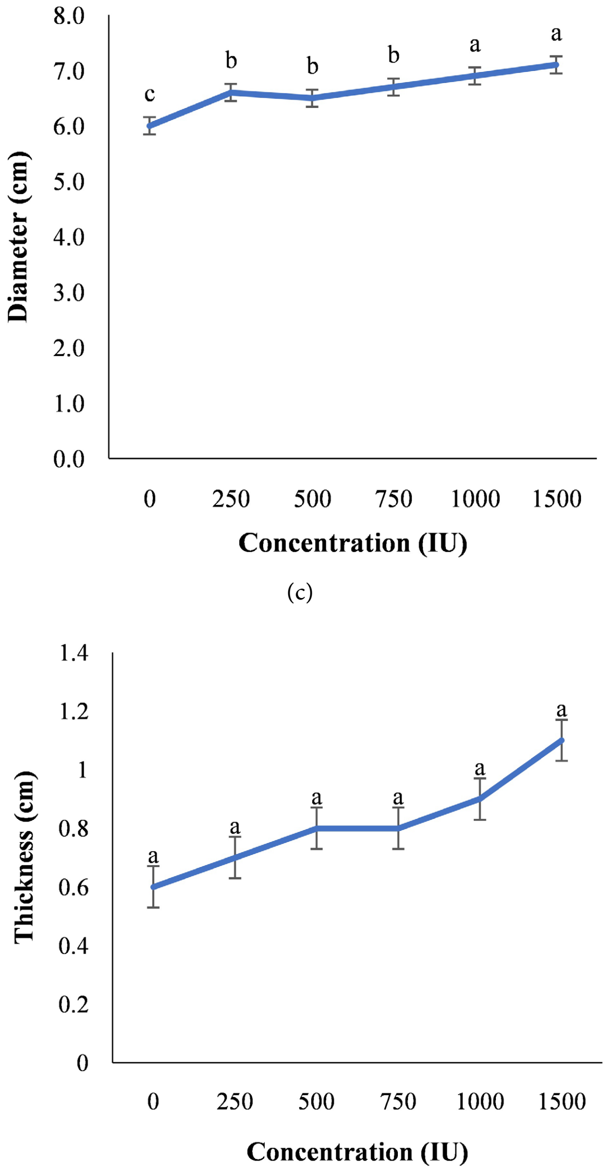
Figure 4 presents the results of the impact of different treatments (xylanase concentrations) on the textural properties of cookies. The textural properties analyzed include hardness, fracturability, diameter, and thickness of cookies. Xylanase treatments had a discernible effect on the textural properties of the cookies. All textural parameters exhibited a statistically significant ($p < 0.05$) association with enzyme concentration. An increase in enzyme concentration resulted in a decrease in cookie hardness (**Figure 4(a)**). Conversely, the fracturability, diameter, and thickness of the cookies demonstrated an upward trend, indicating an increase with higher enzyme concentrations (**Figures 4(b)-(d)**, respectively). The decrease in cookie hardness with increasing xylanase concentration agrees with



(a)



(b)



(c)

(d)

Figure 4. Textural properties of cookies treated with different enzyme concentrations. (a) represents cookie hardness; (b), cookie fracturability; (c), cookie diameter; (d), cookie thickness.

several studies. For example, [22] reported a significant softening effect of xylanase on cookies prepared with wheat flour. In a similar study, [36] noted that the addition of xylanase decreased the hardness of cookies. The decrease in the hardness of cookies can be attributed to the partial degradation of arabinoxylans in the flour, resulting in a more relaxed gluten network. [29] also found that the application of xylanases from *Aspergillus niger* causes dough softening. Therefore, in this study, xylanase action may enhance the tendency of the cookies to break or crumble more easily, leading to an increase in the observed fracturability. The effect of xylanase on cookie thickness and diameter could not be directly explained. Therefore, it could be important to analyze dough rheology (spreadability and stretchability) after xylanase treatment.

