Research article

Analysis of the impact of drying on common wheat quality and safety

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ABSTRACT

Mycotoxin contamination in grain has been an ongoing concern in the world. Wheat, as a staple crop in China, is particularly notable for its mycotoxin contamination. The main mycotoxins in wheat include deoxynivalenol (DON) and its derivates, zearalenone (ZEN) and aflatoxin B_1 (AFB$_1$). After harvest, drying process is an effective technique and a necessary step to ensure the long-term safe storage of wheat. In this study, the moisture content, the concentrations of total fungi and main mycotoxins in post-harvest wheat of three wheat growing areas in the North China Plain were examined, and the effect of different drying methods on wheat quality was evaluated. The results showed that 87.5% of wheat samples were simultaneously contaminated with two or more mycotoxins. Due to the pre-harvest heavy rainfall, the moisture content, the levels of total fungi and mycotoxins in wheat samples of Liaocheng city were significantly higher compared to other regions. Moreover, the effects of different drying methods on the starch gelatinization and viscosity properties of wheat were investigated. The results showed that both natural air drying and dryer drying altered the crystal structure within starch particles and affected the gelatinization and viscosity properties of wheat starch. However, there is no significant difference between the wheat samples treated with two drying methods.

1. Introduction

Mycotoxins are secondary metabolites produced by several fungi. The mycotoxins in grains primarily include zearalenone (ZEN), deoxynivalenol (DON), and fumonisins (FBs) produced by some *Fusarium* species, and aflatoxin B_1 (AFB$_1$) produced by some *Aspergillus* species [1–4]. Mycotoxin contamination can occur during the processes of grain harvesting, storage, transportation, and processing [5, 6]. Long-term consumption of food contaminated with mycotoxins can lead to a series of health problems, such as liver and kidney damage, reproductive disorders, immune system damage, and even death [7–9].

The Food and Agriculture Organization of the United Nations (FAO) estimated that approximately 25% of the global food crops were contaminated with mycotoxins each year, leaving approximately 2% of crops inedible due to high contamination levels [10]. In 2020, a global analysis using data of around 500,000 analyses indicated that the detection rate of mycotoxins in all food and feed crops worldwide was up to 60%–80% [11,12]. Many countries and regions have established limits for mycotoxins, including ZEN, AFB$_1$, and DON in grains and their derivatives [13–15]. The European Union (EU) has established a uniform limit of 100 μg/kg for ZEN in

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unprocessed wheat. In China, the maximum allowable level of ZEN and AFB$_1$ in wheat are 60 μg/kg and 5 μg/kg, respectively [16]. The limit for DON in unprocessed wheat in China and United States is 1000 μg/kg, which is lower than the maximum permitted level in EU with 1750 μg/kg in durum wheat and 1250 μg/kg in soft wheat [17].

Wheat is susceptible to fungal diseases, notably by *Fusarium* species. *Fusarium* infection and subsequently mycotoxins production occurs during the flowering and filling stages, the key period of wheat growing. During the two key stages in May 2023, the rainfall in the Northern China Plain including the three primary wheat-producing areas of Henan, Hebei, and Shandong was significantly higher than that in previous years [18,19]. The heavy rainfall provided an ideal environment for fungal infection, proliferation and spread, and mycotoxins production in wheat. Therefore, it is necessary to investigate fungi and mycotoxin contamination in post-harvest wheat in the three areas.

Drying process contributes to extend the shelf life of grain and prevents it from being contaminated with mycotoxins during storage. Meanwhile, several researchers have found that the drying process also contributes to remove mycotoxins from the grains. The reason may be that hot air can blow away some impurities contaminated with mycotoxins on the surface of the grains, or the violent friction between the grain kernels during the drying process can remove the mycotoxins on the surface of the grains [20,21]. In addition, due to differences in processes and parameters, drying can also have several impacts on the physical structure and functional characteristics of grains [22,23]. In this study, the mycotoxin contamination in wheat samples collected from the North China Plain in June 2023 was analyzed. Additionally, the effects of different drying methods on the level of total fungi carried and the concentration of mycotoxin in wheat, as well as the pasting properties and viscosity properties of wheat were studied.

