

Physicochemical properties of wheat grains affected by after-ripening

S. Ma, X.X. Wang*, X.L. Zheng, J.Z. Tian, K. Bian, L. Li and R. Xu

College of Grain Oil and Food science, Henan University of Technology, Lianhua street, Zhengzhou 450001, China P.R.;
xxwanghaut@126.com

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RESEARCH ARTICLE

Abstract

The current work examines the physicochemical properties of wheat grains after 30, 60, 90, 120, and 150 days of storage. Storage time had a considerable influence on the quality of wheat, which remained stable for up to 90-120 days. Compared with freshly harvested wheat, increased storage time resulted in a decrease in catalase activity. However, damaged starch content, flour yield and gluten index increased during storage. The storage period of 60 days positively affected falling number, amylose content and wet gluten content except for reducing sugar content. Additionally, the three wheat varieties differed in terms of quality changes during storage. Results revealed that after-ripening had multiple effects on improving on three traits, which are particularly associated with wheat quality.

Keywords: after-ripening, physicochemical properties, wheat grains

1. Introduction

Wheat is the second largest cereal crop in the world, and is mostly used as a raw material for staple food and fermentation products. Wheat grain is usually stored until the next harvest as it is generally produced once a year. However, the stored grain is easily contaminated by storage fungi, or infected with stored-grain insects (Kindred *et al.*, 2008; Uygun *et al.*, 2005). In addition, the quality of new harvest can be variable, resulting in undesirable flour with poor processing quality. For example, the steamed bun and bread made of new-harvest wheat flour displayed dark colour and weak structures, leading the baked products to collapse and shrivel (Barrera *et al.*, 2007).

Wheat is generally stored in silos equipped with temperature and moisture monitoring systems, as well as aeration and fumigation equipment. During storage, the functional and nutritional properties of wheat can change and its relative processing characteristics, such as stretch resistance, viscoelasticity, protein content and gluten content are also improved (Alsaffar, 2010; Crowley *et al.*, 2002; Tako *et al.*, 2009). However, an entire process

of after-ripening requires 2-3 months, requiring increased processing fees which limit the usefulness of the application (Gooding *et al.*, 2003; Hossain *et al.*, 2011). Therefore, there is significant interest to improve our understanding of the physicochemical properties of wheat during storage. A previous study found that the ageing of wheat grains was associated with changes in the antioxidant defence system and soluble sugar content in wheat embryos (Lehner *et al.*, 2008). Furthermore, sprouting tests found that the sprouting capacity of grains decreased with storage time (Mathew, 2010). A later study showed that the storage time of 3 months positively affected wheat quality, however, hectolitre weight, gluten content, Zeleny sedimentation volume, enzyme activity, acidity and colour of wheat deteriorated beyond 3 months (Karaoglu *et al.*, 2010). Due to the limited scope of these few studies, the after ripening effect of wheat on flour yield and the physicochemical properties of wheat remains poorly understood. Therefore, the goal of this study was to examine the influence of after-ripening on wheat grain characteristics, flour quality properties and pasting properties of three common wheat varieties in China, with the aim to shorten the storage time while maintaining desired quality for wheat products.

2. Material and methods

Materials

Three most widely cultivated white wheats were used in this work. Among them, JI17 (hard) and JI62 (medium hard) were purchased from Shandong grain market, TK6 (soft) was supplied by Henan Academy of Agricultural Sciences (Zhengzhou, China P.R.). The characteristics of these wheat grains are shown in Table 1. All reagents and chemicals used were of analytical grade.

Sample preparation

Wheat grains were cleaned manually to remove the dust and other foreign material immediately after harvest. The grains were loaded in 25 kg bags according to varieties, and stored at room temperature. Each variety was randomly sampled at the 30th, 60th, 90th, 120th and 150th day of storage; 6.0 kg of each seed sample was used for flour milling. The moisture content of grains was tempered to 14–16% and wetting time was 24 h. The milling procedure was according to AACC 26-21A and AACC26-30A methods (AACC, 2000).