3.5.2. Effect of Enzyme on Color of Cookies

The data in **Table 8** present the color properties of cookies treated with different enzyme concentrations, ranging from 0 to 1500 IU. The "Treatment" effect, *i.e.*, the level of enzyme concentration, had the highest mean squares for all colorimetric properties (L*, a*, and b*). These values were statistically significant ($p \leq 0.001$), suggesting that the different enzyme concentrations significantly influenced the color properties of the cookies. The impact of the xylanase enzyme on cookie color was significant, and this effect varied with different dosages compared to the control. There was a general decrease in lightness (L*) with increasing enzyme concentration. Cookies treated with higher enzyme concentrations appeared darker than those treated with lower concentrations. The difference became statistically significant ($p \leq 0.05$) at 1000 IU and higher. These results agreed with those reported by [37], where bread crumb L values were found to decrease with the addition of xylanase. While there appeared to be a slight increase in redness (a*) with increasing concentration, the differences were not statistically significant across all concentrations except at 1500 IU. However, the treatments were significantly higher than the control (0 IU). [37] discovered that the redness value (a*) increased with the addition of xylanase, which conforms to our study. Similar to redness, there was a slight upward trend in yellowness (b*) with increasing xylanase concentration, but the changes were not statistically significant, although the treatments were significantly higher than the control. When the enzyme dosage was lower, there was a reduced breakdown of complex sugars, leading to decreased readiness for participation in the Maillard and caramelization reactions, which are the primary determinants of product color [37] [38] Consequently, the cookies appeared lighter. On the other hand, higher enzyme dosages exhibited decreased L values, indicating a darker product color. The a and b values showed an increased shift towards more positive values, signifying a color spectrum extending towards red (in the case of a*) and more yellow/brown tones (in the case of b*).

Table 8. Color properties of cookies treated with different enzyme concentrations (IU).

Conc. (IU)	L*	a*	b*
0	67.59 ± 0.62^{a}	7.98 ± 0.37^{c}	24.26 ± 0.45^{b}
250	67.20 ± 1.91^{a}	11.92 ± 0.96^{b}	28.41 ± 0.18^{a}
500	61.04 ± 0.94^{ab}	12.11 ± 0.76^{b}	29.43 ± 0.18^{a}
750	61.16 ± 2.47^{ab}	12.61 ± 0.32^{b}	29.66 ± 0.76^{a}
1000	58.60 ± 0.80^{b}	13.31 ± 0.21^{b}	29.89 ± 0.72^{a}
1500	55.78 ± 1.05^{b}	16.38 ± 0.22^{a}	30.61 ± 0.57^{a}

The values presented are means ± standard deviations of triplicate measurements. Means with the same letter along the column are not significantly different at $p \leq 0.05$; Conc. = Concentration.

3.5.3. Consumer Acceptability of Cookies by Sensory Attributes

The radar chart (**Figure 5**) depicts the average consumer acceptability scores for various sensory attributes of cookies prepared from flour treated at different xylanase concentrations (IU). The polygon closer to the outer edge indicates higher acceptability. Consumers rated most sensory aspects, including appearance, color, aroma, and overall acceptability, highly across all enzyme concentrations, with scores ranging between 6.00 and 6.60 on a hedonic scale of 1 (dislike extremely) to 7 (like extremely). This high rating suggests that consumers found the cookies to be appealing and palatable regardless of the xylanase concentration used in their preparation. Similar findings have been reported in previous studies. For example, in a study by [39], researchers evaluated the sensory attributes of baked cakes supplemented with enzyme-treated flour and found that consumers rated the attributes highly, indicating a positive perception of the product. This consistency in consumer acceptance aligns with the results of our study and underscores the feasibility of incorporating enzyme-treated flour in bakery products. Taste received the highest scores among all sensory attributes, followed by appearance and color. This finding implies that consumers placed more weight on the taste profile of the cookies, which may have influenced their overall perception of the product. Texture scores showed some variation across different enzyme concentrations but remained within a highly acceptable range. While texture is an important sensory attribute that can significantly impact consumer perception, the minor variation observed in our study suggests that the addition of xylanase did not adversely affect the texture of the cookies. This finding is supported by the work of [40], who demonstrated that enzyme supplementation in baked goods can improve texture attributes without compromising overall acceptability.