2. Materials and methods

2.1. Chemicals

All reagents used in the analysis were of analytical grade purity. High-performance liquid chromatography (HPLC) grade methanol and acetonitrile were purchased from Fisher Scientific (Fisher Chemicals HPLC, USA). ZEN, AFB$_1$, and DON standards were purchased from Sigma-Aldrich Chemicals (USA). ToxinFast immunoaffinity columns for ZEN, AFB$_1$, and DON were purchased from Huaan Magnech Biotechnology (Beijing, China). ZEN, AFB$_1$, and DON were dissolved in methanol at a concentration of 0.1 mg/mL as a standard stock solution and stored at −20 °C.

Fig. 1. Sampling points from the North China Plain.

2.2. Sample collection and preparation

During the harvest in June 2023, a total of 24 wheat samples were collected from local farmers in 9 different regions of Shandong, Heben, and Henan provinces. The detailed sampling locations are shown in Fig. 1. The sampling procedure was carried out with the methodology reported by Sadhasivam et al. [24].

Three sets of wheat samples were subjected to drying treatment simultaneously. The drying methods include natural air drying for 3 days and drying for 10–12 h using a 5HQX-10 type Air suction circulating grain dryer (Hebei Haokai, Shijiazhuang, China, 10–30 t/d). After drying, at least 10 sub-samples of 100 g were combined according to the Regulation (EC) No 401/2006 [25]. Then, each 200 g wheat sample was grinded into fine power capable of passing through a 29 mm mesh sieve using a DFY-500C High-speed multi-functional pulverizer (Top Calendar, Wenzhou, China). The wheat powder was stored at 4 °C prior to determination.

2.3. Determination of moisture content

The moisture content of wheat samples was determined by automatic analysis, using an Aqualab 4TE (Decagon Devices, Pullman, WA, USA). For each sample, approximately 2 g of wheat was weighed and placed into the measuring instrument.

2.4. Determination of total fungi on wheat samples

The determination of fungi on wheat samples was conducted using a previous methodology outlined by Xing et al. [26] with minor modifications. About 5 g of each sample was randomly separated, shaken in sterile water for 30 min and filtered through sterile filter paper. The filtrate was diluted with PBS buffer to the appropriate concentration. Then, 100 μL of the dilution was spread to a PDA plate and incubated at 28 °C, and monitored daily. The number of total fungi was calculated.

2.5. Determination of mycotoxins in wheat samples

The wheat power samples treated as described in 2.2 were used for mycotoxin determination. The samples were pre-treated according to the extraction methods for the different toxins, as specified in the immunoaffinity column manual (Huaan Magnech, China). Specifically, 25 g of wheat flour was added to 125 mL of 70% methanol solution. The mixture was vibrated in a Vortex for 3 min, followed by the centrifugation at 8000 rpm for 10 min. Five microliters of the supernatant were taken and mixed with 20 mL of distilled water. After mixing, the mixture was passed through an immunoaffinity column targeting different types of mycotoxins, followed by cleaning the immunoaffinity column with 10 mL of distilled water. Finally, 1 mL of methanol was used to elute the mycotoxins, and the eluent was collected for detection.

The three extracted mycotoxins were analyzed by HPLC using a method previously reported by Ayalew [27]. An Agilent 1260 HPLC (California, USA) with a reversed-phase C18 column (4.6 mm × 250 mm, 5 μm) was used for mycotoxins detection. The detection times for ZEN and AFB_1 were 10 min, and for DON was 20 min. The excitation and emission wavelengths for ZEN were 274 nm and 440 nm, AFB_1 were 360 nm and 440 nm, respectively. The detection wavelength of DON was 218 nm. The mobile phases for ZEN, AFB_1, and DON were acetonitrile-water (70:30, v/v), methanol-water (70:30, v/v), and acetonitrile-water (10:90, v/v), respectively.

2.6. Measurement of wheat quality

2.6.1. Differential scanning calorimetry (DSC)
The gelatinization of wheat flour was tested using DSC. The methods of determination were referred to Kiatponglarp et al. [28] with minor adaptations. The 2.5 ± 0.05 mg of starch was weighed and placed into a sterilized stainless-steel pot. Then, the ratio of wheat flour to water in the DSC pan was adjusted to 1:3 (w/v) by adding distilled water. The DSC pans were sealed and left undisturbed overnight before analysis. The analysis was carried out using a heating program from 20 °C to 120 °C at a scanning rate of 5 °C/min.