Wheat grain characteristics

Starch content was estimated by hydrochloric acid dissolution according to ICC standard method no. 123 (ICC, 1994). Amylose content was determined by a colorimetric method (McGrance *et al.*, 1998). Damaged starch (DS) content was determined by SDmatic by Chopin Technologies (Paris, France; Medcalf and Gilles, 1965). Falling number (FN) values were determined according to the AACC method 56-81 (AACC, 2000). Amylase activity was determined by the Bernfeld method (Bernfeld, 1955). Determination of catalase activity was performed using the Sinha method (Sinha, 1972).

Flour quality properties

Flour yield from break and reducing mills was determined by AACC method 26-21A (AACC, 2000). Wet gluten (WG) content and gluten index was determined using AACC method 38-12 (AACC, 2000). Whiteness of flour was measured by a reflectance meter. Reducing sugar (RS) content was determined by the dinitrosalicylic acid method (Bailey *et al.*, 1992).

Pasting properties

Pasting properties of flour was determined by AACC method 76-21 (AACC, 2000), using a rapid visco analyser (Foss Food Technology Corp., Höganäs, Sweden). Wheat flour suspension (10%, w/w) was equilibrated at 50 °C for 1 min. Then, it was heated to 95 °C at a rate of 6 °C/min. After that, the suspension was cooled to 50 °C at a rate of

Table 1. Intrinsic grain properties of three white wheats.¹

Type	Class	Hardness	Weight/volume (g/l)	Moisture (%)	Protein (%)
JI17	II	79±1 ^a	787±2 ^b	11.42±0.28 ^b	13.3±0.28 ^a
JI62	II	61±1 ^b	772±2 ^c	10.26±0.21 ^b	13.6±0.33 ^a
TK6	I	31±2 ^c	803±2 ^a	12.5±0.28 ^a	12.2±0.21 ^b

¹ Values for a particular column followed by different letters differ significantly ($P<0.05$).

6 °C/min and then maintained at this temperature for 5 min. The initial speed was 960 rpm for the first 10 s followed by 160 rpm for the remainder of the experiment.

Statistical analysis

Statistical analysis was performed with ANOVA (level of significance $P<0.05$) followed by Duncan's test with SPSS software (version 15.0; SPSS Inc., Chicago, IL, USA).

3. Results and discussion

Chemical composition of wheat grains

The intrinsic grain properties of three white wheats are shown in Table 1. The hardness and volume-weight of JI62 were 79 and 61 lower than JI17, respectively. And there was no significant difference in moisture and protein content between them. The TK6 showed a significantly lower hardness and protein content, but higher volume-weight and moisture content than others. As shown in Figure 1, RS content significantly decreased after the ageing process compared with the freshly harvested wheat. When the grain

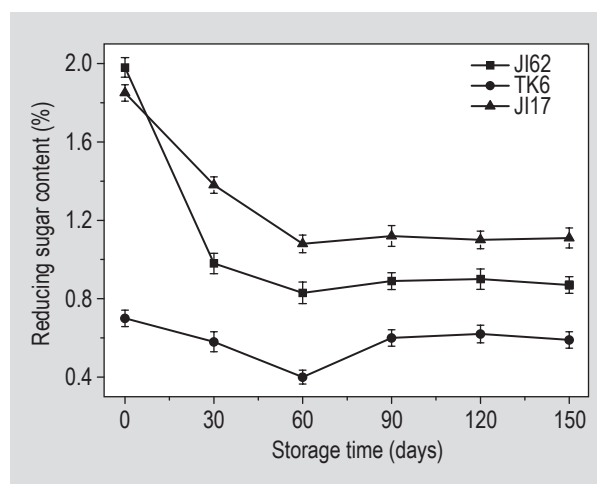


Figure 1. Effect of storage time on reducing sugar content of wheat grain varieties.

had been stored for more than 90 days, the RS content was stable. This is likely because the higher respiration of wheat greatly increased RS consumption during the initial period and then RS was formed by starch hydrolysis during after-ripening, which was gradually balanced with that consumed by respiration (Lehner *et al.*, 2008).