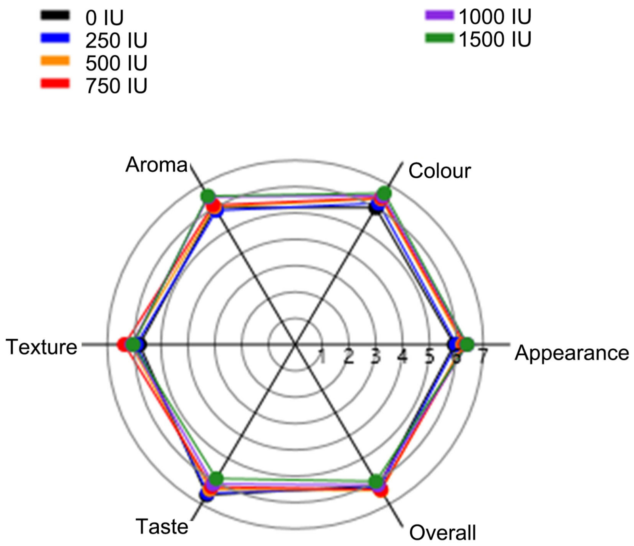


Figure 5. Consumer acceptability of cookies based on sensory attributes using 7-point hedonic scores.

Overall, the results indicate that the incorporation of xylanase in cookie preparation did not result in significant differences in sensory attributes compared to the control cookies. This suggests that consumers found the enzyme-treated cookies to be equally acceptable, if not more so, than their counterparts. Therefore, incorporating xylanase in cookie production is not only feasible but may also enhance certain sensory attributes, particularly taste, without compromising overall acceptability.

4. Conclusion

The findings of this study demonstrate the feasibility of utilizing fruit and vegetable waste, including banana peel, mango peel, and carrot pomace, for the production of xylanase enzymes using *Aspergillus brasiliensis* through solid-state fermentation. Optimization of fermentation parameters revealed that pH and cultivation time significantly influenced enzyme activity, while temperature had no significant impact within the tested range. The interaction between pH and time also played a crucial role in enzyme activity, suggesting a synergistic or antagonistic effect. Textural properties, color, and pasting properties of cookies treated with xylanase enzymes exhibited significant changes, indicating potential applications in food processing. Despite the alterations in these properties, no significant impact was observed on Farinograph properties. Consumer acceptability scores further support the feasibility of incorporating xylanase enzymes in cookie production, with high ratings across sensory attributes. Overall, the study underscores the potential of utilizing agricultural waste for enzyme production and highlights the value of xylanase enzymes in food processing applications. These findings contribute to the growing body of research on sustainable waste utilization and enzyme technology, with implications for the food industry and environmental sustainability efforts.

Funding

This work was financially supported by the TAGdev program under Mastercard and RUFORUM.

Ethics

Ethical permission was granted by Egerton University Institutional Scientific and Ethics Review Committee EUISERC.

Consent

All panellists provided informed consent before participating in the sensory evaluation, and the study was conducted in accordance with Egerton University Institutional Scientific and Ethics Review Committee guidelines (Approval No. *EUISERC/APP/258/2023*).

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Authors' Contribution

[Timar P. Menbere]: Conceptualization, Methodology, Writing—Original Draft, Software, Data Analysis, Funding Acquisition

[Joseph W. Matofari]: Validation, Supervision, Writing—Review & Editing.

[John M. Nduko]: Visualization, Resources, Supervision, Methodology, Writing—Review & Editing.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

References

[1] Esparza, I., Jiménez-Moreno, N., Bimbela, F., Ancín-Azpilicueta, C. and Gandía, L.M. (2020) Fruit and Vegetable Waste Management: Conventional and Emerging Approaches. *Journal of Environmental Management*, **265**, Article 110510. https://doi.org/10.1016/j.jenvman.2020.110510

[2] Sharma, V., Tsai, M., Nargotra, P., Chen, C., Kuo, C., Sun, P., *et al.* (2022) Agro-industrial Food Waste as a Low-Cost Substrate for Sustainable Production of Industrial Enzymes: A Critical Review. *Catalysts*, **12**, Article 1373. https://doi.org/10.3390/catal12111373

