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Research Article

Effects of Commercial Yeast on the Quality of Frozen Dough and Steamed Bread in Different Regions of China

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This study delved into the impact of various commercial yeast strains from different geographic regions on the quality attributes of dough and steamed bread. The investigation encompassed aspects such as fermentation dynamics, texture profiles, and overall quality features of frozen dough and steamed bread products. Eighteen distinct commercial yeast strains were utilized to prepare dough samples. The findings revealed minimal disparity in the color and height-to-diameter ratio of the resulting steamed bread across all samples. However, frozen doughs formulated with commercial yeast sourced from the southern regions of China exhibited enhanced CO_2 production, heightened freezing resilience, a more pronounced gluten network structure, increased flexibility, and reduced presence of weakly bound water that contributes to ice crystal formation within the dough matrix. Each yeast strain exhibited a CO_2 production volume exceeding 900 mL. Notably, the strains sourced from the southern region of China displayed the most superior freeze-tolerance rate (mean 0.84), surpassing those originating from central China (0.81) and northern China (0.74). Textural analyses unveiled that frozen dough steamed bread produced with yeast strains from the northern region exhibited diminished pliability and chewiness. This comprehensive study serves as a valuable resource for the judicious selection of commercial yeast strains in the realm of industrial frozen dough and steamed bread production.

1. Introduction

Amid shifts in dietary habits, the transformation of traditional staple foods into an industrialized trend has gained momentum in China [1]. Concurrently, the restaurant chain sector has witnessed the ascendancy of the "central kitchen" business model [2], paralleled by the ascendancy of frozen dough technology as a pivotal preservation method [3]. This pioneering approach to steamed bread fabrication considerably extends bread's shelf life, enabling consumers to indulge in freshly prepared steamed bread while concurrently alleviating the workload for bakers [4].

Notwithstanding the convenience associated with dough freezing, certain limitations warrant consideration. Findings from Yang et al.'s study [5] underscore that the freezing process can induce water migration and recrystallization, impairing the structural and qualitative attributes of the dough. Ke et al.'s observations [6] emphasize the potential for bran networks to weaken, compromising the quality of the final baked output. Furthermore, as elucidated by Lu et al. [7], ice crystal formation during freezing substantially curtails CO_2 production and bread volume by impinging on yeast cell activity. Lastly, as posited by Zhang et al. [8], subjecting dough to low temperatures can attenuate yeast activity and provoke the deterioration of gluten proteins, ultimately yielding air retention challenges.

The yeasts play an important role in the quality, flavor, and appearance of frozen dough products [9]. Research has revealed that the freezing tolerance of yeast varies based on factors like growth medium, strain, freezing storage temperature and time, lipid composition, and alginate content. Freeze-tolerant yeasts in frozen dough have a high aeration capacity, but their ability varies depending on the commercial product [10]. Common fermentation products are sourdough and commercial yeast, with differences in sourdough possibly due to regional variations in ingredients, temperature, environment, and preparation methods [11, 12]. Suo et al. [13] suggest that the microbiological composition of yeast is significantly influenced by different artisanal practices and geographic regions. As for commercial yeast, further research is needed to determine if such differences exist.

Commercial yeast stands as a superior choice for frozen dough and bread production [10]. Presently, research endeavors center on the development of freeze-tolerant yeast strains and additives to enhance freeze resistance within frozen dough steamed bread. However, an insufficiency of information prevails concerning variances in commercial yeasts across diverse regions. Additional research is imperative to comprehensively grasp the ramifications of regional commercial yeasts on frozen dough steamed bread during the production phase. Gaining a more profound understanding of the regional discrepancies in commercial yeast throughout China necessitates the comprehensive acquisition of industrially cultivated commercial yeast from each distinct locale. In this inquiry, a total of 18 commercial yeasts sourced from diverse Chinese regions were harnessed to craft individually frozen dough specimens, facilitating scrutiny of their fermentation attributes, freeze tolerance, rheological traits, water distribution, and steamed bread quality. The findings of this study furnish theoretical underpinning for the industrial-scale manufacture of steamed bread derived from frozen dough substrates.

Table 1: The information of 18 commercial yeasts.

Number*	Name	Production area	Latitude
s1	Forise	Chongzuo	22°40′N
s2	Angie	Chongzuo	22°40′N
s3	Baoli	Chongzuo	22°40′N
s4	Kingain	Chongzuo	22°40′N
s5	Swallow	Laibin	23°73′N
s6	Chuibao	Dehong	25°20′N
c1	Jiaomuwang	Zhengzhou	34°75′N
c2	Xifa	Linyi	35°06′N
c3	Colourful	Heze	35°24′N
c4	Wonder Farm	Zhangjiakou	39°30′N
c5	Yanshan	Zhangjiakou	39°30′N
c6	Wuweiliangcang	Zhangjiakou	39°30′N
n1	Eagle	Chifeng	42°27′N
n2	Zhanyi	Ili	43°49′N
n3	Mauripan	Harbin	45°75′N
n4	Xinliang	Suihua	46°38′N
n5	Damofang	Suihua	46°38′N
n6	Aoli	Tacheng	47°15′N

Note: *Commercial yeasts are divided into three regions according to the latitude of origin, and each region is being numbered from lowest to highest according to latitude. s1-s6 indicate commercial yeast produced in the southern region of China, c1-c6 indicate commercial yeast produced in the central region of China, and n1-n6 indicate commercial yeast produced in the northern region of China.

