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Research Article

Study on the Dehydration Characteristics of Spring Maize after Physiological Maturity and the Suitable Period of Mechanical Grain Harvest

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The high moisture content of seeds during harvesting results in a large amount of grain that breaks during mechanical harvesting, which becomes a key problem that hampers the promotion of mechanical grain harvesting technology. Maize in southern Xinjiang physiologically matures from early September to early October. In this study, 52 varieties of maize at different maturity stages were studied in 2019-2020 and were categorized in the order of physiological maturity time: early September (PD1), mid-September (PD2), late September (PD3), and early October (PD4). The goal of this study was to analyze the differences in content of kernel moisture at physiological maturity and the rate of dehydration after physiological maturity of varieties at different stages of maturity, so as to determine the suitable period for mechanical grain harvesting of maize at different stages of maturity. The results showed that the content of seed moisture at different maturity stages varied in a two-stage linear model, with periods of fast and slow dehydration. An analysis of variance (ANOVA) showed that the content of seed moisture at different stages of physiological maturity did not differ significantly ($P > 0.05$).

1. Introduction

As an important food and cash crop in China, maize occupies an important position in the structure of agricultural planting industry. Since Xinjiang is a highly suitable region for the mechanical grain harvesting of maize in China, this harvesting technology is being promoted in a large area in this region. Therefore, it is important to study the characteristics of seed dehydration of different maize varieties after maturity in this region to comprehensively promote the promotion and demonstrate the mechanical grain harvesting technology [1, 2].

The content of seed moisture during mechanical harvest is a key factor that affects the quality, safe storage, and economic efficiency of the maize mechanical grain harvest [3, 4]. The average content of seed moisture during the current Chinese corn harvest is 26.83% [5], which fails to meet the seed moisture content requirement for mechanical grain harvest. In other countries, the seed moisture content during the period of mechanical grain harvesting is typically 15%-25% [6, 7], and the peak of harvest is one month later than the peak of physiological maturity, with conditions for drying in the field on a standing pole [8]. The content of seed moisture at harvest is influenced by the moisture content at physiological maturity and the rate of seed dehydration after maturity. Therefore, the selection of varieties with seeds that quickly dehydrate, have a low content of seed moisture at physiological maturity, and can be harvested at the appropriate grain harvesting period is the key to solving the problem of obtaining high quality grain from mechanical harvesting [9]. According to the local climatic conditions, high quality mechanical grain harvesting can be achieved

