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A strategy for reducing acrylamide content in wheat bread by combining acidification rate and prerequisite substance content of *Lactobacillus* and *Saccharomyces cerevisiae*

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ABSTRACT

This study mainly focused on a strategy for reducing acrylamide(AM) content in wheat breads by combining *Lactobacilli* and *Saccharomyces cerevisiae* in sourdough, in comparison with natural fermentation. The results showed that acrylamide levels in breads using sourdough were much lower (102.02–129.37 μg/kg) than control group (204.79 μg/kg). The pH value of sourdough directly influenced the formation of acrylamide in breads ($P <$ 0.01). Furthermore, significant ($P < 0.05$) correlations were also found between protein and acrylamide contents. There no significant correlations were observed between acrylamide and reducing sugar contents. According to the different effects of strains, it could be concluded that the acrylamide reducing potential of strains was strain-specific, with *Pediococcus pentosaceus* being the most effective. This suggests that sourdough fermentation with appropriate strains can be used as an advantageous technology to reduce the acrylamide content of wheat breads.

1. Introduction

Thermal process is an essential step in the production of baked foods, which can not only prolong the shelf life of food, but also gives food a unique flavor and color. In 2002, Swedish National Food Administration (SNFA) researchers found acrylamide (AM) in fried food for the first time, and proved that AM widely exists in hot processed food (Richard et al., 2002). Acrylamide formation was found to occur during a thermal process, by Maillard reaction(MR), of reducing sugars with asparagine at temperatures above 120°C (Neda et al., 2021). The MR is often used by food manufacturer to develop appealing aromas, color or texture in baked foods. However, despite some positive aspects, the MR could decrease the nutritional value of baked foods, generate potentially harmful compounds (Neda et al., 2021; Gu et al.,2022). In 1994, THE International Agency for Research on Cancer (IARC) listed AM as a “robable human carcinogen (Class 2A)" (IARC, 1994).

This acrylamide concentration in baked foods has become a very serious health issue, that may cause gene mutation and damage the nervous system. For the general population, in addition to the absorption of AM through cosmetics, packaging materials, smoking and other channels, most of the oral intake, and foods intake is considered to be one of the most rapid and complete absorption of AM. AM in baked foods is widely distributed in various tissues in the body through the blood circulation system, such as brain, heart, liver and kidney, and causes damage to the body in the process (Komoike et al., 2020; Matoso et al., 2019; Xiang et al., 2020). Therefore, it is essential to reduce acrylamide in baked foods even if the concentrations of acrylamide are low (Sarion et al., 2021).

Many technological measures have been considered for acrylamide reduction in baked foods (Neda et al., 2021). Up to now, the factors affecting AM content in baked goods include initial concentration of precursor substances, flour quality, hot processing methods, fermentation conditions, processing conditions (Wang et al., 2017). In order to reduce the formation of AM, appropriate addition of asparaginase, glucose amylase and other enzymes in food formula is also an effective means (Muso et al., 2016; Han et al.,2021). Studies have pointed out that the formation of AM is related to pH value. The lower the pH value, the lower the AM level in baked foods (Huang et al., 2008; Behera et al.,

Abbreviations: acrylamide, AM; Maillard reaction, MR.

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2021). Other studies have shown that the use of different univalent and divalent ions, such as K^+, Na^+, Mg^{2+} and Ca^{2+}, reduces the formation of AM in MR reactions. These approaches are aimed at reducing the content of reactants, that is, such as asparagine and reducing sugars (Esfahani et al., 2017; Sazesh et al., 2020), making conditions for the Maillard reaction unfavorable, or eliminating or reducing acrylamide following its formation.

However, in bakery foods, studies have pointed out that using cationic additives or enzyme to reduce the baking foods AM forming method, but often use levels are activated to restrain activity of yeast in bread, reduce the gas formed in the fermentation process, reduce the starch hydrolysis and proteolytic activity. At the same time, blindly lowering pH value will have adverse effects on food nutrition, sensory characteristics (taste, texture, color, etc) and food safety (Andreea et al., 2020; Chandra et al., 2021). The most suitable methods are ones that, besides the reduction of acrylamide, cause no alterations to the other properties and quality of foods, and at the same time are safe (Gülcan et al., 2020; Joanna et al., 2020). Dry yeast fermentation seems to be a suitable and efficient approach. It has been demonstrated that prolonged fermentation of dough with yeast only can reduce acrylamide in bread via the extensive consumption of high amounts of free asparagine. However, acrylamide reduction by dry yeast fermentation would not be so successful in fermented breads because of the increased release of fructose by yeast.