2. Materials and Methods

2.1. Materials. The flour used in this study was purchased from the Zhengzhou Jinyuan Noodle Co. (Zhengzhou, China). The flour moisture, protein, and ash concentrations were 13.02%, 12.4%, and 0.51%, respectively. The farinograph parameters of flour are 34.95% wet gluten content, falling number of 432 FN, and 58.6% water absorption. The yeast employed in this investigation was sourced from multiple regions within China, with details regarding producers and locales documented in Table 1. All additional reagents employed met or exceeded analytical-grade standards.

2.2. Preparation of Samples

2.2.1. Preparation of Dough. The dough was prepared according to the method of He et al. [14]. The dough, distilled water, and yeast were put into a dough mixer in the ratio of 100 : 50 : 1 for 8 min (B5A, Wilbur Hospitality Equipment Co., Ltd., Guangzhou, China). The mixed dough was rolled in a dough molding machine to make the surface smooth (JCXZ 95, Dongfu Jiuheng Instrument Technology Co., Ltd., Beijing, China). The finished dough was chilled in a refrigerator at -35°C for 1 hour. The frozen dough was then placed in self-sealing bags and refrigerated at -18°C for 60 days.

2.2.2. Preparation of Steamed Bread. Steamed bread was crafted in alignment with Zhang et al.'s protocol [15]. The frozen dough underwent initial thawing (at a temperature of 30°C and relative humidity of 85%) within a controlled temperature escalating oven (FX-15S, Systa Machinery Equipment, Guangzhou, China). Subsequent to thawing, the dough was allowed to undergo proofing at 35°C and 85% humidity for an additional 45 minutes. Following proofing, the dough was subjected to steaming at 100°C for a duration of 25 minutes (FL-ZFX-1, Huafengte Kitchen Equipment Manufacturer, Shandong, China).

2.3. Rheofermentometer Test. The fermentation properties and total volume of CO_2 production (V_t) of the dough were examined using a rheofermentometer [1] (F4, Chopin Technologies, Paris, France). The thawed frozen dough is quickly placed in the fermentation vessel and measured according to the manufacturer's recommendations. The measurement parameters were 315 g of dough, a temperature of 35°C, a time of 3 hours, and a weight mass of 2000 g.

2.4. Freeze-Tolerance Rate. The freeze-tolerance rate of yeast in the dough was determined by evaluating yeast fermentative capacity before and after freezing [10]. V_t is used to indicate the fermentation capacity of the yeast.

$$\text{Freeze-tolerance rate}(\%) = \frac{Vt2}{Vt1} \times 100, \quad (1)$$

where V_{t1} denotes the fermentation power of fresh dough, while V_{t2} denotes the fermenting power of frozen dough.

2.5. Dynamic Rheological Test. Rheological properties were assessed utilizing a DHR-2 rotational rheometer (TA Instruments, Inc., America) equipped with a P35 probe and a 35 mm-diameter plate fixture [16]. The measurement protocol involved the placement of 10 g of dough onto the rheometer platform, followed by a relaxation phase of 25 minutes at 25°C. Prior to measurement, any surplus dough was excised, and the platform was allowed to stabilize for 5 minutes, facilitating the dissipation of residual stress. Frequency sweep examinations were conducted across the range of 0.1 to 20 Hz, employing a strain value of 0.1%.

2.6. Nuclear Magnetic Resonance (NMR) Test. Water distribution within the dough was evaluated through the determination of spin-spin relaxation time (T_2) using a nuclear magnetic resonance (NMR) apparatus (MicroMR, Shanghai Niumag Electronics Technology Co. Ltd., Shanghai, China) [9]. The experimental procedure entailed thawing the dough until central temperature equilibrium was attained prior to commencing the experiment. Subsequently, 2 g of each sample was placed within a small test tube positioned within the system's corresponding RF coil, with efforts to align the piece's center, the NMR center, and the coil center as precisely as feasible. The Carr-Purcell-Meiboom-Gill (CPMG) pulse sequence was employed for measuring transverse relaxation (T2). Essential parameters for the CPMG experiment encompassed a sampling interval Tw of 1500 ms, 8 instances of multiple repetitive scans, a repetition time TR of 2000 ms, a TD of 104902, and a TE of 0.21 ms.

2.7. Texture Profile Analysis (TPA) Test. A TA-XT Plus Texture Analyzer (Stable Micro Systems Ltd., UK) was used to determine the texture of the steamed bread [16]. A P35 probe was used in the texture profile analysis (TPA) test. Steamed bread was sliced transversely to obtain uniform slices with thicknesses of 10 mm. Two pieces taken from the centre of the bread were evaluated. The test parameters encompassed a speed of 1.0 mm/s, a deformation magnitude equating to 40% of the sample's height, and a trigger force set at 0.05 N.

2.8. Color of Steamed Bread. The color of steamed bread was measured using a CS-200 colorimeter (Jiu Lian Technology Co. Ltd., Suzhou, China). The L^* value represents the lightness and varies from 100, for perfect white, to zero, for black [16].

2.9. Specific Volume of Steamed Bread. The specific volume of steamed bread was measured by dividing its volume by weight [16]. Its volume is determined using the rapeseed displacement method.

