INTRODUCTION

Sourdough has been traditionally used as a natural starter for making fermented baked products as an alternative to bakery’s yeast and chemical leavening (Arora et al., 2021). Due to unique microbial flora and functionality, sourdough influences dough and bread by increasing the loaf volume, slowing staling and improving flavor and hygienic properties compared to conventional breads (Olojede et al., 2020; Yu et al., 2019). In addition, the acidification of dough affects its microbial growth and enzymes, dough rheology, and bread sensory attributes, and shelf life (Jagelaviciute & Cizeikiene, 2021). Yeasts and lactic acid bacteria (LAB) are the main components of sourdough microbial composition and have an important role in acidification, aroma formation, and bread’s unique characteristics (Frazier et al., 2020; Xi et al., 2020). Depending on the type of flour, the mixtures of carboxylic acids with antimicrobial properties are produced in sourdough (Jagelaviciute & Cizeikiene, 2021). Alpha-amylase activity from the LAB acidification process mainly influence bread texture by producing low molecular weight dextrins decreasing the amylpectin associated retrogradation and interfering between gluten-starch interactions during bread storage, thus lowering the firming rate (Frazier et al., 2014).

The potential nutritional and biological significance of food proteins has driven the interest in the production of “functional” foods that are nutritious and healthy (Nikoo et al., 2021; Sarteshnizi et al., 2021; Sun et al., 2020). Amaranth (Amaranthus
**hypochondriacus** is a pseudocereal, which is considered as an alternative crop due to its nutritional (high quality proteins and low saturated fatty acids) and technological properties for the baking industry (Janssen et al., 2017). Amaranth grain consists of three major proteins such as albumins (40%), globulins (20%), and glutelins (25–30%) with 2%–3% prolamin (Tamsen et al., 2018). Amaranth flour (AF) also has been used in many food products including cakes, muffins, breads, pan cakes, noodles, dumplings, baby purees, cookies, and nuggets (Jiménez et al., 2020; Miranda-Ramos et al., 2019; Tamsen et al., 2018). Amaranth seeds or parts of it possess several biological functions such as antioxidant, anti-diabetic, anti-inflammatory, and antihyperlipidemic effects (Miranda-Ramos et al., 2019). Moreover, amaranth protein hydrolysates have been suggested as a promising source of bioactive peptides with potential health benefits (Delgado et al., 2011; Mudgil et al., 2019; Tironi & Añón, 2010).

In recent years, the demand for foods containing fermented products is increasing (Olojede et al., 2020). During sourdough fermentation, LAB and yeast proteolytic activities produce bioactive peptides from the peptide fraction of the protein matrix (Olojede et al., 2020). During sourdough fermentation is one of the traditional techniques for improving the nutritional and functional health properties of many foods (Francesca et al., 2019; Gänzle et al., 2007; Suo et al., 2021). The use of protein hydrolysates in sourdough may improve processing conditions with regard to the acidification rate, improved fermentation process, and bread properties. Given the above-mentioned explanations, the current study aimed to evaluate the effects of ASPH on sourdough fermentation and bread properties and shelf life.

## 2 | MATERIALS AND METHODS

### 2.1 | Preparation of amaranth protein isolates

AF was obtained by the grinding (FP970 series, Multipro Excel, Kenwood Company) of dried amaranth seeds and sieved (100 μm sieve size) to obtain a fine powder. It was defatted using hexane (1:10 g/ml) under continuous stirring for 24 h at 4°C (Ayala-Niño et al., 2019). The flour of amaranth was dried at room temperature (24 ± 1°C) for 24 h and then stored at 4°C until used. The moisture content in AF was 6.7% and 7.3% before drying and after defatted, respectively. The total proteins-rich fraction was solubilized at a pH value of 11.0 using 1 mol/L NaOH and then precipitated at pH ~5 by 1 mol/L HCl. After centrifugation at 4000 × g for 10 min at 4°C, the precipitate was freeze-dried and referred to as the amaranth protein isolates (API).

### 2.2 | Preparation of ASHP

The API (10 mg/ml) was mixed with distilled water and preheated at 50°C for 30 min. Further, the pH was adjusted to 8.0 by 1 mol/L NaOH and hydrolysis was performed using Alcalase (Sigma-Aldrich Co) at an enzyme to substrate ratio of 1:20 (g:g) according to previous research (Nikoo et al., 2019). After the specified reaction time (3 h), the enzyme was deactivated by heating at ~95°C for 10 min and then cooled using iced water for 10 min. The hydrolysate solution was centrifuged (4000 g, 4°C, 10 min) to obtain a clear supernatant and then freeze-dried as well.