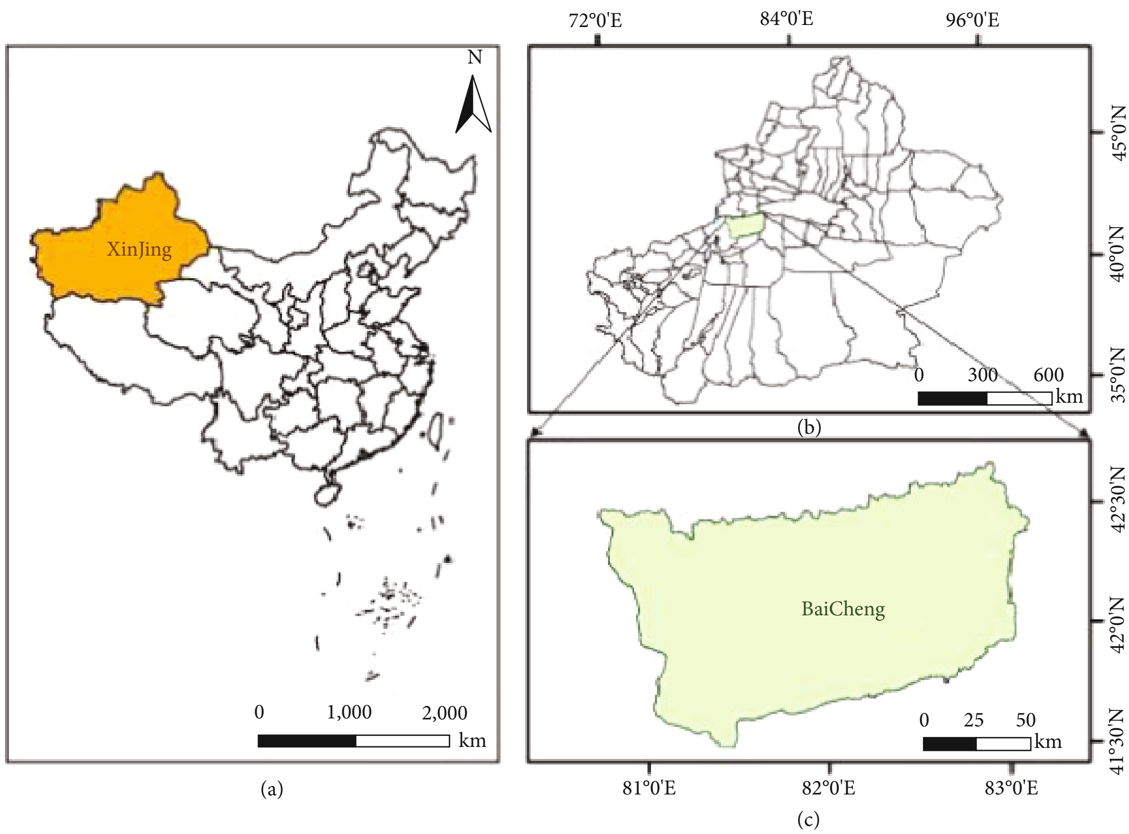


Figure 1: Xinjiang, located in northwest China (a), is characterized by a desert climate (b). The study site belongs to an extremely arid region in east Xinjiang (c).

by drying the maize in the field at the right time and ceasing irrigation to meet the moisture content requirements for harvesting grain. In this study, we studied the dynamic changes in content of seed moisture after the physiological maturity of several varieties that differed in the time they took to mature, analyzed the rate of dehydration after the physiological maturity of maize and the suitable period for grain harvesting, and provided a basis for the promotion of mechanical grain harvesting technology.

2. Materials and Methods

2.1. Experimental Site. The experimental site is located in Baicheng County, Xinjiang, (Figure 1) which has a temperate continental arid climate with cold winters and cool summers, an average annual temperature of 7.8°C, an extreme maximum temperature of 38.3°C, an extreme minimum temperature of -28°C, a frost-free period of 163 days, an average annual sunshine factor of 2,780.1 hours, including 1,564.3 hours of sunshine from April to September, an average annual temperature of 7.6°C, and an average annual precipitation of 94 mm. The maximum depth of permafrost is 0.80 meters (Figure 2).

2.2. Experimental Design. The trial was conducted from 2019 to 2020 at the Agricultural Experiment Station in Baicheng County, Xinjiang, with 52 varieties/sowing periods as test materials, including B1-B4 for four sowing periods of KX9384. In 2019 and 2020, the seeds were sown on April 14 and April 22, respectively, and each variety was planted on an area of 1,000 m^2 with drip irrigation under a film and then planted in wide and narrow rows of 40 cm + 70 cm, respectively. The planting density was 135,000 plants/hm^2 and managed according to dense and high-yield cultivation. The local maize physiologically matured from early September to early October, and to enhance the ability of studying the rate of seed dehydration after the physiological maturity of varieties at different maturity stages, these stages were categorized as early September (September 1 to 9), mid-September (September 10-19), late September (September 19 to 29), and early October (October 1-10) and were designated PD1, PD2, PD3, and PD4 (Table 1), respectively. The maize varieties at different physiological maturity period are shown in Table 1, and the distribution of seed moisture contents of different maize varieties at physiological maturity and machine harvest is shown in Figure 3.

2.3. Determination of Seed Moisture Content. In 2019 and 2020, the content of seed moisture was measured by sampling every 5-7 d from July 14 to August 1, respectively. Once the crop neared physiological maturity, it was sampled once every 2-3 d and then every five days after the physiological maturity was determined until harvest on October 8,