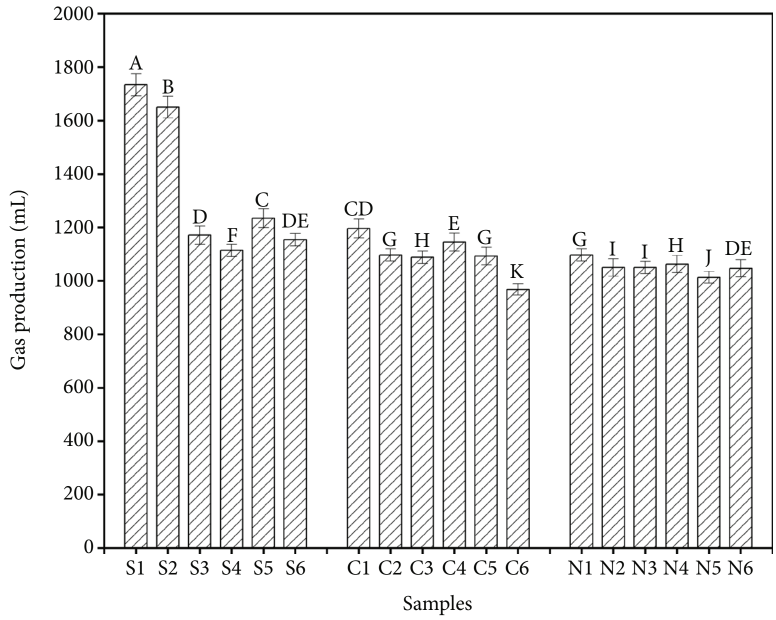
2.10. Height-to-Diameter Percentage of Steamed Bread. The height and diameter were measured using vernier callipers to calculate the steamed bread's height-to-diameter rate [14].

2.11. Statistical Analysis. All experiments were conducted in triplicate, and the outcomes were presented as the mean ± standard deviation (SD). Statistical analysis was done using SPSS statistical software (SPSS 19.0, SPSS Inc.) and the rigin Pro 8.6 program (Origin Lab Inc.). The analysis of variance (one-way ANOVA) was supplemented with Duncan's multiple-range tests. Differences were deemed statistically significant at $P < 0.05$.

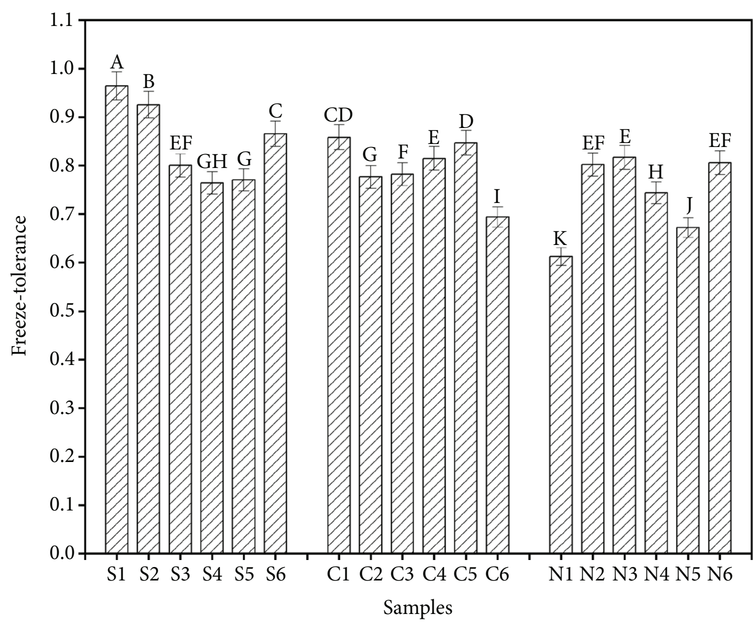
3. Results and Discussion

3.1. Fermentation Characteristics and Freeze-Tolerance Rate of Frozen Dough. The fermentation attributes and freeze-tolerance potential of frozen dough were scrutinized via the F4 Rheofermentometer. The V_t results are illustrated in Figure 1(a). Across all regions, frozen dough formulated with commercial yeast exhibited V_t values surpassing the 900 mL benchmark, as graphically represented. Noteworthy is the elevated V_t evident in frozen dough originating from the southern region, boasting an average of 1343 mL. Particularly, exemplary are samples S6 and S1, displaying V_t values exceeding 1600 mL and markedly outperforming their counterparts. Suo et al.'s observations [13] highlight the susceptibility of strain dynamics to minor perturbations in the ecosystem, such as variations in sucrose levels within the growth medium. Notably, yeast manufacturers in the southern region, mainly concentrated in Guangxi, harness sugarcane waste molasses as a primary raw material for yeast production. This byproduct of cane sugar refinement encompasses approximately 40% sucrose, converted sugars, and a wealth of minerals, particularly phosphorus. This composition aptly caters to the germination and expansion phases of the yeast, culminating in reduced expansion duration, enhanced solid mycelium development, and heightened aeration during yeast production, as substantiated by prior research [17]. In contrast, frozen dough formulated with commercial yeast from the central and northern regions yields V_t values spanning 900 to 1200 mL. These regions predominantly employ beet sugar molasses and glucose molasses for yeast production. Beet sugar molasses, stemming from beet sugar processing facilities, is chiefly prevalent in China's northeast and northwest. Beet sugar content is rich in sucrose but modest in converted sugars, boasting a mere 1.3% cottonseed sugar. Despite a higher nitrogen content than sucrose, only 12-20% is metabolizable by yeast. Moreover, the phosphorus content in beet sugar is minimal. Recent investigations underscore the significant antioxidant content within sugar beet molasses, potentially hampering yeast growth [18, 19]. On the other hand, glucose molasses, primarily sourced from central China, exhibit lower trace element content compared to the two aforementioned types, necessitating increased nutrient salt supplementation for optimal yeast growth.