### 2.3 | Effect of ASHP on the growth of *L. plantarum* and *S. cerevisiae*

ASPH was tested for its effect on the growth of *L. plantarum* PTCC (1896) and *S. cerevisiae* PTCC (5052). Hydrolysates (2 mg/ml) were added into test tubes containing 10^4 cfu/ml bacteria or yeast cells. Next, the *L. plantarum* count was conducted by the pour plate technique on MRS agar (Merck) and *S. cerevisiae* count was grown on PDA (Merck) at 30°C for 48 h (Zhao et al., 2020).

### 2.4 | Preparation of sourdough

Sourdough was prepared according to the method described by Yu et al. (2019) using ASHP. Sourdough composed of 0–5 g/100 g ASHP was prepared, referred to as S-ASHP, and stored at 30°C for 20 h.

### 2.5 | Preparation of bread using S-ASHP sourdough (S-ASHP-B)

The bread was prepared by mixing 100 g flour with salt (1/100 g), bread improver (N300, Nanafza Improver Co., Tehran, Iran, 1/100 g), yeast (1.5/100 g) and 20/100 g S-ASHP sourdough (Katina et al., 2005), and 56 ml water (Katina et al., 2006). Furthermore, the prepared bread using common sourdough (CSB), which was provided without amaranth hydrolysate was considered as the control bread. The dough was allowed to proof for 30 min at 30°C after mixing its ingredients. The dough was kept for final proofing at 30°C and relative humidity of 85% for 90 min. Finally, the dough was baked for 15 min at 220°C (Oven 1600, Mashhad Baking Industries Co.) and cooled at room temperature (25 ± 1°C) for 1 h before being packed into polyethylene bags (Zip. Kip Co., Karaj, Alborz, Iran) according to a previous study (Meignen et al., 2001).

### 2.6 | Sourdough properties

The counts of *L. plantarum* and *S. cerevisiae*, as well as pH, and TTA were determined at time 0 and 20 h of sourdough fermentation. The pH was determined using a pH meter after mixing sourdough with water (1:10 g:g), and TTA (expressed as mL of NaOH) was measured by the method of Katina et al. (2006).
2.7 | Moisture and $a_w$

The moisture of the bread crumb was determined after heating 5 g of a slice from the bread center at 105°C for 12 h (AOAC, 2005), followed by measuring the water activity ($a_w$) of fresh bread crumb using a Novasina $a_w$ Sprint TH500 (Pfäffikon, Switzerland) after equilibration at 25°C.

2.8 | Bread texture properties

The texture of the bread without crust the (2 × 2 × 2 cm) was measured by a Texture Analyzer TA-XT2i (Stable Microsystems) equipped with an aluminum 25-mm diameter cylindrical probe. The measurement parameters were set as the distance of 5 mm, test speed of 0.5 mm/s, trigger force of 5 g, post-test speed 10.00 mm/s, pretest speed 1.00 mm/s, and trigger type auto. The data were measured as force (N) versus time (s) curves. The hardness (g), springiness (cm), cohesiveness (g), and chewiness were recorded (Yu et al., 2019) as well.

2.9 | Bread specific volume

The loaf volume was measured using AACC 10-05 (AACC, 2001) according to Yu et al. (2019) and calculated by dividing the loaf volume by loaf weight.

2.10 | Thermal properties of bread

These properties were determined using a differential scanning calorimeter (DSC) instrument (DSC PT 10, Linseis). Bread crumb (10 mg) was equilibrated at 25°C for 3 min before being heated at 10°C/min to 100°C (Torrieri et al., 2014). The denaturation peak temperature and enthalpy were calculated with TA software.

2.11 | Shelf life of bread

Bread samples were kept at room temperature and mold growth was determined for up to 7 days by visual observations (Gerez et al., 2009).

2.12 | Sensory analysis

The participants consisted of 80 people (40 males and 40 females), ages 22 to 54. The participants scored the bread samples using a scale from 1 to 9 (1 for dislike immensely and 9 for like immensely) as described by Karimi et al. (2021).

2.13 | Statistical analysis

ANOVA tests were applied to analyze $L.\ plantarum$ and $S.\ cerevisiae$ growth, S-ASHP pH and TTA data significant differences between the mean values were compared using Duncan’s multiple range tests at $p \leq .05$, and data were expressed as the mean ± standard deviation. The differences between S-ASHP-B and control bread properties were determined using an independent-samples t test.