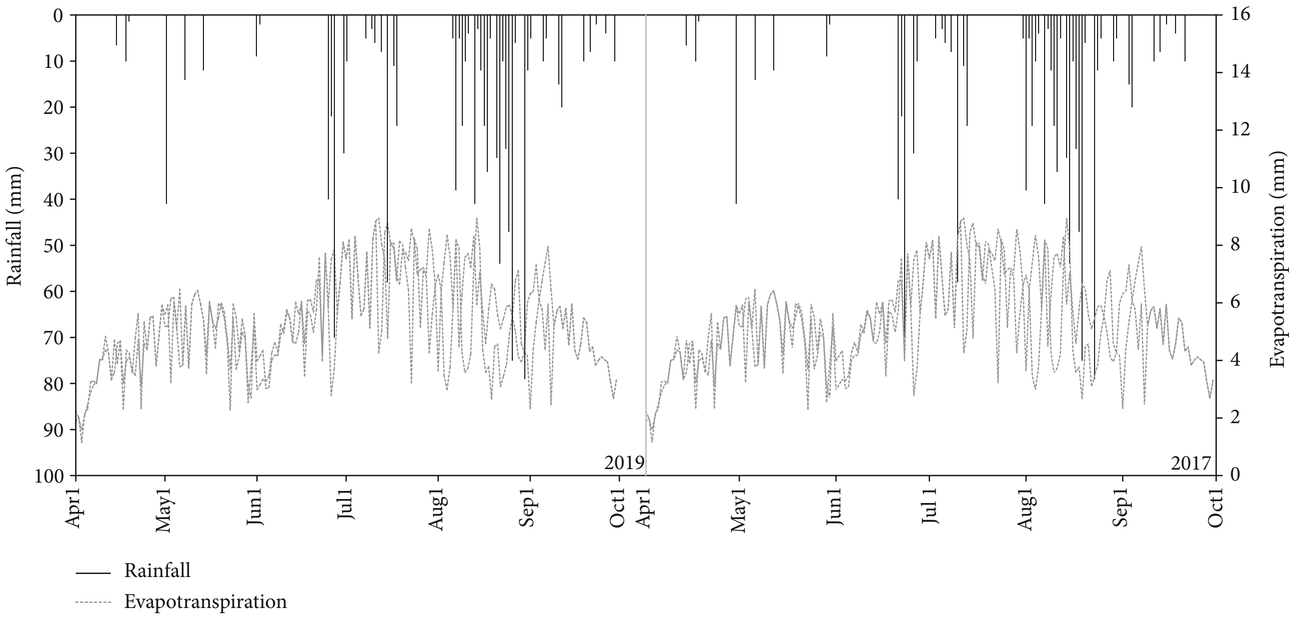


Figure 2: Statistics on temperature and rainfall in the maize growing season in the experimental area.

Table 1: The cultivars of different physiological maturity periods.

Physiological maturity period	Number of cultivars	Cultivars
PD1	2	XY27, XY65
PD2	12	DH113, KWS3376, KX9384, YY137, FK139, JH150, NH213, XY69, DH1786, JX58, B1, B2
PD3	23	DH117, DH119, KX3564, XY335, DH1733, YY119, YY274, YY439, JK968, LC808, NY524, NY525, SD628, SD636, XY32, ZN777, ZD958, NH205, ZJ323, YY369, YD9953, BD309, B3
PD4	15	KX3564, M751, MC670, AD268, DH318, LD295, LD575, LD586, NH213, ZY501, ZY8911, ZY1317, ZD309, ZD1002, B4

2019 and delayed until November 25 in 2020. Three ears of each variety were sampled each time from neatly growing plants in 2019, and five ears were sampled in 2020. After sampling, the ears were placed in self-sealing bags and immediately brought back to the laboratory, threshed manually, and the middle grains of the selected ears were placed in an oven after their fresh weight was determined, killed at 105°C for 30 min, and then baked at 80°C until they reached a constant weight. At this point, they were removed from the oven, and their dry weight was determined. The moisture content of the seeds was calculated by the following formula: $\text{moisture content}\ (\%) = (\text{fresh weight} - \text{dry weight})/\text{fresh weight} \times 100\%$.

2.4. Construction of the Seed Dehydration Segmentation Model. The dewatering process was divided into rapid and slow dewatering periods based on the trend of moisture content of the maize kernels, and the segmentation model expressed the following formula:

$$y1 = a + b \times (x - \text{joint}) \text{ and } y2 = a + c \times (x - \text{joint}), \quad (1)$$