Sourdough fermentation with different *Lactobacilli* (LAB) and *Saccharomyces cerevisiae* (SC) strains versus dry yeast fermentation is another fermentation method in bread baking (Khorshidian et al., 2020; Amal et al., 2021). Therefore, adding probiotics may be a promising method to reduce AM levels in food Wei and Xuhui, 2021. First, In such mixed cultures, yeasts act primarily as leavening agents, while strains contributes mainly to acidification, Secondly, in comparison with yeast fermentation only, mixed cultures of LAB, SC and dry yeast, in the form of sourdough fermentation, have been proven to be for enhancing the texture, palatability, aroma, shelf life, and nutritional value of breads (Nachi et al., 2018). However, there has been no comprehensive study regarding the effects of adding sourdough fermentation on acrylamide content in bakery foods.

The aim of this study was to investigate the potential for acrylamide reduction in wheat breads of some *Lactobacilli* and *Saccharomyces cerevisiae* strains in sourdough, in comparison with nature sourdough fermentation. Then understand the effects of sourdough fermentation (content of organic acids, reducing sugars, protein and pH value) and the qualities of breads (volume, specific volume, TPA full analysis and water Activity) from them to demonstrate the mechanisms by why sourdough fermentation could reduce acrylamide.

2. Materials and methods

2.1. Materials

Lactobacilli fermentum (CICC22704, China Center of Industrial Culture Collection, LF), and *Pediococcus pentosaceus* (JCM3586, Japan Collection of Microorganisms, PP); *Saccharomyces cerevisiae-I* (CGMCC NO.3871, ST), and *Saccharomyces cerevisiae-II* (CGMCC NO.3857, GT) were provided by the State Key Laboratory of Dairy Biotechnology. Jinxiang bread flour (dry protein:12.35, ash:0.63, gluten:35.7, moisture content:11.47 g/100 g, the water absorption is 59%, formation and stabilization time of 1.27 and 8 min, respectively). Active dry yeast (Anqi, China), sugar (Huiyi, China), and edible salt (Taigu, China) were purchased from local supermarkets. Reducing sugar, lactic acid, acetic acid, acrylamide, bovine serum protein standard and other reagents of analytical grade were purchased from Sino pharm (Shanghai) Chemical Reagent Co., LTD.

2.2. Microbial strains and culture conditions

Pediococcus pentosaceus was cultivated anaerobically at 37°C in MRS broth, and *Lactobacilli fermentum* and *Saccharomyces cerevisiae* were cultivated at 30°C in MRS broth (Houngbedji et al., 2021).

2.3. Preparation of sourdough

For experimental use, the strains were activated by two successive transfers in sterile MRS broth for 24 h using 5% (v/v) inoculums respective. Cells were harvested by centrifugation (4500 g, at 4°C, 15 min), washed twice with sterile distilled water, and centrifuged (4500 g, at 4°C, 15 min). Fresh cells were added immediately to the dough, the dough is fermented at 30°C for 24 h (The initial inoculation count of fresh cells is about 8.0logCFU/g sourdough). Sourdough samples were taken after fermentation and analyzed immediately for sourdough parameters. The treatment was listed as following:

(NU-s: Natural sourdough; LF-s: *Lactobacilli fermentum* sourdough.; PP-s: *Pediococcus pentosaceus* sourdough; ST-s: *Saccharomyces cerevisiae-I* sourdough; GT-s: *Saccharomyces cerevisiae-II* sourdough)

2.4. Physicochemical characteristics of sourdough

2.4.1. Measurement of pH value and total titratable acid (TTA)

The pH value and TTA were determined on sourdough following the (Yin et al., 2015) procedure. The pH value was recorded using a Titrando pH meter (Wantong, Switzerland).

2.4.2. Analysis of organic acids in sourdough

Organic acids were determined according to the method of Su et al. (2019).

2.4.3. Analysis of reducing sugars in sourdough

Reducing sugars in the Sourdough were analyzed according to the method described earlier(Neda et al., 2021). The absorbance was measured in a TECAN Infinite M200PRO (Austria Ken Co. Ltd, China) at 530 nm.

2.4.4. Analysis of protein content in sourdough

Protein content were determined by Chen et al. (2020).

2.5. Bread making formulations

With 2.3 sourdough (NU-s, LF-s, PP-s, ST-s, GT-s) replaced 30% of the flour (270 g) made sourdough breads (NU-b, LF-b, PP-b, ST-b, GT-b), and adding sugar (3.74%), active dry yeast (1.56%), table salt (1.00%) and water (58.89%). Bread without sourdough (UF-b) was made by 300 g flour.

Bread doughs were prepared by mixing all the ingredients for 3 min with a spiral mixer at low speed, followed by 8 min at medium speed till dough shaped; then the dough was divided into 50 g loaves, shaped and placed on bakeware for 15 min. The loaves were then proofed in a proofer at 35°C and 75% relative humidity for 60 min. Baking was carried out in heated oven at 185°C for 25 min. The bread parameters were measured after cooling at room temperature.