3 | RESULT AND DISCUSSION

3.1 | Effect of ASHP on the growth of $L.\ plantarum$ and $S.\ cerevisiae$

The effect of selectively hydrolyzed amaranth proteins on the growth of two key sourdough microorganisms was determined and compared with that of API and AF (Figure 1). The growth of LAB and yeast was influenced by ASHP ($p \leq .05$). In the other words, ASHP significantly increased the $L.\ plantarum$ growth by 5.3 and 12.2% compared to API and AF, respectively. Partially hydrolyzed shrimp proteins have been shown to increase $L. casei$ growth (Duan et al., 2011). The study determined the effect of ASHP on the growth of $S.\ cerevisiae$ and the highest growth was observed using ASPH ($p \leq .05$). Control culture medium with API and AF showed lower yeast growth (7.02 and 6.28 log cfu/ml, respectively) compared to the ASHP ($p \leq .05$). Wheat gluten hydrolysates enhanced yeast growth and ethanol production and increased yeast tolerance to ethanol (Yang et al., 2021). Free amino acids and small peptides have an important role in accelerating the growth of microorganisms and acidification during fermentation. APIs have a complex and folded
structure that is inaccessible by. However, a selectively hydrolyzed protein with an unfolded structure can be easily available to microorganisms. Presumably, these peptides are stable and absorbed because of their small size, which is resistant to peptidase (Seppo et al., 2003). The excretion/secretion of yeast proteases into the fermentation environment could hydrolyze larger peptides and proteins into smaller molecules in order to supply the proliferating yeast cells with more available nitrogenous nutrients (Lieske & Konrad, 1994). ASPH with its small size and higher solubility is presumably absorbed more efficiently by LAB and yeast, leading to higher growth compared to protein isolates or AF. Zhang et al. (2011) revealed that small peptides increased LAB growth in comparison with polypeptides and protein isolates or AF. Zhang et al. (2011) reported that shrimp protein hydrolysates increased the growth of *L. plantarum* and lactic acid production in sourdough. Although the higher concentration of ASPH led to the lowest pH while the highest TTA, it increased the acidic taste of the bread. Therefore, bread was produced with a 3% addition of ASPH sourdough. On the other hand, ASPH increased the growth of *L. plantarum* and *S. cerevisiae* in sourdough (Table 1). Sourdough with added ASPH showed higher bacterial and yeast growth compared to common sourdough (*p < .05*). Additionally, higher growth was found by increasing ASPH concentrations in sourdough. Sourdough with 5/100 g ASPH represented the highest growth of *L. plantarum* and *S. cerevisiae* at the end of fermentation.

### 3.2 | Sourdough properties

The characteristics of the prepared sourdough using ASHP at 0–5 g/100 g were measured (Figure 2) and the initial pH of sourdough ranged from 6.28 to 6.40 (*p > .05*). Sourdough fermented with different concentrations of ASHP after 20 h had pH values from 3.92 to 4.18 and was within the ranges reported in a previous study (Yu et al., 2019). There were no differences in TTA among different sourdoughs at time 0 (*p > .05*). The TTA of all ASPH sourdough was higher than that of control sourdough (*p ≤ .05*). Sourdough with 5% ASHP demonstrated the highest TTA (*p ≤ .05*). The increase of TTA in sourdough is assumed to be due to the higher organic acid produced by LAB during the fermentation process (Jagelaviciute & Cizekiene, 2021). Duan et al. (2011) reported that shrimp protein hydrolysates increased the growth of *L. plantarum* and lactic acid production in sourdough. Although the higher concentration of ASPH led to the lowest pH while the highest TTA, it increased the acidic taste of the bread.

![Figure 2](image)

**Figure 2** | pH and TTA of sourdough after 0 and 20 h of fermentation at 30°C. ASHP: amaranth selectively hydrolyzed proteins. Results were calculated from mean values of triplicate determinations. Different superscript small letters denote significant differences among treatments (*p ≤ .05*)

### 3.3 | Characteristics of bread

#### 3.3.1 | Physicochemical properties

S-ASHP sourdough at 2% in bread decreased pH while increasing TTA in comparison with the prepared control bread (Table 2) using common sourdough (CSB, *p ≤ .05*). This was partly attributed to the increased production of organic acids by LAB as fermentation progresses in the dough, leading to decreased pH whereas increased TTA in the bread (Yu et al., 2019). Yu et al. (2019) found that fermentation with specific strains of *L. plantarum* (i.e., NOS7315, MC3, and MC4) led to lower pH values in breads compared to other strains. ASPH significantly increased the growth of *L. plantarum* (Table 1) that has high acidification capacity (Prückler et al., 2015) and amylolytic enzyme activity (Bartkiene et al., 2017), leading to a low pH level in bread. The prepared sourdough prepared with amaranth hydrolysates potentially contributed to higher TTA in the resulting bread. This was coincidental with a higher specific volume (4.57 ml/g) in *S. cerevisiae* and *L. plantarum* at the end of fermentation.