This study further probed the freeze-tolerance rate of commercial yeast hailing from distinct regions within frozen dough, the outcomes delineated in Figure 1(b). Yeast strains across the southern, central, and northern regions exhibited freeze-tolerance rates ranging between 0.6 and 1. This signifies compromised maintenance of initial fermentative vigor following freezing and subsequent thawing, attributed to pronounced damage to yeast cell plasma membranes



(a)



(b)

Figure 1: (a) The total volume of CO_2 production (V_t) of commercial yeast in the southern, central, and northern regions. Note: S1-S6 denote frozen dough made from commercial yeast produced in the southern region of China, C1-C6 denote frozen dough made from commercial yeast produced in the central region of China, and N1-N6 denote frozen dough made from commercial yeast produced in the northern region of China. (b) The freeze-tolerance rate of commercial yeast in the southern, central, and northern regions.

during these phases [10]. Frozen storage precipitates disruptions in gluten structure due to ice crystal aggregation and recrystallization, ultimately diminishing the dough's gas retention capacity. The proliferation of ice crystals also poses a threat to yeast cell viability, thus impacting the dough's fermentative potential, as corroborated by Cao et al. [20]. Regional disparities in yeast freeze-tolerance rates emerge, with the southern region registering an average rate of 0.84, trailed by the central region at 0.81, and the northern region at 0.74. Addressing the disparity between the southern and central regions' freeze-tolerance rates may be accomplished by selecting from the eighteen yeasts showcasing heightened freezing resilience. Specifically noteworthy are S1, S2, S6, C1, and C5, each exhibiting freeze-tolerance rates surpassing 0.84. The southern region's adeptness in yeast production can be attributed to its heightened tolerance for sucrose, facilitating the synthesis of substantial alginate quantities that safeguard cell membrane integrity and inhibit excessive cell wall separation. In the central region, robust tolerance to hypertonic environments is a consequence of

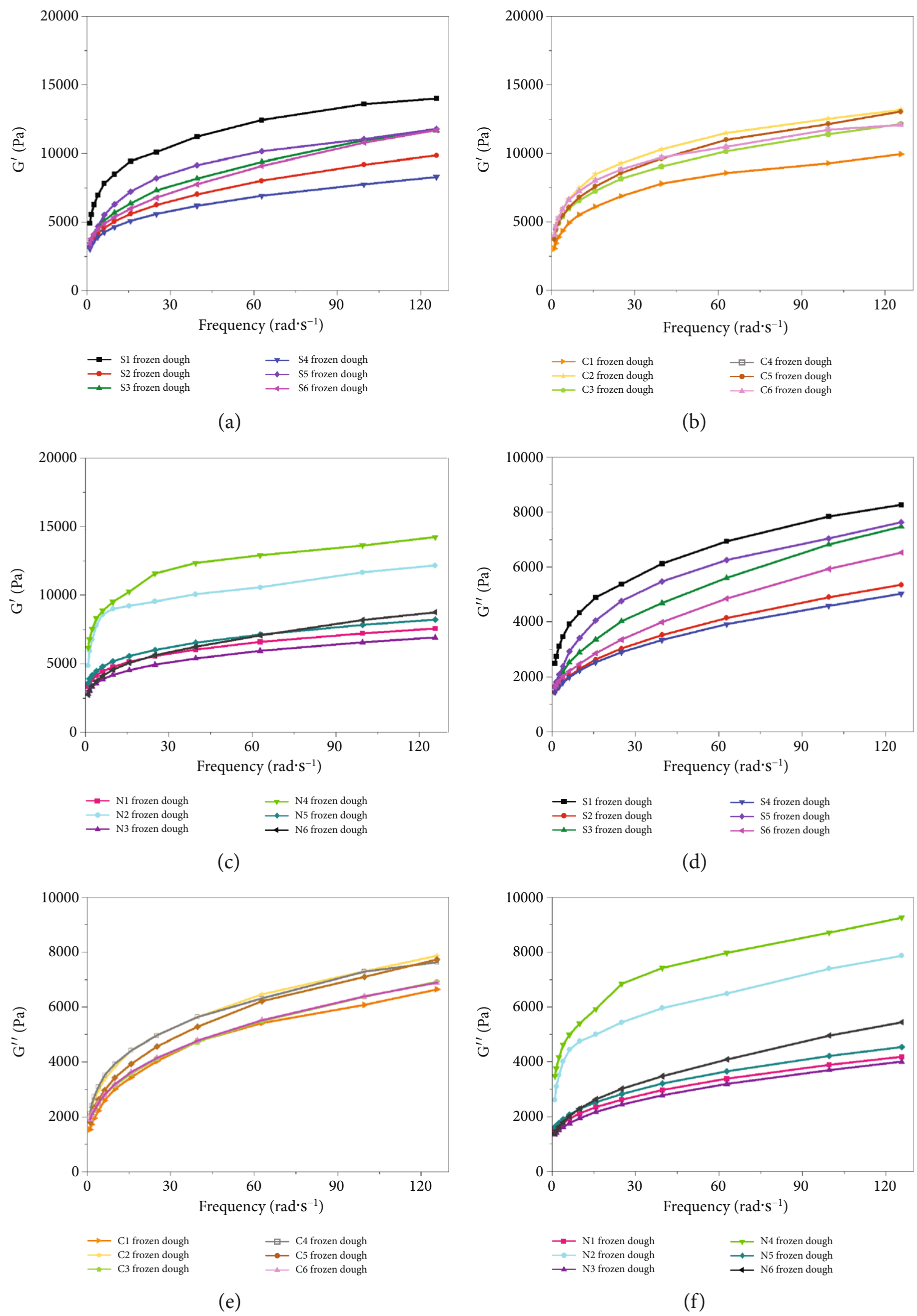


FIGURE 2: The rheological properties of frozen dough with commercial yeast from the southern, central, and northern regions. (a–c) Storage modulus G′. (d–f) Loss modulus G″.

substantial salt utilization during yeast production. Additionally, yeast strains indigenous to tropical climates within the 30°C to 40°C range have inherently acclimated to these temperature settings [21–23].