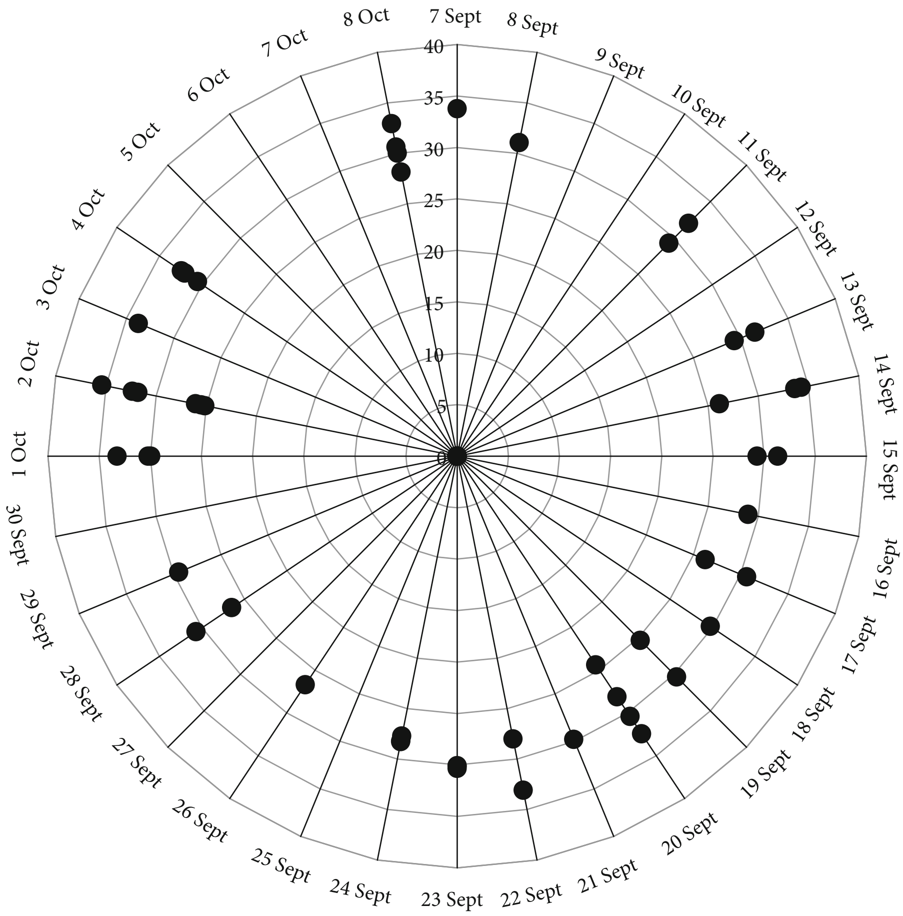
where $y1$ and $y2$ are the moisture contents of seeds during the fast and slow dehydration phases, respectively; x is the number of days after physiological maturity; and b is the slope of the fast moisture decline phase, and its value can be regarded as the average daily dehydration rate in the fast dehydration phase. c is the slope of the slow moisture decline phase of seeds and can be regarded as the average daily dehydration rate in the slow dehydration decline phase.

This study refers to the fitting analysis of segmented regression model by Zhang et al. [10] expressed as $(\text{date} \le \text{joint}) \times (a + b \times [\text{date} - \text{joint}]) + (\text{date} > \text{joint}) \times (a + c \times [\text{date} - \text{joint}])$.

2.5. Statistical Analysis. The data were calculated and plotted using Microsoft Excel 2019, and the segmented simulations of changes in the content of maize were performed using SPSS 23.0 (IBM, Inc., Armonk, NY, USA), and the statistical analysis of the data was performed.