| ASHP (g/100 g) | *S. cerevisiae* | *L. plantarum* |
|---------------|----------------|---------------|
| 0             | 4.56 ± 0.05⁵  | 8.24 ± 0.10⁵  |
| 1             | 4.89 ± 0.08⁶  | 8.80 ± 0.08⁶  |
| 2             | 5.24 ± 0.13⁶  | 9.13 ± 0.13⁶  |
| 3             | 5.60 ± 0.13⁶  | 9.55 ± 0.14⁶  |
| 4             | 5.86 ± 0.07⁶  | 9.90 ± 0.08⁶  |
| 5             | 6.02 ± 0.08⁶  | 10.25 ± 0.09⁶ |

Note: Different small superscript indicate significant difference (*p < .05*).
the fermented bread with S-ASHP sourdough than that of CSB (3.94 ml/g, p ≤ .05). The production of lactic acid and carbon dioxide from glucose by LAB and yeast requires the presence of small chain length peptides and free amino acids (Liu et al., 2018). Therefore, the higher specific volume of the bread made with S-ASHP sourdough might be due to higher yeast growth and carbon dioxide production (Yu et al., 2019). This bread also demonstrated that a lower staling rate is more likely because of an increase in the loaf specific volume (Arendt et al., 2007). Based on the findings, ASHP increased the growth of \textit{S. cerevisiae} and \textit{L. plantarum} and enhanced sourdough fermentation (Table 1, Figure 2), probably leading to an increase in the specific volume of the prepared bread with S-ASHP sourdough. S-ASHP-B bread had higher moisture content (43%) compared to CSB bread (36.9%, p ≤ .05). The effects of sourdough on the properties of dough and bread were assumed to be due to the direct impact of lowering the pH resulting from increased acid production. The activity of flour protease and amylase increases at lower pH, resulting in decreased staling of bread (Arendt et al., 2007). On the other hand, increased proteolytic activities in bread in the presence of peptides cause free water to bind to the gluten network. This indicates that although the moisture content of bread containing peptides is higher, water activity is less and the staling of bread represents a decrease (Arendt et al., 2007). The enthalpy of CSB and S-ASHP-B breads at day 1 was 130.26 J/g and 108.79 J/g, respectively. CSB indicated higher enthalpy in comparison with S-ASHP-B at day 5 of storage (p ≤ .05). A decrease in the staling rate, which was evidenced by bread enthalpy from DSC analysis, has also been reported for breads containing sourdough (Corsetti et al., 1998). Crystallization is the main reason for bread staling (Guo et al., 2020). Particular LAB strains involved in sourdough fermentation contribute to lowering the staling rate of the bread. The produced enzymes by LAB affect the retrogradation properties of the starch, slowing the rate of staling (Fadda et al., 2014). Amaranth peptides have been found to bind with starch, reducing the starch binding with water molecules and lowering starch retrogradation (Karimi et al., 2021). This might explains the lower staling of the S-ASHP-B bread.

### 3.3.2 Textural properties of bread

S-ASHP sourdough influenced bread texture compared to CSB (p ≤ .05, Table 3). Hardness and chewiness decreased in bread fermented with ASHP-S sourdough while an increase was found in cohesiveness and springiness compared to CSB (p ≤ .05).

#### TABLE 2 Effect of different sourdough on pH, TTA, moisture, aw, specific volume, and enthalpy of transition (J/g) of breads

| Properties       | Bread prepared by: | Significance |
|------------------|--------------------|-------------|
|                  | Modified sourdough | Common sourdough (CSB) |
|                  | (S-ASHP-B)          |              |
| pH (pH)          | 5.20 ± 0.02        | 5.29 ± 0.02  |
| TTA (g)          | 4.79 ± 0.06        | 2.71 ± 0.28  |
| Moisture (%)     | 43.03 ± 1.41       | 36.99 ± 0.87 |
| Aw               | 0.94 ± 0.01        | 0.96 ± 0.01  |
| Specific volume (mL/g) | 4.576 ± 0.06 | 3.94 ± 0.11  |
| Anthalpy1 day (J/g) | 108.79 ± 0.70      | 130.26 ± 2.06 |
| Anthalpy5 day (J/g) | 163.81 ± 1.90      | 180.73 ± 1.25 |

Note: n = 3. Sig denotes significance. t denotes an independent-samples t test.