2.6. Determination the quality of sourdough fermentation bread

2.6.1. Measurement of acrylamide in sourdough fermentation bread

The acrylamide in the sourdough breads were analyzed by high performance liquid chromatography (HPLC; Shimadzu Management Co., Ltd., China), as described by Andačić et al. (2020).

Bread samples were homogenized for 2 min in normal hexane (2 ml) then centrifugation (4500g, 15 min), repeat twice. Then add Carrez I (1 ml), Carrez II (1 ml) and Ultrapure water (10 ml), After centrifugation (4500g, 15 min), the water extracts were filtered through 0.22 μm syringe filters, and aliquots of the filtrates were analyzed by HPLC-20 system (Shimadzu Corporation, Kyoto, Japan) equipped with an UV/visible detector (model SPD−20) at 208 nm; this was done using a Shimadzu HPLC-20 infusion pump with the oven temperature of 35°C and a flow rate of 0.8 ml min^{-1}.

2.6.2. Determination of the volume and specific volume sourdough fermentation bread

Volume of breads were measured by rapeseed replacement. Method for measuring breads specific volume was adopted from wang et al. with slight modification. (Wang et al., 2017).

2.6.3. Determination of texture sourdough fermentation bread

Texture was measured by the texture analyzer TA. XT 2i (Stable Micro Systems, Ltd., Godalming, UK) equipped with a plate probe (P/36R), the parameters were set as 4.0 mm/s before test, 1.0 mm/s during test, 4 mm/s after test and 10 mm compression depth. Interval time 10 s (Jian et al., 2021).

2.7. Statistical analysis

Every measurement was performed in triplicate and expressed as mean value (±SD, n = 3). The statistical interpretation was performed with the help of Graph Prism Version 20.0.1 (GraphPad Software Inc., San Diego, CA, USA).

3. Results and discussion

3.1. The content of acrylamide in sourdough fermentation bread

As shown in Fig. 1 (a), compared with natural fermentation and non-fermentation, AM content in bread prepared by *Lactobacilli* fermentation and *S-cerevisiae* fermentation showed a decreasing trend. The content of acrylamide in breads showed a decreasing trend with the extension of fermentation time, and when fermentation reached 10–12 h, it decreases the most. The content of AM in NU breads was 283.30 μg/kg. The decrease rate of AM was the largest in PP-b, which decreased by 55.81%, followed by LF-b, which decreased by 48.73%; Among *S-cerevisiae*, AM content of GT-b and ST-b decreased by 40.10% and 42.22%, respectively.

On the whole Fig. 1 (b), among the two strains of *Lactobacilli*, the content of AM in the bread prepared by *Pediococcus pentosaceus* fermented sourdough was lower, while in the *S. cerevisiae*, the content of acrylamide in bread prepared by *S. cerevisiae-I* fermented sourdough was lower than of *S. cerevisiae-II.* A decrease rate of acrylamide in breads fermented by *Lactobacilli* strains were greater than that by *S.cerevisiae* strains. *Lactobacilli* fermentation can produce a large number of organic acids, consequently reduce the pH value of sourdough environment, and inhibit the formation of acrylamide in food (S et al., 2021). *Saccharomyces cerevisiae* fermentation inhibits the formation of acrylamide by consuming the precursor materials (protein and reducing sugar).

3.2. The biological acidification of sourdough

In order to prove the influence of acidification rate of sourdough on AM content in final wheat bread from the perspective of acidification rate, the change trend of pH value in sourdough under different fermentation time was investigated to investigate the regulation effect of acidification rate on AM. The results showed that (Fig. 2 (a) and (b)) with the extension of fermentation time, pH value decreased from 5.94 to 3.77, while TTA increased. from 1.45 to 9.60 ml. The pH value of fermentation of all strains was lower than that of natural fermentation, while TTA was higher.

Among the four strains, the early stage of fermentation, the growth rate of LF-s was fast in 0–4 h, the acid production rate was accelerated in 2–4 h. After 6 h, acid production rate gradually decreased and stabilized after 12 h. In 0–4 h, the growth rate of PP-s was the lowest, the acid production rate of PP-s was the fastest at 6–8 h and tends to be stable after 16h. In 0–8 h, the growth rate of *S. cerevisiae* strain was the slowest, and the acid production rate was the lowest. In 8–12 h, the growth rate was accelerated, and the acid production rate increased.