3.2. Rheological Properties of Frozen Dough. Rheological properties have been extensively studied to predict better food products' processing behavior and quality [24]. This research examines how different commercial yeasts from various regions affect the rheological properties of dough. In Figure 2, we can see the impact of these yeasts on the G′ and G″ during frequency sweep mode. The results show that the effect of commercial yeasts from different regions on G′ and G″ is similar. The dough's modulus (G′ and G″) increases with higher frequency, and all samples demonstrated higher G′ values than G″. This indicates that dough is a typically polymeric structured material with viscoelasticity and that its elasticity is more significant than its viscous behavior, according to studies by Li et al. [25, 26]. It implies that the dough's deformation can be compressed and returned to its original shape within a particular linear range. The graph illustrates that the maximum and

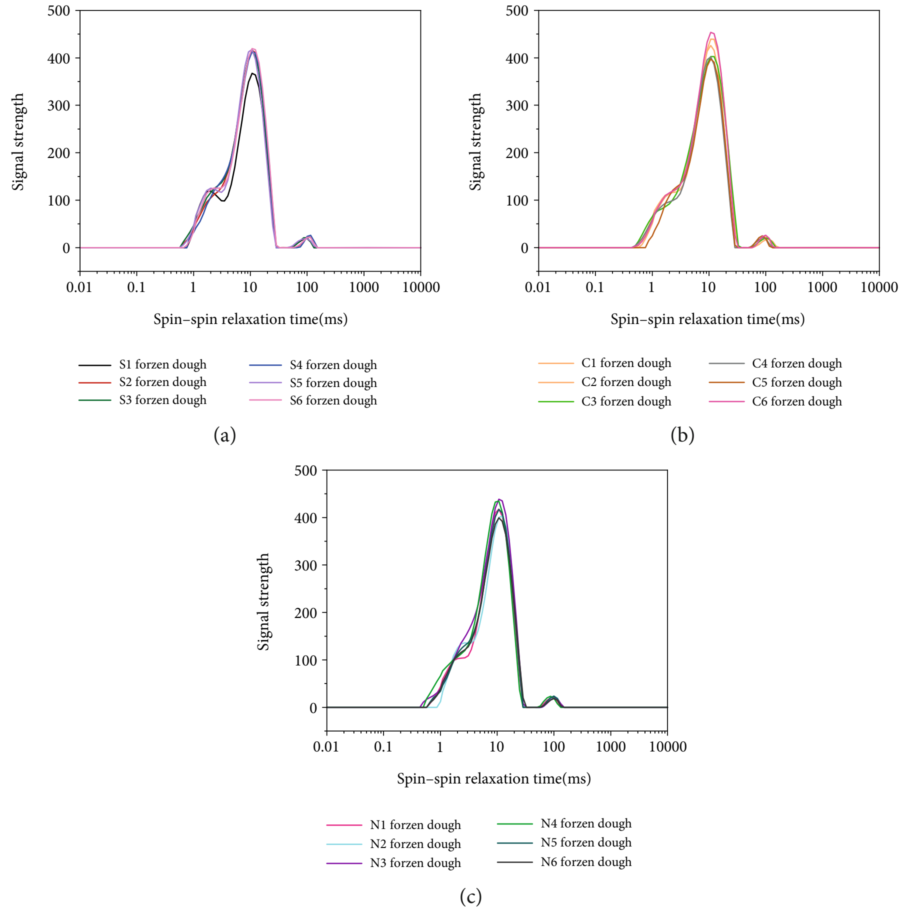


Figure 3: The NMR of commercial yeast in the southern, central, and northern regions. (a) denotes the spin-spin relaxation time (T_2) with frozen dough made from commercial yeast produced in the southern region of China; (b) denotes the spin-spin relaxation time (T_2) with frozen dough made from commercial yeast produced in the central region of China; and (c) denotes the spin-spin relaxation time (T_2) with frozen dough made from commercial yeast produced in the northern region of China.

minimum values of G' and G'' cooccur, indicating a correlation between the elasticity and viscosity of the frozen dough. This is because the rheological properties of the dough are primarily affected by its protein and water content, as noted by Hong et al. [27]. From Figure 2, it is clear that frozen dough made with yeast in different regions exhibits varying degrees of apparent viscoelasticity. Among these, the rheological properties of frozen dough made from yeast in the southern and central regions are superior, as shown by the higher levels of G' and G'' in S1 yeast frozen dough, which also rise more quickly with increasing scan frequency. This indicates a stronger gluten network structure and better dough stability. In contrast, frozen dough made from yeast in the northern region generally exhibits lower G' and G'' values, with a slower rising trend indicating weaker resistance to deformation. It is possible that yeast fermentation during the dough-freezing process produces metabolites that significantly soften the dough, as suggested by Hong et al. [27]. We speculate that this may be due to the effects of ethanol, succinic acid, and glutathione, according to Meerts et al.' study [28].