#### TABLE 3 Textural properties of breads fermented with different sourdough

| Properties         | Bread prepared by: | Significance |
|--------------------|--------------------|-------------|
|                    | Modified sourdough | Common sourdough (CSB) |
|                    | (S-ASHP-B)          |              |
| Hardness (g)       | 388.33 ± 49.66     | 544.33 ± 36.69|
| Cohesiveness       | 0.757 ± 0.03       | 0.655 ± 0.02 |
| Springiness (mm)   | 0.935 ± 0.01       | 0.904 ± 0.01 |
| Chewiness (g)      | 282.67 ± 53.51     | 487.00 ± 46.50|

Note: n = 3. Sig denotes significance. t denotes an independent-samples t test.
sourdough with higher LAB and yeast growth might increase the rate of gas production in bread, leading to a more coherent and flexible bread texture (Figure 3). The textural of bread is highly related to mechanical properties and moisture content (Di Monaco et al., 2015). The competition between hydrolysates with hydrophilic nature and amylose or amylopectin for water molecules led to inadequate starch gelatinization and more heterogeneous crystals as a result of low amylopectin chains mobility and starch retrogradation (Karimi et al., 2021; Niu et al., 2018). The findings suggested that ASHP-S sourdough has the potential to enhance the texture of the bread.

### 3.3.3 Sensory properties of bread

Based on the obtained data, S-ASHP sourdough improved S-ASHP-B bread softness, elasticity, and overall acceptability compared to CSB (p ≤ .05, Table 4). S-ASHP-B bread showed a higher score for flavor and taste in comparison with the prepared CSB using control sourdough. Small peptides and free amino acids from mussel protein hydrolysates increased bread flavor (Vijaykrishnaraj et al., 2016). Moreover, peptides increase the production of lactic acid and alcohol in sourdough due to higher LAB and yeast growth, resulting in bread with better flavor (Yu et al., 2019). In sourdough, glutamine is converted into glutamate and γ-aminobutyric acid by the action of L. plantarum (Stromeck et al., 2011; Vermeulen et al., 2006) improving bread flavor. The conversion of glutamine to glutamate by the action of L. reuteri 100-23 during sourdough fermentation increased bread flavor (Zhao et al., 2015). The higher growth rate of L. plantarum and S. cerevisiae in S-ASHP sourdough might play a role in the better flavor of the S-ASHP-B bread.

### 3.3.4 Shelf life of bread

The growth of the mold on CSB and S-ASHP-B breads stored at room temperature for 9 days was determined in this study. Molds were visible at day 6 of storage in the CSB bread, while no mold growth was observed in S-ASHP-B at day 9. Organic acids are produced by the action of LAB during sourdough fermentation, which could inhibit the growth of pathogenic bacteria and fungi and yeast in bread (Jagelaviciute & Cizeikiene, 2021; Kam et al., 2007). L. plantarum LR 14 produced antimicrobial peptides that inhibited bread spoilage (Gupta & Srivastava, 2014). It was documented that the applied thermophilic LAB for sourdough preparation decreased bread crust surface spoilage and the shelf life of bread was influenced by particular LAB strains (Cizeikiene et al., 2020). Thus, the shelf life of bread made with S-ASHP sourdough increased compared with the CSB.

### 4 CONCLUSIONS

Overall, ASHP further enhanced sourdough fermentation compared to AF and nonhydrolyzed proteins. In addition, the prepared sourdough using ASHP increased the specific volume and TTA, whereas it decreased the water activity and hardness of S-ASHP-B bread compared with the control. Bread with modified sourdough showed a softer texture. Moreover, the sensory properties and shelf life of

| Properties          | Bread prepared by: | Significance |
|---------------------|--------------------|-------------|
|                     | Modified sourdough (S-ASHP-B) | Common sourdough (CSB) | |
| Color               | 4.6 ± 0.22         | 3.8 ± 0.20  | t = 2.683; sig = 0.01 |
| Elasticity          | 4.9 ± 0.10         | 3.2 ± 0.24  | t = 6.32; sig = 0.00 |
| Taste/flavor        | 4.8 ± 0.13         | 3.6 ± 0.16  | t = 5.692; sig = 0.00 |
| Chewiness           | 4.6 ± 0.16         | 3.4 ± 0.22  | t = 4.366; sig = 0.00 |
| Overall acceptability | 4.7 ± 0.15       | 3.6 ± 0.16  | t = 4.919; Sig = 0.00 |

Note: n = 3. Sig denotes significance. t denotes an independent-samples t test.

TABLE 4 Sensory analysis of breads fermented with different sourdough.
bread increased with the S-ASHP addition. The finding indicated the improvement of the quality of bread by sourdough that was prepared with ASHP. Accordingly, ASHP might be useful as the potential natural ingredients of sourdough and wheat bread.