Wheat grains store energy in the form of starch, generally between 60 and 75% of the total dry weight of the grain. The starch was composed of approximately 25% amylose and 75% amylopectin, which was directly associated with quality of flour and wheat-based product. In Table 2, it was observed that the starch content of three wheat varieties slightly fluctuated with increasing storage time, which was stable on the 90th day. The amylose content showed a general upward trend during storage, however, the difference was not significant except for TK6 stored for 15 and 150 days. The amylose content did not differ significantly for the different storage times. The DS content had no significant increase during storage, however, there were significant differences between the wheat varieties. Specifically, JI17 showed the highest DS content and TK6 showed the lowest, probably due to wheat structure. Hard grains have a tighter network of protein and starch granules than soft ones, which are more easily destroyed by the milling process, resulting in higher DS (Ma *et al.*, 2015; Yuan and Tian, 2004).

Table 2. Starch, amylose and damaged starch content of wheat at different storage time.¹

Wheat type	Storage time (days)	Starch (%)	Amylose (%)	Damaged starch (%)
JI17	0	67.25±0.26 ^{ef}	10.88±0.56 ^{abc}	6.93±0.28 ^{abc}
	30	68.00±0.28 ^{cde}	11.32±0.45 ^{abc}	7.13±0.14 ^{ab}
	60	67.59±0.28 ^e	11.80±0.85 ^a	7.17±0.12 ^{ab}
	90	69.24±0.34 ^{bcd}	11.67±0.57 ^{ab}	7.26±0.28 ^a
	120	70.93±0.14 ^a	11.71±0.57 ^{ab}	7.28±0.28 ^a
	150	70.11±0.27 ^{abc}	11.71±0.58 ^{ab}	7.29±0.41 ^a
JI62	0	66.10±0.35 ^f	10.29±0.41 ^{bc}	6.32±0.30 ^c
	30	67.51±0.28 ^e	11.54±0.71 ^{abc}	6.35±0.30 ^c
	60	67.24±0.26 ^{ef}	11.06±0.65 ^{abc}	6.54±0.42 ^{bc}
	90	67.53±0.28 ^e	11.19±0.69 ^{abc}	6.61±0.28 ^{abc}
	120	67.57±0.31 ^e	11.26±0.37 ^{abc}	6.72±0.42 ^{abc}
	150	68.49±0.41 ^{de}	11.24±0.48 ^{abc}	6.76±0.34 ^{abc}
TK6	0	69.00±0.42 ^{cd}	10.22±0.42 ^c	5.11±0.16 ^d
	30	69.11±0.14 ^{cd}	10.71±0.57 ^{abc}	5.13±0.18 ^d
	60	68.30±0.25 ^{de}	11.51±0.57 ^{abc}	5.15±0.20 ^d
	90	70.42±0.63 ^{ab}	11.12±0.56 ^{abc}	5.21±0.28 ^d
	120	70.53±0.35 ^a	11.91±0.65 ^a	5.23±0.27 ^d
	150	70.52±0.14 ^a	11.93±0.43 ^a	5.23±0.33 ^d

¹ Values for a particular column followed by different letters differ significantly ($P < 0.05$).

FN is an important quality characteristic of wheat. Generally, a lower FN is indicative of higher α -amylase activity. Dough formed from wheat flour with excessive α -amylase is sticky and difficult to process (Gooding *et al.*, 2012). In Figure 2, the increase in storage time led to an increase in FN in all three wheat varieties in 90 days, indicating that α -amylase activity was inhibited. After that, the value of the FN was stable.