Lactic acid and acetic acid play an essential role in the general flavor perception of the produced baked foods. LAB in the fermentation process achieves acidification by organic acid production, especially by lactic acid and acetic acid, which are also accountable for bread products' shelf-life extension (Debonne et al., 2020). As shown in Fig. 2 (c) and (d), with the extension of fermentation time, the content of lactic acid and acetic acid in each group of sourdough increased at first and then tended to be stable, and reached the maximum value at 16 h (LF-s, PP-s, GT-s) and 20h (LP-s, PP-s, ST-s) and then began to decline, and the yield of lactic acid was much higher than that of acetic acid. During the sourdough fermentation stage, the total number of lactic acid content remained 1.76 to 13.22 (mg/g sourdough), and acetic acid content remained 1.44 to 1.98 (mg/g sourdough). According to Fig. 2 (c), PP-s produced the most lactic acid in sourdough, and the lactic acid content reached 13.22 mg/g in sourdough at 16 h. According to Fig. 2 (d),

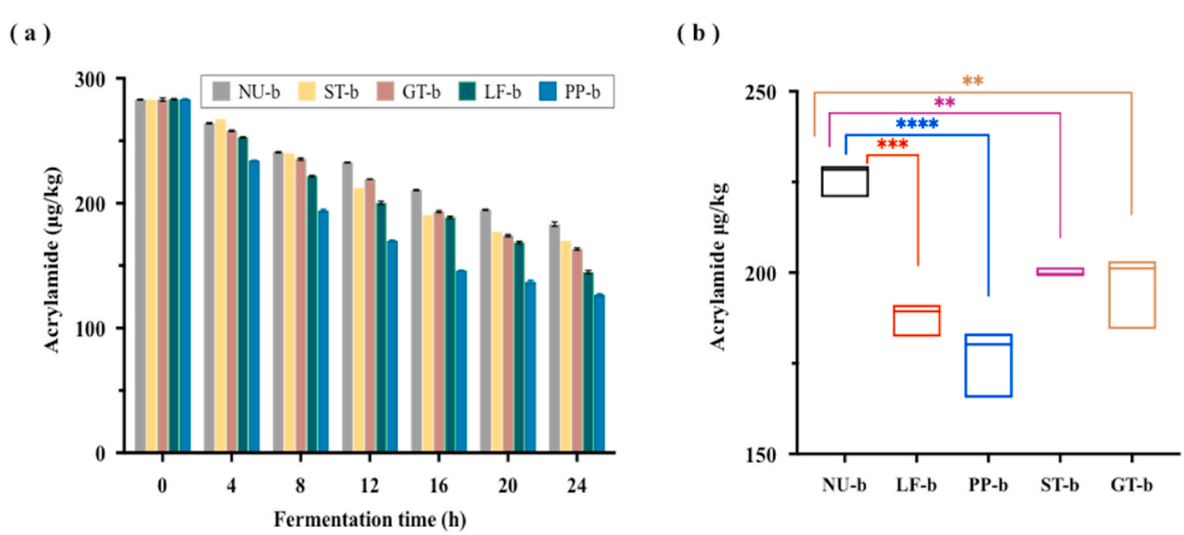

Fig. 1. Acrylamide content in sourdough breads (a) Acrylamide levels in bread samples prepared with sourdough (b) The relationship of acrylamide in different fermentation groups. The *Error bars* represent ±SD. ★★★★: $P<0.001$, ★★★: $P<0.005$, ★★: $P<0.01$, ★: $P<0.05$.