2.6.2. Rapid visco analyzer (RVA)
The stickiness properties of wheat flour were measured by RVA, following the methods outlined by Balet et al. [29]. Samples for measurement were prepared as homogenates at a concentration of 6% (w/v, on a dry basis). The initial speed was set at 960 rpm with a starting temperature of 50 °C, and maintained for 1 min. Subsequently, the speed was maintained at a constant 160 rpm, while the temperature was gradually raised from 35 °C to 95 °C with a rate of 5 °C/min and then equilibrated at 95 °C for 10 min. Following this, the temperature was slowly reduced to 50 °C at a rate of 5 °C/min and held at this temperature for 10 min.

2.7. Data analysis

Each experiment was replicated at least three times, and the corresponding data were presented as the mean ± standard deviation (SD). Statistical evaluations were conducted with SPSS software (Version 21.0, USA) using analysis of variance (ANOVA) for multiple comparisons followed by the Turkey test. The corresponding graphs were generated using Origin 2023.

3. Results and discussion

3.1. Validation of analytical methods

The quality assurance of the analytical methods is summarized in Table 1. All 3 mycotoxins can be quantified within the linear range from 1 to 500 μg/kg, with the correlation coefficient R^2 above 0.9953. The limits of detection (LOD) and the limit of quantification (LOQ) were within the range of 0.2–5 μg/kg and 1–20 μg/kg, respectively. The LOD and LOQ of this HPLC method were significantly lower than the national limit standards, indicating high analytical sensitivity.

3.2. Moisture content and total fungi in wheat samples

Moisture content is one of the most significant indicators affecting the safety and quality of grain during storage. It is influenced by various complex factors such as grain type, original quality, the initial number of total fungi carried, ambient temperature, and others [30,31]. According to the Technical Operating Procedures for Grain Security Storage of Moisture and Supporting Storage in China, the safe storage moisture content of wheat is set at 12.5%. And, in cases of continuous rainfall or severe weather conditions, the moisture content must not exceed 13.5%. As shown in Table 2, the moisture contents of undried wheat samples were significantly different, ranging from 9.1% to 27.2%. The average moisture content of wheat in the Liaocheng area of Shandong province was the highest, all above 15.9%. While in Henan province, it was relatively low, ranging from 9.1% to 13.2%. The moisture content of wheat in the Handan area of Hebei province was only 9.2%.

Different drying methods had no significant effect on the moisture content of wheat (Table 3). The moisture content of naturally air-dried wheat samples ranged from 9.2% to 10.5%. Although there were significant differences between different groups, their moisture contents were all significantly lower than the standard value of 12.5%. The moisture content of wheat samples dried by dryer ranged from 9.2% to 10.0%, and there was no significant difference among different groups, indicating that dryer drying had a more precise control over wheat moisture.

This study also detected the concentrations of total fungi on wheat samples (Table 2), revealing significant differences in total fungi among wheat samples from different regions. There was no significant correlation between total fungi and moisture content in wheat. However, the number of total fungi on dried wheat was significantly reduced (Table 3). Compared to natural air drying, dryer drying was more effective in reducing the number of total fungi in wheat. Taken together, the highest moisture content was observed in the wheat from Liaocheng area, the highest total fungi was obtained in Xinxiang area. After drying, the moisture content and the count of total fungi were significantly decreased.

3.3. The concentration of mycotoxins in dried and pre-dried wheat samples

Concentrations of ZEN, AFB_1, and DON in wheat from different regions were determined (Table 2). The results showed that the average detection rate of ZEN in wheat was 91.7%, with positive detection rates of 91.6%, 85.7%, and 100% in Hebei, Henan, and Shandong, respectively. The average detection concentration of ZEN was 43.06 μg/kg, with 6 samples exceeding the national limit standard 60 μg/kg in China. The detection rate of AFB_1 was 58.3%, and only several wheat samples were contaminated with low level of AFB_1. The detection rate of DON was 83.3%, and the concentration of DON in 6 samples was significantly higher than the national limit standard 1000 μg/kg in China. In addition, 87.5% of the wheat samples were contaminated with two or more mycotoxins, with 95.2% of wheat being contaminated with both DON and ZEN. In Liaocheng area, the concentration range of ZEN in wheat was 15–90 μg/kg, with an average of 67.6 μg/kg. The average concentration of DON was 2556 μg/kg, which exceeds the national limit standard in China by 2.56 times.