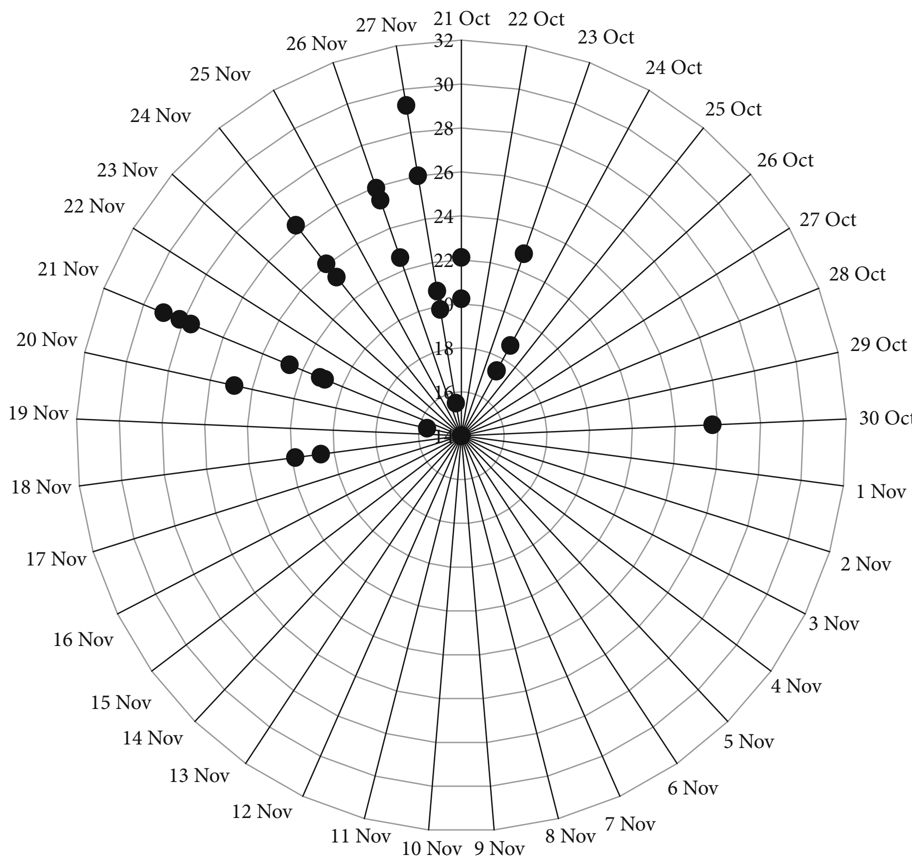
3. Results and Analysis

3.1. Statistics of the Content of Seed Moisture of the Physiological Maturity Period. A statistical analysis of 52



(a)

Figure 3: Continued.



(b)

Figure 3: The distribution of seed moisture content: percentage of maize at physiological maturity (a) and harvest (b).

maize varieties that matured physiologically from September 8 to October 4 during the two year-period showed that the mean value of seed water content at physiological maturity was 30%, with a range of distribution of 29.2% (PD3)-32.5% (PD1) and minimum and maximum values of 24.4% and 35.4%, respectively, where the overall coefficient of variation of varieties was 1.2 (Table 2). An analysis of variance (ANOVA) showed that there was no significant difference ($P = 0.05$) in the content of seed water at different stages of physiological maturity (Table 3).

3.2. Variation in the Content of Seed Moisture after the Maize Reached Physiological Maturity. The content of seed moisture of maize tended to decrease after physiological maturity in two linear patterns, i.e., the rapid dehydration period and the slow dehydration period. The results of the segmented fitting of the trend of seed moisture content of varieties at different maturity stages (PD1-PD4) are shown in Figure 4.

The PD1 segmented fit model is given by

$$\begin{aligned} &x \le 8.261, y = 32.882 - 0.85x, \\ &x > 8.261, y = 29.999 - 0.501x\left(R^2 = 0.761\right). \end{aligned} \tag{2}$$

Table 2: Description of the content of moisture in the seeds during the physiological maturity period.

Physiological maturity period	Moisture content of PM (M ± S)	Minimum value	Maximum value	Coefficient of variation
PD1	32.5 ± 1.9	31.1	33.8	4.2
PD2	30.2 ± 2.5	26.1	34.3	2.4
PD3	29.2 ± 2.5	24.4	35.4	1.8
PD4	30.7 ± 2.6	25.1	33.7	2.2
PD1-PD4	30 ± 2.6	24.4	35.4	1.2

Table 3: ANOVA of seed moisture content in different periods of physiological maturity.

Source of variation	Sum of square	Degree of freedom	Mean square	*F* -value	Significant *P* value
Intergroup	35.906	3	11.969	1.829	0.154
In-group	314.088	48	6.544		
Total	349.994	51			