The investigation of rheological properties holds considerable import in prognosticating the processing dynamics and quality of enhanced food products [24]. Within this context, this study delves into the influence of disparate commercial yeast strains sourced from varied regions on the rheological characteristics of dough. Illustrated in Figure 2 is the impact of these yeast strains on the G' and G'' within the context of frequency sweep mode. The outcomes spotlight a consonance in the effect of diverse commercial yeast strains on G' and G''. Notably, the modulus (G' and G'') of the dough exhibits augmentation with escalating frequency, with all specimens manifesting superior G' values relative to G''. This attests to dough's intrinsic polymeric structure, typified by viscoelastic attributes, wherein elasticity predominates over viscosity, aligning with findings presented by Li et al. [25, 26]. This denotes that the dough's deformation can be compressed and subsequently restored to its original configuration within a defined linear range. The graph perceptibly delineates the concomitant manifestation of maximum and minimum G' and G'' values, signifying an interrelationship between dough elasticity and viscosity. This relationship is underpinned by the pivotal roles played by protein and water content in shaping the rheological attributes of dough, a facet underscored by Hong

Table 2: Textural properties of steamed bread with commercial yeast from southern, central, and northern regions.

Sample	Hardness	Springiness	Gumminess	Chewiness
S1	3383.11 ± 129.97^{h}	0.78 ± 0.02^{b}	996.62 ± 67.78^{h}	2709.82 ± 43.38^{e}
S2	3363.35 ± 298.34^{i}	0.78 ± 0.02^{b}	2878.09 ± 29.24^{c}	2837.60 ± 62.61^{c}
S3	3564.19 ± 407.60^{g}	0.67 ± 0.05^{e}	2863.92 ± 19.64^{c}	2828.51 ± 48.19^{c}
S4	3671.32 ± 295.97^{f}	0.62 ± 0.01^{g}	1955.53 ± 29.65^{e}	3147.00 ± 19.20^{a}
S5	3869.40 ± 117.18^{c}	0.66 ± 0.01^{f}	1094.34 ± 15.81^{gh}	2731.10 ± 76.28^{e}
S6	3847.22 ± 240.04^{c}	0.68 ± 0.03^{d}	1960.92 ± 40.29^{e}	2341.14 ± 18.11^{g}
C1	4170.01 ± 26.49^{a}	0.80 ± 0.04^{a}	1187.91 ± 70.62^{g}	2771.72 ± 53.99^{cd}
C2	3284.03 ± 301.75^{j}	$0.67 \pm 0.01e$	3760.79 ± 20.65^{a}	2444.81 ± 28.14^{g}
C3	3381.09 ± 411.07^{h}	0.70 ± 0.01^{c}	3732.32 ± 29.52^{a}	3054.33 ± 267.05^{ab}
C4	3919.40 ± 58.66^{c}	0.68 ± 0.04^{d}	1334.11 ± 17.32^{f}	2863.60 ± 14.81^{c}
C5	3693.31 ± 150.38^{f}	0.68 ± 0.06^{d}	1275.73 ± 61.99^{fg}	2872.79 ± 61.09^{c}
C6	3771.79 ± 113.90^{e}	0.68 ± 0.05^{d}	1359.84 ± 44.94^{f}	2930.34 ± 12.93^{b}
N1	3586.89 ± 164.57^{g}	0.68 ± 0.02^{d}	2217.29 ± 58.50^{d}	1880.10 ± 16.63^{i}
N2	3873.21 ± 155.33^{c}	0.70 ± 0.03^{c}	1258.21 ± 69.55^{f}	2729.54 ± 67.64^{e}
N3	3801.90 ± 245.21^{d}	0.68 ± 0.03^{d}	1202.50 ± 15.52^{g}	2825.80 ± 38.93^{c}
N4	3685.81 ± 153.20^{f}	0.66 ± 0.02^{f}	1447.73 ± 66.28^{f}	2634.33 ± 19.65^{f}
N5	3443.60 ± 82.51^{h}	0.70 ± 0.05^{c}	3134.61 ± 26.99^{b}	2212.41 ± 23.03^{h}
N6	4044.59 ± 65.51^{b}	0.67 ± 0.01^{e}	1174.20 ± 25.43^{g}	2761.72 ± 45.70^{d}

Note: values are means ± SD. The lowercase letters represent significant differences between the data in the same column ($P < 0.05$). S1-S6 denote frozen dough steamed bread made from commercial yeast produced in the southern region of China, C1-C6 denote frozen dough steamed bread made from commercial yeast produced in the central region of China, and N1-N6 denote frozen dough steamed bread made from commercial yeast produced in the northern region of China.

et al.'s observations [27]. The discernment gleaned from Figure 2 underscores distinct levels of apparent viscoelasticity across frozen dough formulated with yeast strains hailing from distinct regions. Among these, frozen dough crafted with yeast strains originating from the southern and central regions evidences heightened rheological properties, as evidenced by elevated G'' levels in yeast S1 frozen dough, which further exhibit a swifter augmentation trajectory with increasing scan frequencies. This trajectory is indicative of a more robust gluten network structure and enhanced dough stability. In contradistinction, frozen dough originating from the northern region generally registers diminished G'' values, coupled with a more gradual augmentation pattern, indicative of comparatively diminished resistance to deformation. Conceivably, yeast fermentation during the dough-freezing process yields metabolites that significantly temper dough texture, as posited by Hong et al. [27]. It is plausible that ethanol, succinic acid, and glutathione, as underscored in Meerts et al.s' investigations [28], could potentially underscore these effects.