Catalase, as an important antioxidant enzyme in a biological containment system, plays a key role in regulating the stability and integrity of cell membranes. By converting hydrogen peroxide into oxygen and water, it prevents the formation of O_2^- and H_2O_2 , and breaks down potentially harmful toxins (Shim *et al.*, 2003). As can be seen from Figure 3, the catalase activity significantly decreased during 0 to 120 days of storage. The maximum drop in catalase activity of JI62, JI17 and JK6 was 15.0, 10.4 and 14.5%,

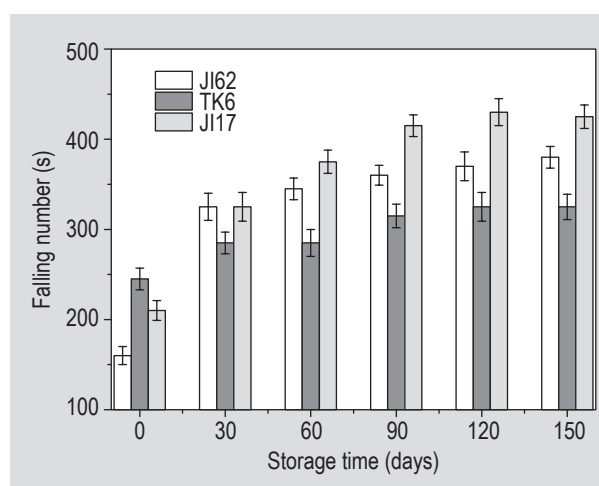


Figure 2. Effect of storage time on falling number of wheat grain varieties.

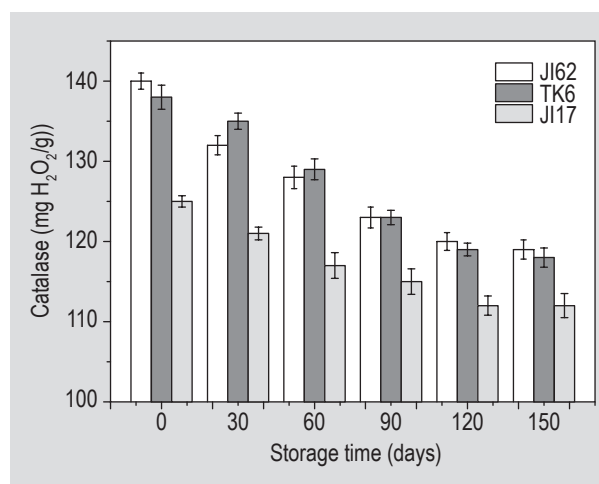


Figure 3. Effect of storage time on catalase activity of wheat grain varieties.

respectively, indicating different enzyme tolerance among wheat cultivars.

Flour quality properties

In Table 3, the flour yield from break and reducing rolls tended to increase with storage time, indicating the milling quality of wheat was improved by after-ripening. The increase in flour yield from break and reducing rolls might be attributed to the variation of wheat structure and characteristics. Compare to post-harvested wheat, a significant increase in break flour yield was observed, and it began to stabilise after 30 days. JI17 and JI62 had a similar trend in reducing flour yield, both of them were significantly higher than that of freshly harvested wheat, but TK6 had a greater increase than others. As for flour whiteness, it seemed that TK6 had a higher degree of whiteness than others, however, there was no obvious difference in flour whiteness during the storage period.

WG provides a quantitative measure of the gluten forming proteins in flour, which is primarily responsible for dough mixing and baking performance. As shown in Figure 4, WG content increased during the storage period. It was generally

stable at the end of 90 days irrespective of wheat variety. JI17 had higher WG content than that of JI62, and both varieties were higher in WG than TK6 after 60 and 90 days. For example, on the 90th day, JI17 had 42.52% WG, while JI62 and TK6 had 34.23 and 31.50% WG, respectively. Similar reports showed that the WG content of wheat generally increased after the third month of storage compared to the point of initial harvest (Karaoglu *et al.*, 2010). Gluten index is used to evaluate gluten strength in wheat. For bread making, the optimum gluten index range is between 60 and 90 days. As indicated in Figure 5, there was a variation in gluten index after 90 days. However, storage time from 90 to 150 days showed an increase of gluten index. In addition, JI17 and TK6 had similar increased gluten index, higher than that of JI62 during storage.