[3] Sarker, A., Ahmmed, R., Ahsan, S.M., Rana, J., Ghosh, M.K. and Nandi, R. (2024) A Comprehensive Review of Food Waste Valorization for the Sustainable Management of Global Food Waste. *Sustainable Food Technology*, **2**, 48-69. https://doi.org/10.1039/d3fb00156c

[4] Sagar, N.A., Pareek, S., Sharma, S., Yahia, E.M. and Lobo, M.G. (2018) Fruit and Vegetable Waste: Bioactive Compounds, Their Extraction, and Possible Utilization. *Comprehensive Reviews in Food Science and Food Safety*, **17**, 512-531. https://doi.org/10.1111/1541-4337.12330

[5] Mohd Zaini, H., Roslan, J., Saallah, S., Munsu, E., Sulaiman, N.S. and Pindi, W. (2022) Banana Peels as a Bioactive Ingredient and Its Potential Application in the Food Industry. *Journal of Functional Foods*, **92**, Article 105054. https://doi.org/10.1016/j.jff.2022.105054

[6] Wani, K.M. and Dhanya, M. (2025) Unlocking the Potential of Banana Peel Bioactives: Extraction Methods, Benefits, and Industrial Applications. *Discover Food*, **5**, Article No.8. https://doi.org/10.1007/s44187-025-00276-y

[7] Macedo, A., Gomes, T., Ribeiro, C., Moldão-Martins, M., Duarte, E. and Alves, V.D. (2022) Membrane Technology for Valorization of Mango Peel Extracts. *Foods*, **11**, Article 2581. https://doi.org/10.3390/foods11172581

[8] Kučuk, N., Primožič, M., Kotnik, P., Knez, Ž. and Leitgeb, M. (2024) Mango Peels as an Industrial By-Product: A Sustainable Source of Compounds with Antioxidant, Enzymatic, and Antimicrobial Activity. *Foods*, **13**, Article 553. https://doi.org/10.3390/foods13040553

[9] Chepkosgei, T.M. and Orina, I. (2021) Quality and Sensory Properties of Instant Fried Noodles Made with Soybean and Carrot Pomace Flour. *African Journal of Food Science*, **15**, 92-99. https://doi.org/10.5897/ajfs2020.2019

[10] Verma, R.C., Hk, J., Yadav, K.K. and Rajpurohit, D. (2018) A Review: Food, Chemical Composition and Utilization of Carrot (*Daucus carota* L.) Pomace. *International Journal of Chemical Sciences*, **6**, 2921-2926.

[11] Hussain, S., Jõudu, I. and Bhat, R. (2020) Dietary Fiber from Underutilized Plant Resources—A Positive Approach for Valorization of Fruit and Vegetable Wastes. *Sustainability*, **12**, Article 5401. https://doi.org/10.3390/su12135401

[12] Pal, P., Singh, A.K., Srivastava, R.K., Rathore, S.S., Sahoo, U.K., Subudhi, S., *et al.* (2024) Circular Bioeconomy in Action: Transforming Food Wastes into Renewable Food Resources. *Foods*, **13**, Article 3007. https://doi.org/10.3390/foods13183007

[13] Chen, Z., Liu, Y., Zaky, A.A., Liu, L., Chen, Y., Li, S., *et al.* (2019) Characterization of a Novel Xylanase from *Aspergillus flavus* with the Unique Properties in Production of Xylooligosaccharides. *Journal of Basic Microbiology*, **59**, 351-358. https://doi.org/10.1002/jobm.201800545

[14] Dahiya, S., Rapoport, A. and Singh, B. (2024) Biotechnological Potential of Lignocellulosic Biomass as Substrates for Fungal Xylanases and Its Bioconversion into Useful Products: A Review. *Fermentation*, **10**, Article 82. https://doi.org/10.3390/fermentation10020082

[15] Maulana Hidayatullah, I., Setiadi, T., Tri Ari Penia Kresnowati, M. and Boopathy, R. (2020) Xylanase Inhibition by the Derivatives of Lignocellulosic Material. *Bioresource Technology*, **300**, Article 122740. https://doi.org/10.1016/j.biortech.2020.122740

[16] Scarton, M., Ganancio, J.R.C., de Avelar, M.H.M., Clerici, M.T.P.S. and Steel, C.J. (2020) Lime Juice and Enzymes in *Clean Label* Pan Bread: Baking Quality and Preservative Effect. *Journal of Food Science and Technology*, **58**, 1819-1828. https://doi.org/10.1007/s13197-020-04693-y