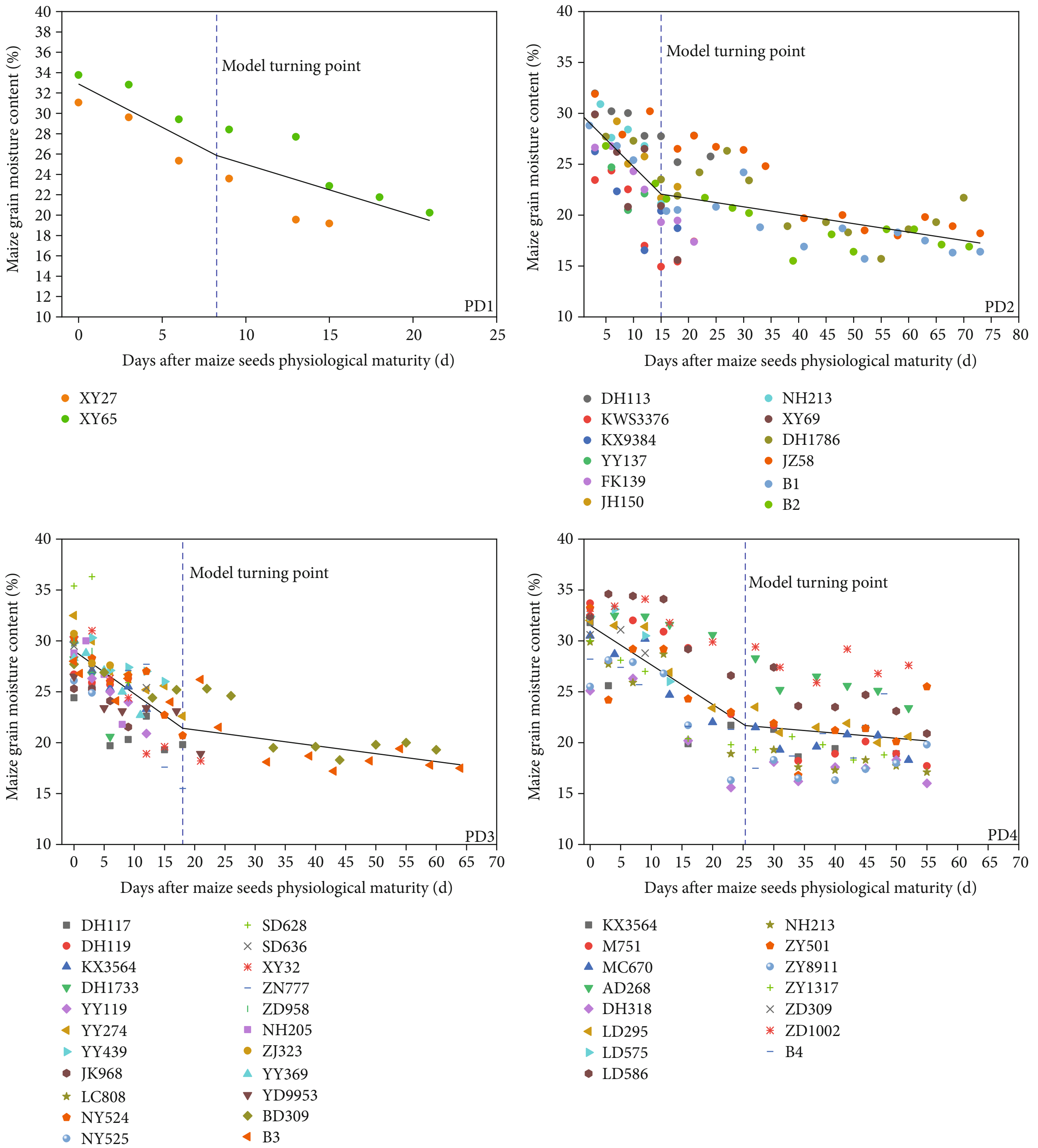


Figure 4: Segmental fitting of grain moisture content in different maturity stages.

The PD2 segmented fit model is given by

$$x \leq 15, y = 30.193 - 0.538x,$$
$$x > 15, y = 23.314 - 0.083x \left(R^2 = 0.614\right). \quad (3)$$

The PD3 segmented fit model is given by

$$x \leq 18, y = 29.029 - 0.423x,$$
$$x > 18, y = 22.819 - 0.078x \left(R^2 = 0.587\right). \quad (4)$$