Table 3. Effect of storage time on whiteness, break and reduction flour yield.¹

Wheat type	Storage time (days)	Break flour (%)	Reduction flour (%)	Whiteness
JI17	0	49.63±0.71 ^f	14.73±0.57 ^f	81.42±0.59 ^{cde}
	30	53.09±0.42 ^{cd}	14.04±0.56 ^f	82.09±0.43 ^{cd}
	60	52.94±0.64 ^d	14.48±0.59 ^f	82.21±0.30 ^c
	90	53.24±0.34 ^{bcd}	15.87±0.59 ^e	81.73±0.57 ^{cd}
	120	54.27±0.38 ^{abc}	15.88±0.57 ^e	81.53±0.42 ^{cd}
	150	54.96±0.58 ^a	15.94±0.42 ^e	81.54±0.28 ^{cd}
JI62	0	53.97±0.70 ^{abcd}	14.66±0.56 ^f	79.21±0.29 ^g
	30	54.22±0.31 ^{abc}	13.81±0.30 ^f	80.51±0.42 ^{ef}
	60	54.57±0.57 ^a	14.47±0.57 ^f	81.88±0.42 ^{cd}
	90	53.97±0.42 ^{abcd}	15.92±0.42 ^e	81.12±0.17 ^{de}
	120	54.41±0.42 ^{ab}	15.95±0.42 ^e	80.04±0.42 ^{fg}
	150	54.49±0.46 ^a	16.44±0.56 ^{de}	80.09±0.42 ^{fg}
TK6	0	46.67±0.57 ^g	17.14±0.42 ^d	85.51±0.42 ^a
	30	50.49±0.49 ^{ef}	18.24±0.34 ^c	85.53±0.47 ^a
	60	51.20±0.28 ^e	20.37±0.52 ^b	84.51±0.43 ^b
	90	50.63±0.56 ^{ef}	20.77±0.42 ^{ab}	85.33±0.46 ^{ab}
	120	50.75±0.57 ^{ef}	20.78±0.42 ^{ab}	85.32±0.42 ^{ab}
	150	50.84±0.57 ^e	21.74±0.42 ^a	85.33±0.30 ^{ab}

¹ Values for a particular column followed by different letters differ significantly ($P<0.05$).

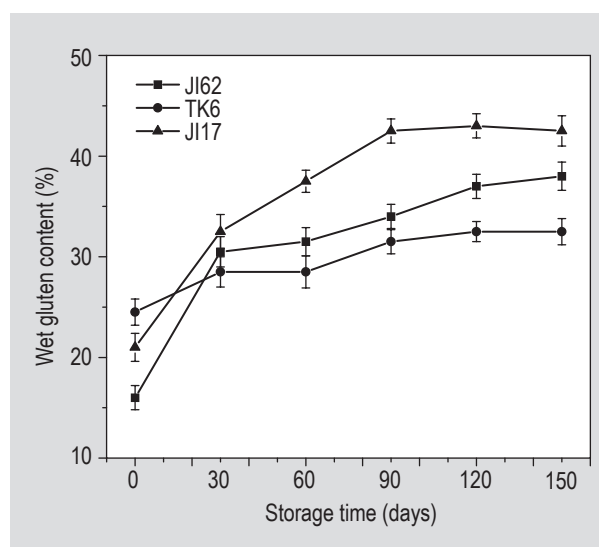


Figure 4. Effect of storage time on wet gluten content of wheat flour varieties.

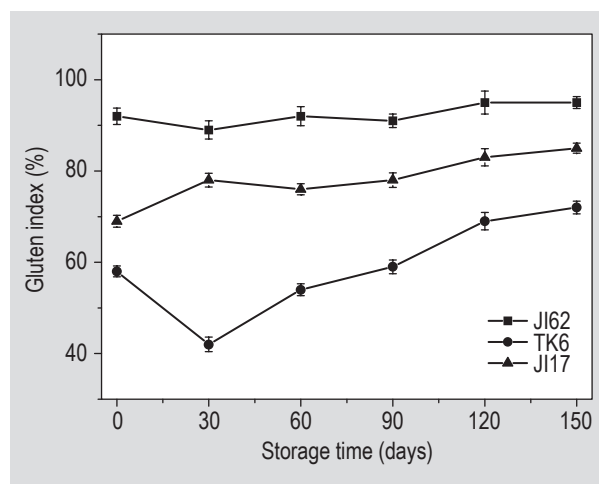


Figure 5. Effect of storage time on wet gluten index of wheat flour varieties.