ACKNOWLEDGMENT
This work was supported by the Urmia University Graduate Studies Office to Ph.D. candidate Nayereh Karimi.

CONFLICT OF INTEREST
The authors certify that they have no conflict of interests with respect to this manuscript.

AUTHOR CONTRIBUTION
Nayereh Karimi: Data curation (equal); Formal analysis (equal); Investigation (equal); Writing-original draft (lead). Fariba Zeynali: Conceptualization (equal); Methodology (equal); Project administration (equal); Supervision (equal); Writing-review & editing (equal). Mahmoud Rezazad Bari: Formal analysis (equal); Investigation (equal); Methodology (equal); Writing-review & editing (equal). Mehdi Nikoo: Conceptualization (equal); Investigation (equal); Project administration (equal); Supervision (equal); Writing-original draft (equal); Writing-review & editing (equal). Forogh Mohtarami: Conceptualization (equal); Data curation (equal); Formal analysis (equal); Writing-original draft (equal); Writing-review & editing (equal). Mehdi Kadivar: Conceptualization (equal); Methodology (equal); Writing-review & editing (equal).

ETHICAL STATEMENT
The care and use of animals and the experimental protocols were approved (No. 952361002–2018-04-17) by the animal science committee of Urmia University.

DATA AVAILABILITY STATEMENT
Data will be made available on responsible request.

ORCID
Fariba Zeynali https://orcid.org/0000-0002-3141-2329
Mahmoud Rezazad Bari https://orcid.org/0000-0002-9455-9977
Mehdi Nikoo https://orcid.org/0000-0001-7928-9588

REFERENCES
AACC. (2001). AACC Method 10–05 Guidelines for Measurement of Volume by Rapeseed, c, 3–6.
AOAC. (2005). Official methods of analysis, 17th ed. Gaithersburg, Maryland: Association of Official Analytical Chemists.
Arendt, E. K., Ryan, L. A., & Dal Bello, F. (2007). Impact of sourdough on the texture of bread. Food Microbiology, 24(2), 165–174. https://doi.org/10.1016/j.fm.2006.07.011
Arora, K., Ameur, H., Polo, A., Di Cagno, R., Rizzello, C. G., & Gobbetti, M. (2021). Thirty years of knowledge on sourdough fermentation: A systematic review. Trends in Food Science & Technology, 108, 71–83. https://doi.org/10.1016/j.tifs.2020.12.008
Ayala-Niño, A., Rodriguez-Serrano, G. M., Jiménez-Alvarado, R., Bautista-Avila, M., Sánchez-Franco, J. A., González-Olives, L. G., & Cepeda-Saez, A. (2019). Bioactivity of peptides released during lactic fermentation of amaranth proteins with potential cardiovascular protective effect: An in vitro study. Journal of Medicinal Food, 22(10), 976–981.
Bartkiewicz, E., Bartkevics, V., Pugayeva, I., Krunglevicute, V., Mayrhofer, S., & Domig, K. (2017). The contribution of P. acidilactici, L. plantarum, and L. curvatus starters and L-(α)-lactic acid to the acrylamide content and quality parameters of mixed rye - Wheat bread. LWT – Food Science and Technology, 80, 43–50.
Cizekienie, D., Jagelaviciute, J., Stankevicius, M., & Maruska, A. (2020). Thermophilic lactic acid bacteria affect the characteristics of sour-dough and whole-grain wheat bread. Food Bioscience, 38, 100791. https://doi.org/10.1016/j.fbio.2020.100791
Corsetti, A., Gobetti, M., Balestrieri, F., Paoletti, F., Russi, L., & Rossi, J. (1998). Sourdough lactic acid bacteria effects on bread firmness and stalin. Journal of Food Science, 63(2), 347–351. https://doi.org/10.1111/j.1365-2621.1998.tb15739.x
Delgado, M. C. O., Tironi, V. A., & Añón, M. C. (2011). Antioxidant activity of amaranth protein or their hydrolysates under simulated gastroduodenal digestion. LWT – Food Science and Technology, 44(8), 1752–1760.
Di Monaco, R., Torrieri, E., Pepe, O., Masi, P., & Cavella, S. (2015). Effect of sourdough with expopolysaccharide (EPS)-producing lactic acid bacteria (LAB) on sensory quality of bread during shelf life. Food and Bioprocess Technology, 8(3), 691–701. https://doi.org/10.1007/s11947-014-1434-3
Duan, S., Zhang, Y. X., Lu, T. T., Cao, D. X., & Chen, J. D. (2011). Shrimp waste fermentation using symbiotic lactic acid bacteria. Advanced Materials Research, 194, 2156–2163. https://doi.org/10.4028/www.scientific.net/AMR.194.196.2156
Fadda, C., Sanguinetti, A. M., Del Caro, A., Collar, C., & Piga, A. (2014). Bread staling: Updating the view. Comprehensive Reviews in Food Science and Food Safety, 13(4), 473–492. https://doi.org/10.1111/1541-4337.12064
Falade, A. T., Emmambux, M. N., Buys, E. M., & Taylor, J. R. N. (2014). Improvement of maize bread quality through modi fication of dough rheological properties by lactic acid bacteria fermentation. Journal of Cereal Science, 60(3), 471–476. https://doi.org/10.1016/j.jcs.2014.08.010
Frablerger, V., Unger, C., Kummer, C., & Domig, K. J. (2020). Insights into microbial diversity of traditional Austrian sourdough. LWT – Food Science and Technology, 127, 109358. https://doi.org/10.1016/j.lwt.2020.109358
Francesca, N., Gagliò, R., Alfonzo, A., Corona, O., Moschetti, G., & Settanni, L. (2019). Characteristics of sourdoughs and baked pizzas as affected by starter culture inoculums. International Journal of Food Microbiology, 293, 114–123. https://doi.org/10.1016/j.ijfoodmicro.2019.01.009
Gänzle, M. G., Vermeulen, N., & Vogel, R. F. (2007). Carbohydrate, peptide and lipid metabolism of lactic acid bacteria in sourdough. Food Microbiology, 24(2), 128–138. https://doi.org/10.1016/j.fm.2006.07.006
Gerez, C. L., Torino, M. I., Rollán, G., & de Valdez, G. F. (2017). Prevention of bread mould spoilage by using lactic acid bacteria with antifungal properties. Food Control, 20(2), 144–148. https://doi.org/10.1016/j.foodcont.2008.03.005
Guo, L., Xu, D., Fang, F., Jin, Z., & Xu, X. (2020). Effect of glutathione on wheat dough properties and bread quality. Journal of Cereal Science, 96, 103116. https://doi.org/10.1016/j.jcs.2020.103116
Gupta, R., & Srivastava, S. (2014). Antifungal effect of antimicrobial peptides (AMPs LR14) derived from L. plantarum strain LR/14 and their applications in prevention of grain spoilage. Food Microbiology, 42, 1–7.
Jagelaviciute, J., & Cizeikiene, D. (2021). The influence of non-traditional sourdough made with quinoa, hemp and chia flour on the characteristics of gluten-free maize/rice bread. LWT – Food Science and Technology, 137, 103116.