3.3. Water Distribution. In accordance with He et al.'s study [14], the water distribution within frozen dough emerges as a pivotal determinant of its quality and internal composition. Low-field nuclear magnetic resonance (LF-NMR) spectroscopy stands employed as a rapid and nondestructive analytical methodology to discern water distribution within the dough. Figure 3 elucidates T_2 distribution profiles for frozen dough originating from yeast strains sourced across diverse regions. The curve is characterized by three discernible peaks: T_{21}, T_{22}, and T_{23}. T_{21}, denoting the initial peak, manifests within the 0.4-2 ms range, encapsulating water firmly bound to starch or gluten proteins, epitomizing diminished mobility. Occupying the 2-30 ms span, T_{22} embodies the secondary peak, representative of immobilized water tethered to proteins, starch, and other macromolecules, showcasing mobility oscillating between that of strongly bound water and liberated water [29]. T_{23}, constituting the tertiary peak, is situated between 30 and 200 ms and signifies free water marked by heightened mobility [12, 30]. Evidently, the T_{23} peak finds representation across all 18 samples investigated, underscoring the presence of marginal free water content within yeast-frozen dough spanning the three regions. It is of note that fresh dough remains bereft of free water, as all water content remains variably tethered to gluten and starch. Two plausible scenarios underlie the manifestation of free water: yeast within the dough potentially engenders free water through aerobic and anaerobic respiration during the freeze-thaw cycle, or a minor degree of condensation surfaces during the thawing process.

A comparative assessment of water distribution within frozen dough crafted from yeast strains across three distinct regions is unveiled within Figure 3. Significantly, yeast-frozen dough hailing from the southern region exhibits diminished immobilized water (T_{22}) relative to counterparts sourced from the central and northern regions. This discrepancy can be attributed to escalated alginate levels inherent to yeast strains originating from the southern region, a factor instrumental in forestalling ice crystal formation during freezing. Figure 3(a) illustrates distinct T_{21} proton clusters within yeast strains (S1, S2, S5, and S6) procured from the southern region, signifying heightened deeply bound water content intimately entwined with bran and starch. In contrast, Figure 3(b) elucidates frozen dough prepared from central region yeast strains, reflecting comparably uniform water profiles, with no distinct T_{21} proton clusters observed. Conversely, the revelations unveiled in Figure 3(c) disclose frozen dough attributable to N1 and N5 yeast strains of the northern region, wherein conspicuous T_{21} proton clusters are absent, indicating the absence of robustly bound water content. This concurs with findings expounded within Sections 3.1 and 3.2, reinforcing the notion that intensely mobile water aggregates amass into substantial ice crystals, subsequently triggering macromolecular protein depolymerization and the degradation of frozen dough quality. Analogous outcomes have been documented by Xin et al. [31], whose observations align with the phenomenon of yeast mortality and subsequent inactivity, relinquishing reduced glutathione that disrupts gluten's disulfide bonds. As water migrates within, minute ice crystals initiate and proliferate, ultimately inducing contraction within the gluten network structure and a concurrent upsurge in porosity.

3.4. TPA of Steamed Bread. Texture profile analysis (TPA) stands as the method employed to gauge steamed bread's textural attributes and elucidate its defining traits. Drawing from Li et al.'s insights [32], the chewiness, hardness, and gumminess of steamed bread exhibit an adverse correlation with quality, while springiness evinces a favorable association. Table 2 delineates the influence of yeast on the textural characteristics of steamed bread originating from southern, central, and northern regions. Outcomes unveil pronounced disparities in texture attributes across yeast-frozen dough-based steamed bread contingent on distinct regions ($P < 0.05$). Amid these regions, C1 yields the most resilient steamed bread, succeeded by S1 and S2. Steamed bread originating from the northern region manifests diminished springiness and complexity, likely attributed to elevated moisture content during the freeze-thaw cycle. This moisture gives rise to ice crystal formation, disrupting the gluten network and adversely impacting steamed bread quality. Furthermore, C1 and N6 region-produced steamed bread exhibit a denser crumb structure, featuring smaller, uneven pores and heightened hardness, stemming from insufficient gas generation subsequent to frozen storage due to yeast cell demise. Chewiness denotes the energy requisite for masticating food, computed through amalgamating hardness, springiness, and cohesiveness [33]. Noteworthy within Table 2 are conspicuous distinctions ($P < 0.05$) in the chewiness of steamed bread realized through yeast-forged dough sourced from the three regions. S4 produced the most satisfyingly chewy steamed bread, followed by C3, while N1 and N5 yielded fewer satisfying results. Research suggests that increased water migration led to amylose aggregation and rearrangement, which accelerated starch ageing and affected the quality of steamed bread's chewiness [34]. In summary, the steamed bread produced with yeast in the southern region is softer and more elastic, likely due to the increased yeast activity in that area. The northern steamed bread made with yeast is more intricate but lacks elasticity and chewiness, resulting in unpleasant steamed bread. The yeast-produced steamed bread in the central region is moderately soft and firm, elastic yet sticky, and of average quality.

Table 3: The quality of steamed bread with commercial yeast from southern, central, and northern regions.