Among the various factors, climate is the key factor influencing the growth of *Fusarium* species and subsequent DON production. In general, higher mycotoxin concentrations in grains are associated with increased rainy days and relative humidity exceeding 75% [32]. Zhao et al. [33] collected and analyzed 181 wheat samples from Northwest China and discovered variations in the level of DON across different regions. DON content in wheat grain positively correlates with local precipitation and air humidity. This implies that higher DON contamination in the wheat may occur in regions experiencing higher rainfall and greater levels of atmospheric moisture. In this study, wheat samples with high level of mycotoxins were collected after rainfall, suggesting a close relationship between the production of these mycotoxins and environmental humidity [34].

Compared to the CK group, the concentrations of ZEN, AFB_1, and DON in natural air dried and dryer dried wheat samples were significantly reduced (Table 3). The fungal contamination occurs from outside to inside of grains, therefore mycotoxins primarily accumulate in the outer layer of grains [35,36]. During the drying process, flipping and blowing, as well as the friction between grains can all remove mycotoxins from the surface of grains. Moreover, hot air also can blow away some impurities and light wheat

Table 1
Validation parameters of applied HPLC method.

Mycotoxins	Limit of Detection (μg/kg)	Limit of Quantification (μg/kg)	Correlation Coefficient (R^2)	Linear Range (μg/kg)	Recovery (%)
ZEN	0.5	2	0.9953	2–200	111.37
AFB_1	0.2	1	0.9987	1–50	102.60
DON	5	20	0.9992	20–500	97.26

Table 2
Moisture content, total fungi and major mycotoxins levels in pre-drying wheat samples.

Sample	City	Moisture content (%)	Total Fungi (cfu/5g)	Mycotoxins		
				ZEN (μg/kg)	AFB$_1$(μg/kg)	DON(μg/kg)
1	Jiaozuo	12.60 ± 0.30^i	840 ± 25^c	2.5 ± 0.2^{no}	0^f	0^l
2		12.60 ± 0.40^i	600 ± 25^d	57.5 ± 3.2^{fg}	5.3 ± 0.5^c	50 ± 3^j
3	Xuchang	13.20 ± 0.40^{hi}	340 ± 20^g	7.5 ± 0.5^{mn}	0^f	25 ± 3^k
4	Pingdingshan	9.10 ± 0.60^l	300 ± 30^{hi}	10.1 ± 2.3^{lm}	0^f	3117 ± 10^a
5	Nanyang	11.20 ± 0.20^j	420 ± 30^f	5.2 ± 1.0^{mno}	5.3 ± 1.0^c	0^l
6	Anyang	12.50 ± 0.40^i	900 ± 20^b	0^o	2.5 ± 0.2^d	0^l
7	Xinxiang	10.80 ± 0.50^{jk}	1250 ± 40^a	5.3 ± 0.5^{mno}	2.5 ± 0.1^d	100 ± 5^{ghi}
8	Handan	9.20 ± 0.30^l	180 ± 25^{kl}	0^o	7.5 ± 0.5^b	0^l
9	Liaocheng	27.20 ± 0.20^a	330 ± 35^{gh}	81.4 ± 5.2^{cd}	0^f	2600 ± 5^b
10		22.50 ± 0.90^b	400 ± 20^f	65.4 ± 3.2^e	0^f	2510 ± 20^d
11		18.00 ± 0.50^d	510 ± 30^e	87.0 ± 5.0^{bc}	2.5 ± 1.0^d	2550 ± 15^c
12		15.90 ± 0.80^e	520 ± 25^e	90.1 ± 10.4^b	0^f	2560 ± 5^c
13		15.90 ± 1.10^e	360 ± 15^g	15.2 ± 2.4^l	2.5 ± 0.1^d	2560 ± 30^c
14	Cangzhou	15.30 ± 0.40^{ef}	120 ± 15^m	40.0 ± 3.1^k	5.2 ± 0.4^c	97 ± 3^{hi}
15		14.60 ± 0.60^{fg}	150 ± 10^{lm}	42.5 ± 3.2^{jk}	10.2 ± 0.5^a	110 ± 3^{fgh}
16		14.00 ± 0.70^{gh}	160 ± 25^l	80.5 ± 0.4^d	0^f	97 ± 3^{hi}
17		19.90 ± 0.40^c	160 ± 25^l	46.1 ± 1.4^{ij}	0^f	95 ± 3^i
18		13.20 ± 0.30^{hi}	150 ± 30^{lm}	42.5 ± 3.2^{jk}	5.0 ± 0.3^c	100 ± 3^{ghi}
19		16.20 ± 0.50^e	150 ± 20^{lm}	45.3 ± 2.1^{ijk}	2.5 ± 0.1^d	112 ± 3^{fg}
20		11.20 ± 0.50^j	250 ± 20^j	50.3 ± 2.0^{hi}	1.0 ± 0.1^e	120 ± 5^f
21		10.00 ± 0.50^{kl}	180 ± 20^{kl}	52.0 ± 2.1^{gh}	2.5 ± 0.2^d	100 ± 10^{ghi}
22		9.70 ± 1.00^l	210 ± 15^k	60.4 ± 5.3^{ef}	0^f	90 ± 4^i
23		10.00 ± 0.40^{kl}	270 ± 20^{ij}	100.3 ± 5.1^a	0^f	150 ± 5^e
24		16.00 ± 1.40^e	270 ± 10^{ij}	50.4 ± 2.0^{hi}	2.5 ± 0.2^d	100 ± 5^{ghi}