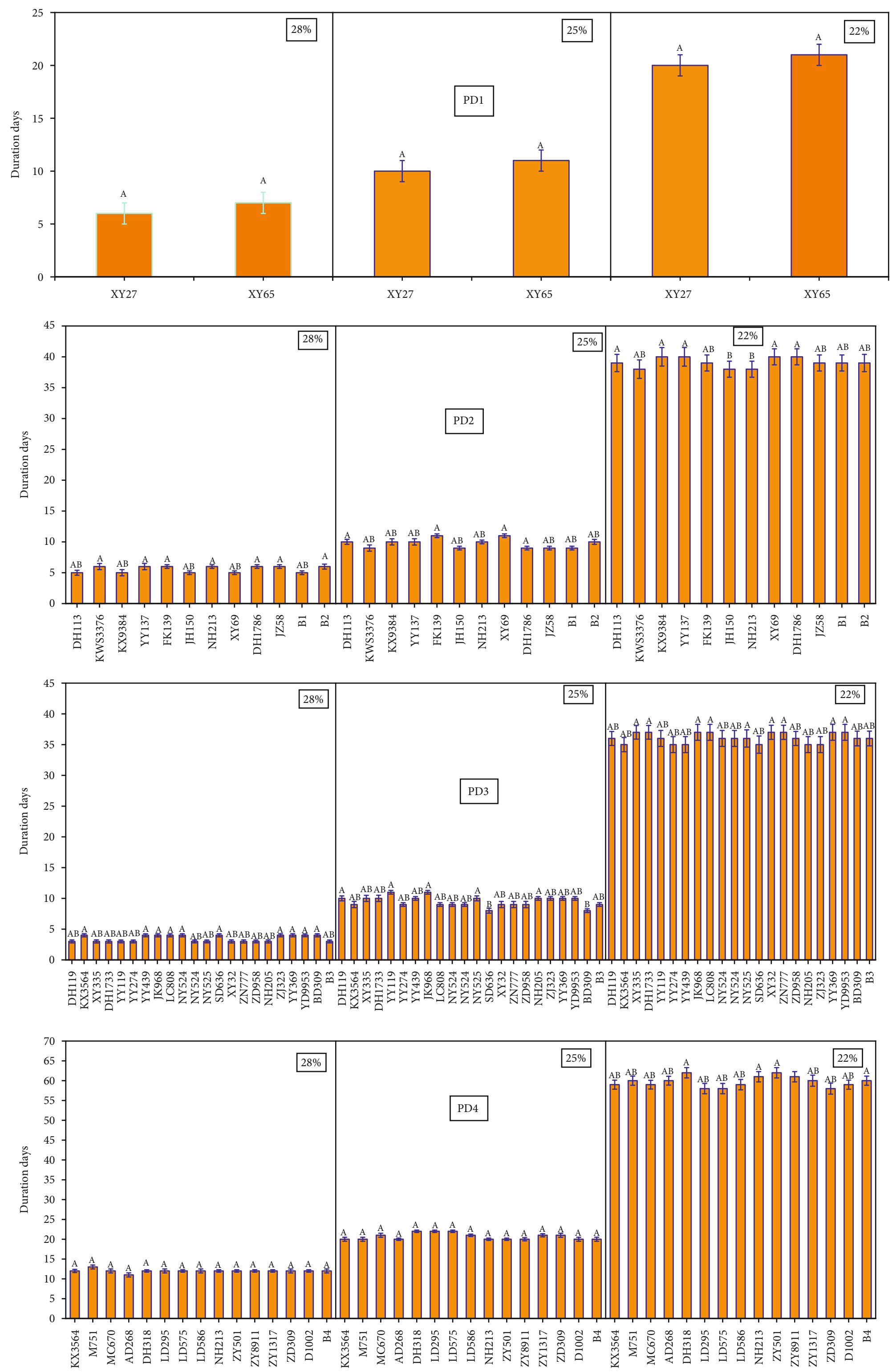


Figure 5: Variation rule of the days required for the water content of varieties to decrease to 28%, 25%, and 20% in different physiological maturation periods.

The PD4 segmented fit model is given by

$$x \leq 25.358, y = 31.530 - 0.388x,$$
$$x > 25.358, y = 22.985 - 0.051x \left(R^2 = 0.585\right). \quad (5)$$

It is apparent that the content of moisture of maize seeds at maturity from PD1 to PD4 can be clearly divided into two stages: a rapid and a slow decline, in which the rapid decline stage lasted 8.261 d, 15 d, 18 d, and 25.358 d, respectively. The content of moisture of the seeds decreased from

32.882% to 25.86%, 30.139% to 22.069%, 29.029% to 21.415%, and 31.531% to 21.692%, respectively. The average daily dewatering rates reached 0.85%, 0.538%, 0.423%, and 0.388%, respectively. The average daily dewatering rates were 0.501%, 0.083%, 0.078%, and 0.051%, respectively. This showed that the rate of seed dehydration decreased with the delay in maturity during both stages of dehydration.

3.3. Prediction of the Number of Days Elapsed for Different Physiological Maturation Time Periods owing to the Drop in Target Moisture Content. The graph shown in Figure 5 describes the variation in the number of days required to reduce the seed moisture content to 28%, 25%, and 20% for different time periods of physiological maturity of varieties that has been analyzed with a two-stage linear model. It is apparent that there is no significant difference between PD1, PD3, and PD4 in terms of the number of days required to reach the target moisture content at the physiological maturity time. There was no significant difference between PD2 and other varieties in terms of the number of days required to reach the target moisture content of 28% and 25% at the time of physiological maturity, and there was a significant difference between FD 139 and JH 150 and the other varieties in terms of the number of days required to reach the target moisture content of 22% ($P < 0.05$). However, there was no significant difference between the other varieties.