Pasting properties

The RVA pasting test is generally used to evaluate pasting properties. During the test, starch granules start to swell and absorb water as temperature increases. Meanwhile, starch molecules leach out of the solution, resulting in increase in the viscosity of the suspension. Pasting properties of various wheat starches are summarised in Table 4. The peak viscosity of starch stored for 30 days was significantly higher than that of post-harvest. This is likely because high temperature and humidity in the new harvest wheat induced microorganism activity, leading to protein decomposition and the release of starches, resulting in an increase in peak viscosity. In general, JI62 showed higher peak viscosity than JI17, and both strains were lower than TK6. Attenuation was found to be the lowest for JI17 stored at the 60th day and the highest for TK6 stored at the 30th day. The increase in final viscosity was also observed during storage, probably due to aggregation of the amylose molecules (Miles *et al.*, 1985). The setback of starches showed a sharp increase in the first 30 days, which was stable after 90 days.

4. Conclusions

This study showed that after-ripening had a positive effect on the grain characteristics, flour quality, and pasting properties of wheat. In the first 60 days, RS content in

wheat decreased with increased storage time, whereas the opposite results were observed in the FN and WG content. Amylose content of wheat slightly fluctuated during storage, however, the WG content was stable after 90 days of storage, and RS content, catalase activity and gluten index tended to be stable after 120 days. Three wheat varieties had stable starch content during storage. An increase in storage time led to a decrease in catalase activity, but opposite results were observed in DS content, flour yield and gluten index. JI62 showed lower RS content, gluten index and catalase activity but higher break flour yield. Three varieties showed significant differences in pasting property. In conclusion, this research revealed that the after-ripening improved wheat quality overall, and further investigation will be needed to more fully understand the observed differences in pasting characteristics.

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Table 4. Effect of storage time on pasting property of wheat starch.¹

Wheat type	Storage time (days)	Peak (cp)	Attenuation (cp)	Final viscosity (cp)	Setback (cp)
JI17	0	1,303±11 ^m	650±7 ^j	1,450±14 ⁱ	753±11 ⁱ
	30	2,152±14 ^l	682±10 ⁱ	2,506±14 ^h	1,032±13 ^g
	60	2,201±16 ^k	534±11 ^k	2,518±11 ^h	1,087±10 ^f
	90	2,503±14 ^h	651±8 ^j	2,950±16 ^f	1,300±11 ^b
	120	2,250±11 ^j	652±11 ^j	3,004±10 ^e	1,180±12 ^{de}
	150	2,300±12 ^j	653±7 ^j	3,105±11 ^d	1,202±11 ^{cd}
JI62	0	2,150±14 ^l	459±11 ^l	2,504±13 ^h	1,004±10 ^h
	30	2,600±14 ^f	951±8 ^e	2,801±13 ^g	1,161±14 ^e
	60	2,650±13 ^e	890±12 ^f	3,000±11 ^e	1,284±13 ^b
	90	2,680±14 ^d	880±14 ^f	3,209±12 ^b	1,290±13 ^b
	120	2,600±11 ^f	820±13 ^g	3,003±13 ^e	1,203±11 ^{cd}
	150	2,555±14 ^g	781±16 ^h	2,954±11 ^f	1,103±10 ^f
TK6	0	2,551±14 ^g	1,109±6 ^b	2,505±14 ^h	1,050±11 ^g
	30	2,850±14 ^b	1,150±11 ^a	3,100±14 ^d	1,380±13 ^a
	60	3,000±11 ^a	1,058±14 ^c	3,252±14 ^a	1,304±10 ^b
	90	2,800±16 ^c	1,010±13 ^d	3,104±11 ^d	1,210±13 ^c
	120	2,805±14 ^c	995±10 ^d	3,150±12 ^c	1,221±14 ^c
	150	2,810±14 ^c	1,002±10 ^d	3,154±14 ^c	1,222±13 ^c

¹ Values for a particular column followed by different letters differ significantly ($P<0.05$).

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