Janssen, F., Pauly, A., Rombouts, I., Jansens, K. J., Deleu, L. J., & Delcour, J. A. (2017). Proteins of amaranth (Amaranthus spp.), buckwheat (Fagopyrum spp.), and quinoa (Chenopodium spp.): A food science and technology perspective. Comprehensive Reviews in Food Science and Food Safety, 16(1), 39–58.

Jiménez, D., Lobo, M., Iriaray, B., Grompone, M. A., & Sammán, N. (2020). Oxidative stability of baby dehydrated purees formulated with different oils and germinated grain flours of quinoa and amaranth. LWT – Food Science and Technology, 127, 109229. https://doi.org/10.1016/j.lwt.2020.109229

Kam, P. V., Blanchini, A., & Bullerman, L. B. (2007). Inhibition of mold growth by sourdough bread cultures. RURALS: Review of Undergraduate Research in Agricultural and Life Sciences, 2(1), 5.

Karimi, A., Gavilghic, H. A., Sarteshnizi, R. A., & Udenigwe, C. C. (2021). Effect of maize germ protein hydrolysate addition on digestion, in vitro antioxidant activity and quality characteristics of bread. Journal of Cereal Science, 97, 103148. https://doi.org/10.1016/j.jcs.2020.103148

Katina, K., Arndt, E., Liukkonen, K. H., Autio, K., Flander, L., & Poutanen, K. (2005). Potential of sourdough for healthier cereal products. Trends in Food Science & Technology, 16(1–3), 104–112. https://doi.org/10.1016/j.tifs.2004.03.008

Katina, K., Heiniö, R. L., Autio, K., & Poutanen, K. (2006). Optimization of sourdough process for improved sensory profile and texture of wheat bread. LWT – Food Science and Technology, 39(10), 1189–1202. https://doi.org/10.1016/j.lwt.2005.08.001

Lieske, B., & Konrad, G. (1994). Protein hydrolysis—The key to meat flavoring systems. Food Reviews International, 10(3), 287–312. https://doi.org/10.1080/08755929409541004

Liu, T., Li, Y., Sadiq, F. A., Yang, H., Gu, J., Yuan, L., Lee, Y. K., & He, G. (2018). Predominant yeasts in Chinese traditional sourdough and their influence on aroma formation in Chinese steamed bread. Food Chemistry, 242, 404–411. https://doi.org/10.1016/j.foodchem.2017.09.081

Lutti, S., Mazzoli, L., Ramazzotti, M., Galli, V., Venturi, M., Marino, G., & Pazzagli, L. (2020). Antioxidant and anti-inflammatory properties of sourdoughs containing selected Lactobacilli strains are retained in breads. Food Chemistry, 322, 126710.