[17] Huilong, J., Xin, G., Wenxuan, W., Zhuang, M. and Qing, Q. (2021) Isolation of Xylanase Producing Strains, Optimization of Fermentation Conditions and Research on Enzymatic Properties. *Journal of Biology and Life Science*, **12**, 1. https://doi.org/10.5296/jbls.v12i2.18483

[18] Laswai, F.C., Matofari, J.W. and Nduko, J.M. (2024) Pectinolytic Enzyme Production from Orange Processing Waste Using *Aspergillus brasiliensis* Strain. *Biomass Conversion and Biorefinery*, **14**, 25173-25186. https://doi.org/10.1007/s13399-023-04603-0

[19] Ahmad, Z., Butt, M.S., Ahmed, A. and Khalid, N. (2013) Xylanolytic Modification in Wheat Flour and Its Effect on Dough Rheological Characteristics and Bread Quality Attributes. *Journal of the Korean Society for Applied Biological Chemistry*, **56**, 723-729. https://doi.org/10.1007/s13765-013-3132-7

[20] Liu, L., Sun, Y., Yue, Y., Yang, J., Chen, L., Ashraf, J., *et al.* (2020) Composition and Foam Properties of Whole Wheat Dough Liquor as Affected by Xylanase and Glucose Oxidase. *Food Hydrocolloids*, **108**, Article 106050. https://doi.org/10.1016/j.foodhyd.2020.106050

[21] Baran, B. and Yurdugül, S. (2020) The Role of Thermostable Xylanase Enzymes in Bread Making. *International Journal of Innovative Approaches in Science Research*, **4**, 130-140. https://doi.org/10.29329/ijiasr.2020.312.4

[22] Bilgiçli, N. and Levent, H. (2014) Utilization of Lupin (*Lupinus albus* L.) Flour and Bran with Xylanase Enzyme in Cookie Production. *Legume Research—An International Journal*, **37**, 264. https://doi.org/10.5958/j.0976-0571.37.3.040

[23] Hikal, W.M., Said-Al Ahl, H.A.H., Bratovcic, A., Tkachenko, K.G., Sharifi-Rad, J., Kačániová, M., *et al.* (2022) Banana Peels: A Waste Treasure for Human Being. *Evi-*

dence-Based Complementary and Alternative Medicine, **2022**, Article ID: 7616452. https://doi.org/10.1155/2022/7616452

[24] Tuyen, D.T., Cuong, N.T., le Thanh, N.S., Thao, N.T., Hoang, L.T., Trang, N.T.H., *et al.* (2021) Cloning, Expression, and Characterization of Xylanase G2 from *aspergillus Oryzae* VTCC-F187 in *Aspergillus niger* VTCC-F017. *BioMed Research International*, **2021**, Article ID: 8840038. https://doi.org/10.1155/2021/8840038

[25] Zhou, P., Zhang, G., Chen, S., Jiang, Z., Tang, Y., Henrissat, B., *et al.* (2014) Genome Sequence and Transcriptome Analyses of the Thermophilic Zygomycete Fungus *Rhizomucor miehei*. *BMC Genomics*, **15**, Article No. 294. https://doi.org/10.1186/1471-2164-15-294

[26] Fasiku, S.A., Bello, M.A. and Odeniyi, O.A. (2023) Production of Xylanase by Aspergillus Niger GIO and Bacillus Megaterium through Solid-State Fermentation. *Access Microbiology*, **5**, 1-17. https://doi.org/10.1099/acmi.0.000506.v5

[27] Ire, F.S., Chima, I.J. and Ezebuiro, V. (2021) Enhanced Xylanase Production from UV-Mutated Aspergillus Niger Grown on Corn Cob and Sawdust. *Biocatalysis and Agricultural Biotechnology*, **31**, Article 101869. https://doi.org/10.1016/j.bcab.2020.101869

[28] Dwivedi, S., Tanveer, A., Yadav, S., Anand, G. and Yadav, D. (2022) Agro-Wastes for Cost Effective Production of Industrially Important Microbial Enzymes. In: Chowdhary, P., Mani, S. and Chaturvedi, P., Eds., *Microbial Biotechnology*, Wiley, 435-460. https://doi.org/10.1002/9781119834489.ch23

[29] Ahmad, Z. (2014) Production and Characterization of Xylanase for Utilization in Baking. Doctor of Philosophy in Food Technology National Institute of Food Science University of Agriculture.