Reported values correspond to the mean $\pm$ standard deviation, different letters indicate significant differences between the same column ($p < 0.05$).

Table 3
Moisture level, fungal load and major mycotoxin level in dried wheat samples.

Sample	Moisture content (%)	Total fungi (cfu/5g)	Mycotoxins		
			ZEN (μg/kg)	AFB$_1$(μg/kg)	DON(μg/kg)
CK-1	13.30 ± 0.20^b	150 ± 20^b	42.5 ± 1.2^c	4.2 ± 0.4^a	92 ± 2^b
CK-2	15.30 ± 0.40^a	160 ± 10^b	60.0 ± 2.1^a	6.2 ± 0.4^b	97 ± 3^{ab}
CK-3	15.00 ± 1.40^a	250 ± 10^a	50.4 ± 2.0^b	2.5 ± 0.2^c	100 ± 5^a
Air dry-1	9.20 ± 0.10^d	140 ± 10^{bc}	35.5 ± 1.5^e	0^d	60 ± 5^e
Air dry-2	10.50 ± 1.10^c	120 ± 10^{cd}	27.0 ± 2.5^f	0^d	50 ± 5^f
Air dry-3	9.60 ± 0.30^{cd}	140 ± 15^{bc}	37.2 ± 1.5^{de}	0^d	50 ± 5^f
Dryer dry-1	10.00 ± 0.50^{cd}	100 ± 20^d	20.0 ± 1.5^g	0^d	65 ± 5^{de}
Dryer dry-2	9.30 ± 0.70^d	120 ± 10^{cd}	40.2 ± 2.5^{cd}	0^d	70 ± 3^{cd}
Dryer dry-3	9.20 ± 0.30^d	120 ± 15^{cd}	35.4 ± 5.0^e	0^d	75 ± 3^c

Reported values correspond to the mean $\pm$ standard deviation, different letters indicate significant differences between the same column ($p < 0.05$).

contaminated with high level of mycotoxins, and reduced the mycotoxins contamination. In summary, there was a significant correlation between high moisture content and high mycotoxin concentration, while drying could reduce mycotoxins contamination in wheat.