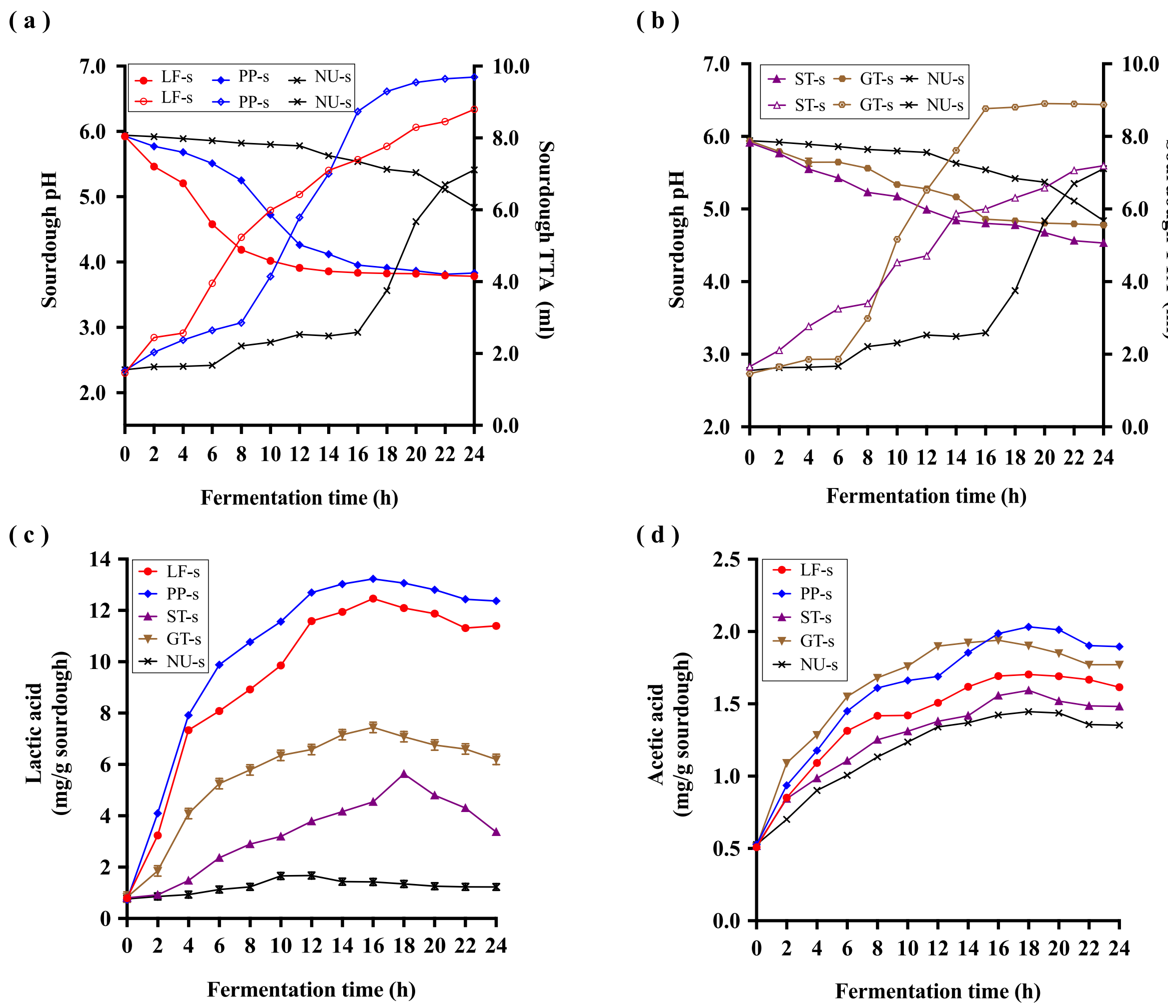

Fig. 2. Acidic characteristics of sourdough. (a) Changes of pH value and TTA during *lactobacilli strains* fermentation of sourdough. (b) Changes of pH value and TTA during *saccharomyces cerevisiae* fermentation of sourdough. (c) The change of lactic acid content in sourdough. (d) The change of acetic acid content in sourdough.

the highest acetic acid content in the sourdough was in the GT-s, and the acetic acid content was as high as 1.92 mg/g sourdough at 20 h. LF-s and GT-s could promote the accumulation of acetic acid.

3.3. *The reducing sugar and protein content of sourdough*

The change trend of protein and reducing sugar in sourdough under different fermentation time was investigated to demonstrate the relationship between the content of precursors and the formation of AM. From Table 1, with the prolongation of fermentation time, the reducing sugar content in sourdough first increased and then decreased, the reducing sugar content of 24 h fermentation was similar to that of early fermentation. As the extension of fermentation time, PP-s and LF-s had a higher reducing sugar content than NU-s, ST-s, and GT-s, which is due to the accumulation of organic acids produced by LF and PP, leading to the decrease of pH values and the increase of activities of amylase and glucoamylase and promoting the decomposition of flour.(Chavan et al., 2011).

From Table 1, the protein content in sourdough gradually decreased with the extension of fermentation time. At the beginning of

Table 1
Reducing sugar and protein content during sourdough fermentation.

		Fermentation time					
Content	Sample	4h	8h	12h	16h	20h	24h
Reducing sugar	NU-s	41.32±1.02^{a}	42.51±1.01^{a}	42.09±1.34^{a}	41.47±1.06^{a}	39.66±1.14^{a}	39.00±1.44^{a}
	LF-s	47.01±1.15^{a}	54.82±0.43^{c}	55.95±1.19^{c}	52.58±0.66^{b}	48.40±1.39^{b}	47.27±1.36^{b}
	PP-s	55.16±5.24^{b}	60.11±1.94^{a}	60.73±1.17^{c}	54.83±2.15^{b}	51.76±1.99^{a}	50.07±1.49^{c}
	ST-s	40.45±1.53^{a}	41.05±1.91^{a}	43.46±1.87^{a}	38.78±1.32^{a}	37.91±1.48^{a}	37.18±1.50^{a}
	GT-s	44.64±1.62^{a}	45.21±2.59^{b}	47.70±1.29^{b}	44.73±1.24^{a}	42.61±2.04^{a}	42.33±1.84^{a}
Total protein	NU-s	75.70±1.50^{a}	70.24±2.29^{b}	70.15±1.68^{a}	69.33±1.03^{a}	67.89±1.39^{a}	65.56±2.19^{a}
	LF-s	72.19±1.57^{a}	64.24±1.34^{c}	62.73±2.16^{c}	60.97±1.40^{e}	58.50±1.10^{c}	56.96±1.39^{c}
	PP-s	72.31±1.09^{a}	65.39±1.44^{c}	61.37±1.96^{d}	60.61±1.42^{c}	60.43±1.13^{d}	58.67±3.04^{b}
	ST-s	69.36±0.97^{b}	63.24±1.13^{d}	58.80±1.71^{e}	58.40±1.08^{e}	54.57±1.46^{d}	53.84±1.44^{d}
	GT-s	73.62±1.07^{a}	73.83±0.75^{a}	68.57±1.06^{a}	67.73±1.20^{a}	66.05±1.48^{a}	63.60±2.82^{a}