[30] Azzouz, Z., Bettache, A., Djinni, I., Boucherba, N. and Benallaoua, S. (2022) Biotechnological Production and Statistical Optimization of Fungal Xylanase by Bioconversion of the Lignocellulosic Biomass Residues in Solid-State Fermentation. *Biomass Conversion and Biorefinery*, **12**, 5923-5935. https://doi.org/10.1007/s13399-020-01018-z

[31] Nochur, S.V., Roberts, M.F. and Demain, A.L. (1993) True Cellulase Production by *Clostridium thermocellum* Grown on Different Carbon Sources. *Biotechnology Letters*, **15**, 641-646. https://doi.org/10.1007/bf00138556

[32] Fadel, M., Keera, A.A., Abdel-Aziz, S.M. and Kahil, T. (2014) Clean Production of Xylanase from White Corn Flour by Aspergillus Fumigates F-993 under Solid State fermentation. *World Applied Sciences Journal*, **29**, 326-336.

[33] Zehra, M., Syed, M.N. and Sohail, M. (2020) Banana Peels: A Promising Substrate for the Coproduction of Pectinase and Xylanase from *aspergillus Fumigatus* Ms16. *Polish Journal of Microbiology*, **69**, 19-26. https://doi.org/10.33073/pjm-2020-002

[34] Mohammadi, M., Zoghi, A. and Azizi, M.H. (2022) Effect of Xylanase and Pentosanase Enzymes on Dough Rheological Properties and Quality of Baguette Bread. *Journal of Food Quality*, **2022**, Article ID: 2910821. https://doi.org/10.1155/2022/2910821

[35] Ghoshal, G., Shivhare, U.S. and Banerjee, U.C. (2017) Rheological Properties and Microstructure of Xylanase Containing Whole Wheat Bread Dough. *Journal of Food Science and Technology*, **54**, 1928-1937. https://doi.org/10.1007/s13197-017-2627-3

[36] Uysal, H., Bilgiçli, N., Elgün, A., İbanoğlu, Ş., Herken, E.N. and Kürşat Demir, M. (2007) Effect of Dietary Fibre and Xylanase Enzyme Addition on the Selected Properties of Wire-Cut Cookies. *Journal of Food Engineering*, **78**, 1074-1078. https://doi.org/10.1016/j.jfoodeng.2005.12.019

[37] Çakır, N., Bilgiçli, N. and Yaver, E. (2021) Impact of Xylanase-Treated Wheat Milling By-Products on the Physical and Chemical Properties of Cakes. *Journal of the Science of Food and Agriculture*, **101**, 6331-6337. https://doi.org/10.1002/jsfa.11303

[38] Lebesi, D.M. and Tzia, C. (2011) Effect of the Addition of Different Dietary Fiber and Edible Cereal Bran Sources on the Baking and Sensory Characteristics of Cupcakes. *Food and Bioprocess Technology*, **4**, 710-722. https://doi.org/10.1007/s11947-009-0181-3

[39] Khemakhem, B., Smaoui, S., El Abed, H., Fendri, I., Hammami, H. and Ayadi, M.A. (2018) Improving Changes in Physical, Sensory and Texture Properties of Cake Supplemented with Purified Amylase from Fenugreek (*Trigonella foenum graecum*) Seeds. *3 Biotech*, **8**, Article No. 174. https://doi.org/10.1007/s13205-018-1197-z

[40] Chen, J.S., Wang, S.Y., Deng, Z.Y., Zhang, X.Y., Feng, S.L., Yuan, H.Q., *et al.* (2012) Effects of Enzymatic Hydrolysis of Protein on the Pasting Properties of Different Types of Wheat Flour. *Journal of Food Science*, **77**, C546-C550. https://doi.org/10.1111/j.1750-3841.2012.02677.x