3.4. Quality of wheat pre- and post-drying treatment

The viscosity parameters and pasting characteristics of wheat starch following air drying and dryer drying treatments were studied, and the results are shown in Fig. 2 and Table 4. The DSC analysis indicated no significant change in the onset temperature (T_o) and peak temperature (T_p) for wheat before and after drying. An increase in the conclusion temperature (T_c) suggested a shift in the thermal degradation or the endpoint of the gelatinization process. The rise in T_c indicated that the starch required a higher temperature to complete the gelatinization process after drying, which could be due to a more stable crystal structure or changes in the interaction between amylose and amylopectin within the starch granules. However, there was no significant difference in the impact of natural air drying and dryer drying on T_c, indicating that the Hebei Haokei 5HQX-10 type air suction circulating grain dryer has a similar effect on wheat gelatinization to natural air drying. Additionally, in actual production and processing, starch regularly undergoes the drying process, which affects its crystal structure and pasting characteristics [37].

Hydrogen bond rearrangement occurs between water and starch molecules during the pasting process. Significant changes in the chemical and physical properties of starch granules can result in the collapse of the molecular sequences within the granules or their destruction. These changes in the properties of starch are irreversible [38,39]. The enthalpy change (ΔH) reflects the energy required
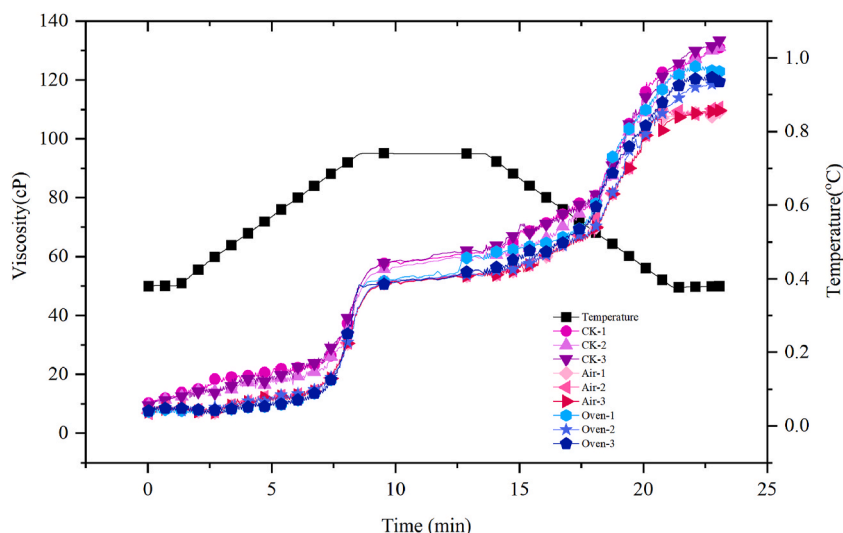
Fig. 2. Viscosity parameters of wheat starch with pre- and post-drying treatment.

Table 4
Pasting characteristics of wheat starch pre- and post-drying treatment.

Samples	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)	PT (°C)	PV (mPa·s)	BV (mPa·s)	SB (mPa·s)
CK-1	59.82 ± 2.91^a	63.89 ± 3.86^a	67.44 ± 3.25^{ab}	-4.43 ± 0.09^e	69.8 ± 0.9^{de}	51.42 ± 1.01^e	1.709 ± 0.04^{ab}	60.29 ± 1.09^d
CK-2	58.23 ± 3.75^a	62.55 ± 2.78^a	66.46 ± 2.96^b	-5.23 ± 0.21^f	64.2 ± 0.6^f	56.89 ± 0.37^c	1.669 ± 0.05^b	70.98 ± 0.98^a
CK-3	59.56 ± 2.40^a	63.05 ± 2.78^a	68.46 ± 1.95^{ab}	-3.98 ± 0.11^d	65.2 ± 0.7^f	55.87 ± 0.92^c	1.735 ± 0.02^a	65.18 ± 1.18^c
Air-1	59.52 ± 1.93^a	62.59 ± 1.56^a	71.94 ± 4.14^a	-2.83 ± 0.19^a	72.8 ± 0.6^{ab}	53.92 ± 0.91^d	1.209 ± 0.04^f	55.29 ± 2.09^e
Air-2	59.65 ± 2.16^a	62.30 ± 2.25^a	72.11 ± 3.81^a	-2.75 ± 0.11^a	73.4 ± 1.2^a	54.30 ± 1.31^d	1.198 ± 0.02^f	54.70 ± 2.11^e
Air-3	58.65 ± 1.26^a	62.10 ± 2.35^a	69.12 ± 2.18^{ab}	-3.57 ± 0.20^c	70.9 ± 0.8^{cd}	56.10 ± 0.39^c	1.318 ± 0.05^e	55.73 ± 1.11^e
Oven-1	58.42 ± 2.95^a	62.20 ± 1.88^a	69.46 ± 1.26^{ab}	-3.23 ± 0.22^b	69.2 ± 0.5^e	59.09 ± 0.57^b	1.465 ± 0.02^c	56.28 ± 0.68^e
Oven-2	58.93 ± 1.84^a	63.06 ± 2.99^a	68.92 ± 4.12^{ab}	-3.34 ± 0.18^{bc}	71.9 ± 1.0^{bc}	63.50 ± 0.83^a	1.369 ± 0.05^{de}	67.77 ± 1.21^b
Oven-3	59.57 ± 1.32^a	62.36 ± 2.15^a	69.83 ± 3.42^{ab}	-3.93 ± 0.21^d	72.5 ± 0.6^{ab}	55.90 ± 0.65^c	1.396 ± 0.02^d	60.37 ± 0.71^d