Sample	L value	Specific volume	Height-to-diameter ratio
S1	82.34 ± 0.46^{b}	2.87 ± 0.03^{a}	0.61 ± 0.00^{bc}
S2	83.32 ± 0.10^{a}	2.01 ± 0.05^{g}	0.48 ± 0.01^{e}
S3	79.22 ± 0.89^{e}	1.94 ± 0.02^{h}	0.64 ± 0.01^{b}
S4	80.31 ± 0.46^{d}	2.32 ± 0.02^{de}	0.59 ± 0.01^{c}
S5	80.68 ± 0.68^{d}	2.61 ± 0.06^{b}	0.47 ± 0.01^{e}
S6	80.79 ± 0.23^{d}	2.21 ± 0.02^{f}	0.58 ± 0.01^{c}
C1	80.81 ± 0.41^{d}	2.46 ± 0.03^{c}	0.56 ± 0.01^{cd}
C2	81.19 ± 0.49^{c}	1.81 ± 0.01^{j}	0.69 ± 0.01^{a}
C3	81.03 ± 1.24^{c}	1.95 ± 0.04^{h}	0.48 ± 0.01^{e}
C4	83.48 ± 0.23^{a}	2.39 ± 0.02^{d}	0.58 ± 0.01^{c}
C5	82.60 ± 0.29^{b}	2.26 ± 0.02^{e}	0.54 ± 0.00^{d}
C6	80.80 ± 0.79^{d}	2.63 ± 0.03^{b}	0.59 ± 0.02^{c}
N1	80.89 ± 0.77^{d}	1.99 ± 0.13^{gh}	0.54 ± 0.01^{d}
N2	82.02 ± 1.08^{b}	2.51 ± 0.03^{bc}	0.54 ± 0.03^{d}
N3	82.82 ± 0.45^{b}	2.50 ± 0.02^{bc}	0.66 ± 0.00^{ab}
N4	82.72 ± 0.74^{b}	2.29 ± 0.03^{e}	0.56 ± 0.00^{cd}
N5	78.46 ± 0.76^{f}	1.81 ± 0.02^{i}	0.57 ± 0.01^{cd}
N6	83.01 ± 0.40^{a}	2.34 ± 0.02^{de}	0.60 ± 0.01^{bc}

Note: values are means ± SD. The lowercase letters represent significant differences between the data in the same column ($P < 0.05$).

3.5. Steamed Bread Quality. Measuring the color characteristics of yeast-steamed bread from various regions is crucial for commercialization. Table 3 indicates notable variations in the brightness of steamed bread produced with yeast from different areas. This is due to the impact of different yeasts on the color of the steamed bread. Notably, steamed bread made from yeast-frozen dough from all three regions resulted in white bread. The S2, C4, and N6 steamed bread stood out due to their bright and well-coloured appearance.

The specific volume is a crucial indicator that reflects the yeast activity and gluten network structure. It plays a vital role in determining the quality of steamed bread, as highlighted in a study by Luo et al. [1]. Examination into the impact of yeast strains hailing from disparate regions on steamed bread specific volume is articulated within Table 3. Evidently, S1 garners the loftiest specific volume, pursued by S5 and C6. Conversely, C2 and N5 exhibit diminished specific volumes, a manifestation potentially attributed to impaired gluten network architecture and yeast vitality loss. Consequently, compromised air generation and retention within the dough culminate in reduced specific capacities for the steamed bread loaves, resonating with insights from Liang et al. [35, 36].

Frozen dough steamed bread, birthed through the agency of S3, C2, and N3 yeast strains, registers as possessing the most elevated height-to-diameter ratio. However, regrettably, S3 and C2 engender steamed bread of reduced specific volumes consequent to yeast vitality wane and suboptimal fermentation. Contrarily, S1 and N3 yield steamed bread exuding favorable specific volumes alongside heightened height-to-diameter ratios, thereby yielding an enhanced visual impression. Plausible attributions span yeast's fortification of the gluten network and concomitant curbing of gas dissipation, thereby sustaining an optimal bread configuration. An alternate rationale may be deduced from yeast's enzymatic breakdown, engendering marginal glycerol quantities, augmenting gluten network architecture during the cooking process, and facilitating steamed bread sculpting.

4. Conclusions

The study revealed distinctive attributes among frozen doughs incorporating yeast from diverse geographical regions, encompassing varied fermentation characteristics, rheological properties, and water distribution. This divergence consequently translated into discernible dissimilarities in the ensuing steamed bread, discernible in terms of coloration, specific volume, firmness, elasticity, stickiness, and chewiness. Notably, frozen dough imbued with commercial yeast sourced from the southern region showcased augmented V_t, an observation accentuated by samples S6 and S1. In sharp contrast, frozen dough formulated with commercial yeast from the Central and Northern regions displayed diminished V_t. The TPA assessments underscored that steamed bread emerging from the southern region manifested superior elasticity, whereas counterparts originating from the central region boasted a compact crumb structure, replete with diminutive, uneven pores and heightened firmness.

Pertinently, dough crafted from yeast rooted in the southern region demonstrated heightened gas generation and frost resilience, trailed by yeast-derived dough from the central region. In contrast, dough originating from yeast in the northern region exhibited subdued gas generation and frost resistance. A salient observation is the reduced susceptibility of yeast-infused dough from the southern regions to ice crystal formation, attributed to its diminished weakly bound water content. In the realm of steamed bread formulation, the application of frozen dough populated with yeast from the southern region yields more elastic, less rigid, and adhesive steamed bread, boasting elevated chewiness, brightness, specific volume, and height-to-diameter ratios.

In summation, yeast emanating from the southern regions of China underpins the production of premium-quality steamed bread, attributed to the variegated substrate conditions and yeast cultivation practices across distinct regions. In the context of central kitchen-driven production, the judicious selection of region-appropriate commercial yeast emerges as a pivotal determinant. The present discourse underscores the pivotal role and applicability of commercial yeast-infused frozen dough within the precincts of industrial production.

Data Availability

The data supporting this study's findings are available on request from the corresponding author.

Conflicts of Interest

The authors have declared no conflicts of interest for this article.

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