Meignen, B., Onno, B., Gélins, P., Infantes, M., Guliois, S., & Cahagnier, B. (2001). Optimization of sourdough fermentation with Lactobacillus brevis and baker’s yeast. Food Microbiology, 18(3), 239–245.

Miranda-Ramos, K. C., Sanz-Ponce, N., & Haros, C. M. (2019). Evaluation of technological and nutritional quality of wheat bread enriched with amaranth flour. LWT – Food Science and Technology, 114, 108418. https://doi.org/10.1016/j.lwt.2019.108418

Mudgil, P., Omar, L. S., Kamal, H., Kilari, B. P., & Maqsood, S. (2019). Multi-functional bioactive properties of intact and enzymatically hydrolysed quinoa and amaranth proteins. LWT – Food Science and Technology, 110, 207–213. https://doi.org/10.1016/j.lwt.2019.04.084

Nikoo, M., Benjakul, S., Yasemi, M., Gavilghi, H. A., & Xu, X. (2019). Hydrolysates from rainbow trout (Oncorhynchus mykiss) processing by-product with different pretreatments: Antioxidant activity and their effect on lipid and protein oxidation of raw fish emulsion. LWT – Food Science and Technology, 108, 120–128. https://doi.org/10.1016/j.lwt.2019.03.049

Nikoo, M., Regenstein, J. M., Noori, F., & Gheshlaghi, S. P. (2021). Autolysis of rainbow trout (Oncorhynchus mykiss) by-products: Enzymatic activities, lipid and protein oxidation, and antioxidant activity of protein hydrolysates. LWT – Food Science and Technology, 140, 110702.
dry yeast. Food Bioscience, 38, 100775. https://doi.org/10.1016/j.fbio.2020.100775
Yang, H., Coldea, T. E., Zeng, Y., & Zhao, H. (2021). Wheat gluten hydrolysates promotes fermentation performance of brewer’s yeast in very high gravity worts. Bioresources and Bioprocessing, 8(1), 1-10.
Yu, Y., Wang, L. I., Qian, H., Zhang, H., Li, Y., Wu, G., Qi, X., Xu, M., & Rao, Z. (2019). Effect of selected strains on physical and organoleptic properties of breads. Food Chemistry, 276, 547–553. https://doi.org/10.1016/j.foodchem.2018.10.048
Zhang, Q., Ren, J., Zhao, M., Zhao, H., Regenstein, J. M., Li, Y., & Wu, J. (2011). Isolation and characterization of three novel peptides from casein hydrolysates that stimulate the growth of mixed cultures of Streptococcus thermophilus and Lactobacillus delbrueckii subsp. bulgaricus. Journal of Agricultural and Food Chemistry, 59(13), 7045–7053.
Zhao, C. J., Hu, Y., Schieber, A., & Gänzle, M. (2013). Fate of ACE-inhibitory peptides during the bread-making process: Quantification of peptides in sourdough, bread crumb, steamed bread and soda crackers. Journal of Cereal Science, 57(3), 514–519. https://doi.org/10.1016/j.jcs.2013.02.009
Zhao, C. J., Kinner, M., Wismer, W., & Gänzle, M. G. (2015). Effect of glutamate accumulation during sourdough fermentation with Lactobacillus reuteri on the taste of bread and sodium-reduced bread. Cereal Chemistry, 92(2), 224–230.
Zhao, Y., Zhang, J., Wei, Y., Ai, L., Ying, D., & Xiao, X. (2020). Improvement of bread quality by adding wheat germ fermented with Lactobacillus plantarum dy-1. Journal of Food Quality, 2020, 1–8.

How to cite this article: Karimi, N., Zeynali, F., Rezazad Bari, M., Nikoo, M., Mohtarami, F., & Kadivar, M. (2021). Amaranth selective hydrolyzed protein influence on sourdough fermentation and wheat bread quality. Food Science & Nutrition, 9, 6683–6691. https://doi.org/10.1002/fsn3.2618