T_o, onset temperature; T_p, peak temperature; T_c, conclusion temperature; ΔH, enthalpy change; PT, pasting temperature; PV, peak viscosity; BV, breakdown viscosity; SB, setback viscosity. Reported values correspond to the mean ± standard deviation, different letters indicate significant differences between the same column ($p < 0.05$).

for the starch to transition during gelatinization. A decrease in ΔH in the dried samples may imply that the starch has undergone partial gelatinization during the drying process, indicating that less energy is needed for gelatinization during the DSC analysis (Table 4). This could also suggest that the starch granules have lost some of their crystallinity or have become more amorphous after drying. Comparing the ΔH of wheat starch between natural air drying and dryer drying, the results showed significant differences between different groups, but there is no significant pattern, which cannot conclude that natural drying or dryer drying has a greater impact on the ΔH of wheat starch. Junka and Rattanamechaiskul [40] found that the starch underwent gelatinization with a partial disruption of the orderly structure of the starch granules.

In the RVA analysis (Table 4), it was observed that the pasting temperature (PT) of wheat starch increased after drying, especially in the dryer drying group. It indicated that the drying process enhanced the thermal stability, resistance to swelling, and rupture of starch granules [41]. Zhang and Moore [42] found that the significant differences in pasted starch during drying may be related to the reorganization of the crystalline structure of starch granules. The slight reduction in setback (SB) suggested that the drying treatment reduced the tendency of the starch granules to recrystallize during cooling. This reduction could be due to the partial pre-gelatinization of the starch granules caused by drying, thereby reducing intermolecular interactions and consequently diminishing the setback phenomenon. A difference was observed in the gelatinization temperature of wheat starch between the natural air drying group and dryer drying group, but it is not significant. Overall, the drying process affects the gelatinization and viscosity properties of wheat starch. However, there is no significant difference in the effects of relatively mild (natural air) and relatively efficient (dryer) drying methods on the gelatinization and viscosity properties of wheat starch.

4. Conclusions

This research analyzed the moisture content, fungal and mycotoxin contamination of harvest wheat in the North China Plain. Due to the increased rainfall in the early stage of wheat harvest in the Liaocheng area of Shandong province, the moisture content, mycotoxin concentration, and fungal count in harvest wheat were significantly higher than those in other areas. The concentration of

mycotoxins and fungal count in wheat significantly decreased after drying, which may be attributed to the high temperature, friction between wheat, and blowing. The drying process altered the crystal structure within the starch granules, enhancing their thermal stability and impacting the pasting characteristics of wheat starch. However, the drying process is necessary for wheat and other grains before long-term storage. Moreover, there is no significant difference between the effects of natural air drying and dryer drying on the gelatinization and viscosity characteristics of wheat starch.

CRediT authorship contribution statement

Yuanyuan Tian: Methodology. **Xiaoyu Tian:** Methodology, Conceptualization. **Bolei Yang:** Methodology. **Junning Ma:** Writing – review & editing. **Jihao Shan:** Conceptualization. **Fuguo Xing:** Conceptualization.

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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