The data are the means of three independent experiments ± standard deviations. $^{a-e}$ Significant difference of different superscript letter values in the same column ($P < 0.05$).

fermentation, the protein content was higher, which was due to the slow growth of the strain and the slow hydrolysis of protein and starch in wheat flour, and the protein degradation was accelerated at 12 h of fermentation. The protein content in sourdough decreased due to the decomposition activity of bacteria.

Considering the acidification rate and prerequisite substance that can inhibit acrylamide, when fermentation lasts for 12 h, with the low reducing sugar content increasing, However, when the protein content was higher and decreased, the acrylamide content in bread decreased significantly.

3.4. The effect of acidification rate and prerequisite substance content on acrylamide content

In order to prove the influence of acidification rate and the contents of precursors of sourdough on the formation of AM in final wheat bread, the correlations between reducing sugar, protein content, pH and AM contents were determined to investigate the regulation effect of acidification, protein and reducing sugar content rate on AM (Fig. 3). The results indicated that there was a linear correlation between acrylamide and pH value and protein content, and a wireless relationship between acrylamide and reducing sugar content. The correlation between pH value and protein content and AM was a significant ($P < 0.01$). In all studies, acrylamide decreased with increasing acid. Acrylamide content was positively correlated with pH value and negatively correlated with protein content. It is hypothesized that low pH value inhibits the Maillard reaction pathway related the formation of AM by blocking asparagine and carbonyl residue.

The explanation is that the first step to form acrylamide in MR is the formation of schiff base with asparagine and reducing sugar. Because only the protonation form of asparagine can form schiff base, when the pH value reaches the isoelectric point of asparagine amino acid. The initial amino-carbonyl reaction may be blocked due to the protonation of the amino group, thus reducing the MR and the acrylamide content of the bread. The decrease in pH value is caused by the production of organic acids through fermentation by strains especially lactic acid. With the continuous metabolic activities of the strains, the pH value reached lower values below 4.3 at the end of fermentation, which can also be seen in several studies led to different substrates(Gaglio et al., 2020; Hashemi et al., 2019).

3.5. The quality of sourdough fermentation bread

3.5.1. The volume and specific volume of sourdough fermentation bread

Fig. 4 shows the changes in volume, specific volume and water activity of naturally fermented sourdough bread (NU-b) and *Lactobacilli* and *Saccharomyces cerevisiae* strains fermented sourdough bread. It can be seen from Fig. 4 (a) and (b), the volume and specific volume of bread in ST-s and GT-s was significantly increased ($P<0.05$), by 16.36% and 23.51%, respectively, compared with NU-s. In conclusion, ST-s and GT-s can be effectively used to improve the specific volume of bread.

According to Fig. 4 (c) and (d), compared with natural fermentation, the water activity of bread crust and bread core was significantly different ($P< 0.05$), and the water activity of sourdough bread fermented by *Lactobacilli* and *Saccharomyces cerevisiae* strains was relatively low. This is mainly due to a large number of organic acids produced in the two groups of bread, which can effectively prevent the spread and loss of water in the bread core. On the other hand, organic acids also decreased the gas retention capacity and diminished the gluten network. In conclusion, the ST sourdough bread can delay the decrease of water content of bread core during storage. With the extension of bread storage time, bread Aw will gradually decrease, *Lactobacilli* and *Saccharomyces cerevisiae* strains fermentation sourdough can effectively delay the aging of bread.

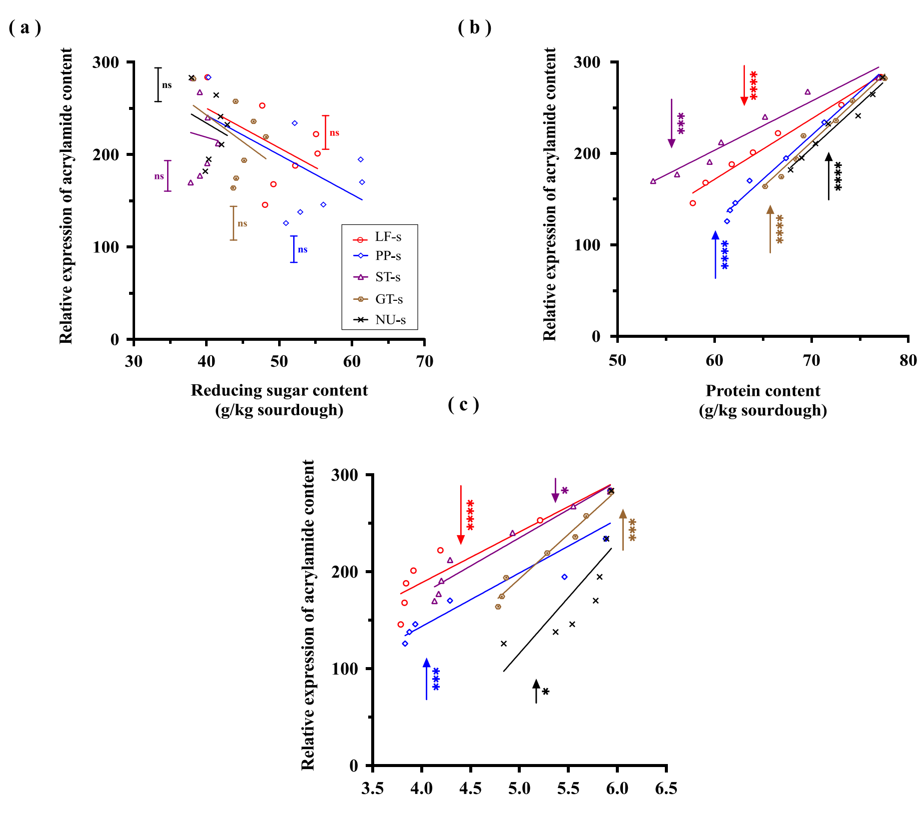

Fig. 3. The relationship between acidification rate, prerequisite substance content of sourdough with acrylamide levels. (a) The relationship between reducing sugar content of sourdough with acrylamide in bread (b) The relationship between protein content of sourdough with acrylamide in bread (c) The relationship between pH of sourdough with acrylamide in bread. The *Error bars* represent ±SD. ★★★★: $P<0.001$, ★★★: $P<0.005$, ★★: $P<0.01$, ★: $P<0.05$

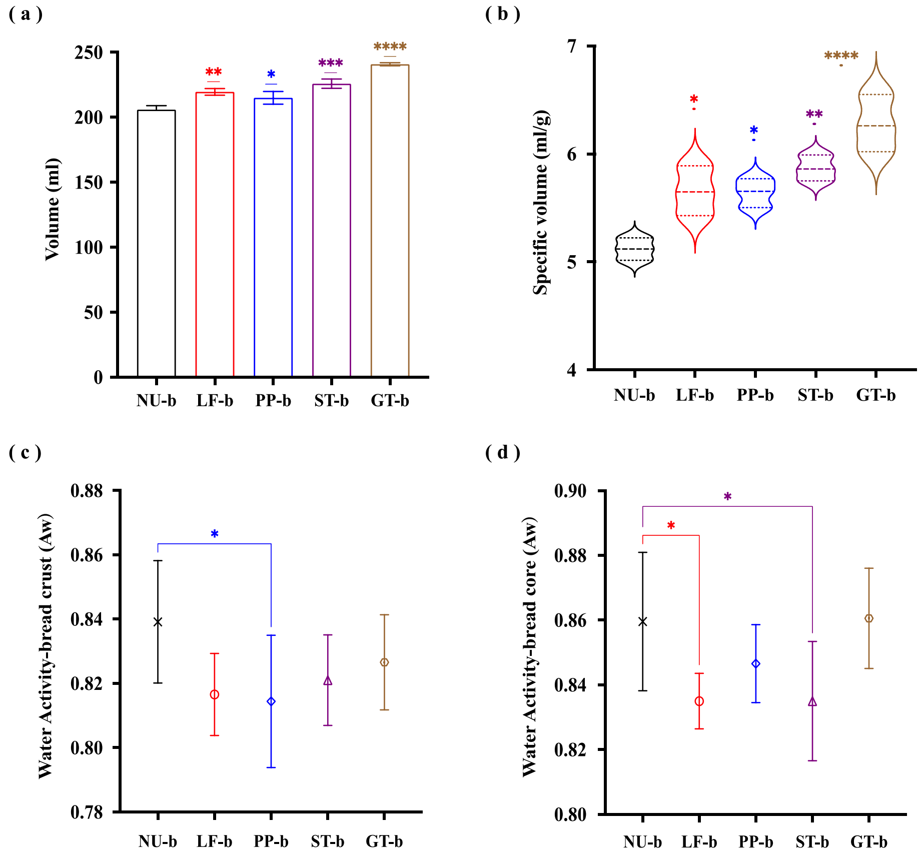

Fig. 4. Quality of Sourdough fermentation bread (a) Volume of sough dough bread (b) Specific volume of sourdough bread (c) Water activity of bread crust (d) Water activity of bread core. The *Error bars* represent ±SD. ★★★★: $P<0.001$, ★★★: $P<0.005$, ★★: $P<0.01$, ★: $P<0.05$.

3.5.2. The texture of sourdough fermentation bread

The springiness, cohesiveness and resilience of bread were positively correlated with bread quality, while hardness, gumminess and chewiness were negatively correlated with bread quality. According to Table 2, the quality of sourdough breads was significantly ($P< 0.05$) improved compared with bead without sourdough (UF-b), GT-b showed the most significant improvement ($P< 0.05$). The hardness value of four stains sourdough breads core decreased by 21.61%–63.14%. This suggests that sourdough breads are more and soft, and the fermentation of the strain are conducive to carbon dioxide accumulation, which improves the ductility of the dough and ensures that the dough fully expands during baking. Among sourdough breads, GT-b was the lowest chewiness and gumminess value, indicating that the bread is easy to melt and swallow. The cohesiveness and resilience value of GT-b, ST-b and PP-b were better than that of LF- b, this may be related to the degree of acidification of the strain, which exposes starch particles from the gluten protein and prevents the formation of cohesive tissue structures during heat(Olojede et al., 2020). In conclusion, sourdough fermentation can improve the quality of bread in some cases, and it can be seen that different strains can provide advantages for bread through fermentation (Wang et al., 2017).

4. Conclusion

Currently, fermentation with strains is known as an efficient method for acrylamide reduction in baked foods, where the reduction is due to reduced levels of pH value and prerequisite substance content. The results of the present study revealed that *Lactobacilli fermentum*, *Pediococcus pentosaceus*, and *Saccharomyces cerevisiaes* could be used to reduce acrylamide. The volume of the sourdough breads increased and the water activity decreased, which helped prolong the storage and shelf life of the bread, however, the bread hardness increased slightly, but it did not affect the quality of the bread. The content of acrylamide in wheat breads were in all cases lower than those in the control group, and its content reduced 24.38%–58.83% by sourdough fermentation. At the same time, it can be concluded that the acrylamide reducing potential of

Table 2
The effect of different strains on the texture of sourdough fermentation bread.

Sample	The texture of sourdough fermentation bread						Sensory evaluation/(score)
	Hardness	Gumminess	Chewiness	Springiness	Cohesiveness	Resilience	
UF-b	1183.71±14.01^{a}	986.09±10.15^{a}	902.22±1.52^{a}	0.97±0.04^{a}	0.79±0.05^{a}	0.39±0.36^{a}	82.25±2.12^{a}
NU-b	850.45±17.40^{d}	627.34±17.51^{d}	610.41±7.18^{e}	0.93±0.04^{d}	0.77±0.01^{b}	0.43±0.43^{cd}	88.24±1.55^{c}
LF-b	927.96±12.35^{b}	871.77±9.36^{b}	702.47±1.03^{b}	0.92±0.04^{b}	0.74±0.04^{b}	0.42±0.39^{b}	85.23±1.02^{b}
PP-b	715.70±5.17^{c}	555.78±12.99^{c}	528.14±6.42^{d}	0.92±0.05^{c}	0.80±0.04^{c}	0.44±0.44^{c}	91.65±1.04^{d}
ST-b	565.86±15.66^{e}	469.24±11.93^{e}	450.22±16.77^{d}	0.92±0.03^{e}	0.86±0.02^{b}	0.52±0.52^{ce}	93.65±1.53^{d}
GT-b	436.34±16.02^{f}	324.69±26.34^{f}	342.63±15.18^{c}	0.93±0.05^{f}	0.85±0.01^{b}	0.50±0.50^{cd}	95.67±2.39^{e}

The data are the means of three independent experiments ± standard deviations. $^{a\text{-}f}$ Significant difference of different superscript letter values in the same column ($P <$ 0.05).

sourdough fermentation is strain specific, with *Pediococcus pentosaceus* being the most effective. These results are the consequence of the combined effects of the increased levels of sourdough acidity, and the reduced levels of protein content. However, besides the complexity of the associations between *Saccharomyces cerevisiae* and *Lactobacilli* in sourdoughs, sourdough and dough are also dynamic systems, in order to use this technology with various microbial strains, primary researches are required to understand processes leading to reduced acrylamide production.

CRediT authorship contribution statement

Xiaoli Zhou: Conceptualization, Writing – review & editing. **Mengjie Duan:** Investigation, Writing – original draft, Preparation. **Shijie Gao:** Formal analysis. **Tian Wang:** Data curation. **Yibao Wang:** Methodology. **Xinyi Wang:** Methodology. **Yiming Zhou:** Investigation, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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