It is also apparent that the seed water content of the 52 varieties tended to decrease overall after physiological maturity, and the number of days required to reduce the moisture content of seed water to 28% after physiological maturity was greater in PD1 than in PD2 and PD3 for PD1 to PD4 mature varieties, which is related to the fact that the seed water content of PD1 mature varieties (32.5%) is higher than that of PD2 (30.2%) and PD3 (29.2%), indicating that the content of moisture in the seeds during physiological maturity is the cause of the rate of dehydration, but the PD1-PD3 stage is smaller than that of the PD4 stage, indicating that the rate of seed dehydration slows later in the maturity stage. The number of days required to reduce the content of moisture in the seeds to 25% after physiological maturity at the PD1 to PD3 stages is equal, but smaller than that of the PD4 stage, indicating that physiological maturity moisture content and the rate of dehydration are the causes of changes in the content of seed moisture at harvest. The number of days required to reduce the moisture content of seeds to 20% increased sequentially from PD1 to PD4, and the distribution of the number of days required was 20 d to 59 d.

The physiological maturity of varieties, such as XY 27 and XY65, during PD1 reached 28%, 25%, and 22% of the average number of days in 6, 10, and 20 days, respectively, with a span of 14 days. At PD2 maturity, DH113, KWS3376, KX9384, YY137, FK 139, and the other varieties of maize reached 28%, 25%, and 22% of the average number of days to decrease to 22% of the seed moisture content. The average number of days was 5, 10, and 40, respectively, with a span of 25 days. The PD2 maturity section DH117, DH119, KX3564, XY335, DH1733, YY119, YY274, YY439, JK968, and other corn varieties had a seed moisture content that reached as low as 28%, 25%, and 22% on calendar days of 3, 10, and 37 days, respectively, with a span of 33 days. The PD4 maturity section of the maize varieties KX3564, M751, MC670, AD268, DH 318, LD 295,LD 575, LD 586, and others reached contents of seed moisture of 28%, 25%, and 22% at days of 12, 20, and 59 days over a time span of 47 days.

Table 4: Fitting equations for maize seed dehydration characteristics and meteorological factors.

Physiological maturity period	Fitting equation	R^2
PD1	$y = 0.378X1 + 5.557X2 - 4.944X3 + 2.97$	0.49^*
PD2	$y = 0.528X1 + 4.127X2 - 3.156X3 + 4.23$	0.39^*
PD3	$y = 0.452X1 + 7.391X2 - 5.439X3 + 7.12$	0.41^*
PD4	$y = 0.511X1 + 5.193X2 - 6.126X3 + 5.97$	0.40^*

Note: y: maize seed moisture content; X1: average temperature; X2: average wind speed; X3: evaporation. $^*P < 005$.

3.4. A Correlation Analysis between Seed Dehydration Characteristics and Meteorological Factors at Different Time Periods of Physiological Maturity. In this study, the correlations between three meteorological indicators, including rainfall, temperature, and evapotranspiration, and the characteristics of seed dehydration were analyzed based on meteorological factors as shown in Table 4. Among them, the fitted coefficient of the determination of dehydration rate of maize kernels in PD2, PD3, and PD4 relative to the later maturity period was relatively low, but all the fitted equations indicated significant differences ($P < 0.05$). Thus, the fitted equations can indicate that the moisture content of maize seeds correlates with the average temperature, average wind speed, and evapotranspiration to some extent, but further research is needed owing to the low interannual span of meteorological data monitored in this study.

4. Discussion

The content of seed moisture is a key indicator that determines the mechanical grain harvesting period, and a suitable moisture content during the harvesting period ensures high harvest quality and efficiency. The content of seed moisture varies significantly among varieties at physiological maturity, which is primarily influenced by the combination of genetic characteristics of varieties, cultivation practices, and environmental and meteorological conditions [10, 11]. In comparison with the meteorological conditions during the same period of the calendar year in the project area for maize maturity (September and October) in 2019-2020, the temperature during the two years of harvest in the experimental period did not differ significantly from the normal year and could represent the meteorological conditions of the calendar year. On this basis, the variability of seed water content at different maturity stages was analyzed, and the results showed that there was no significant difference in the content of seed water at different maturity stages. The

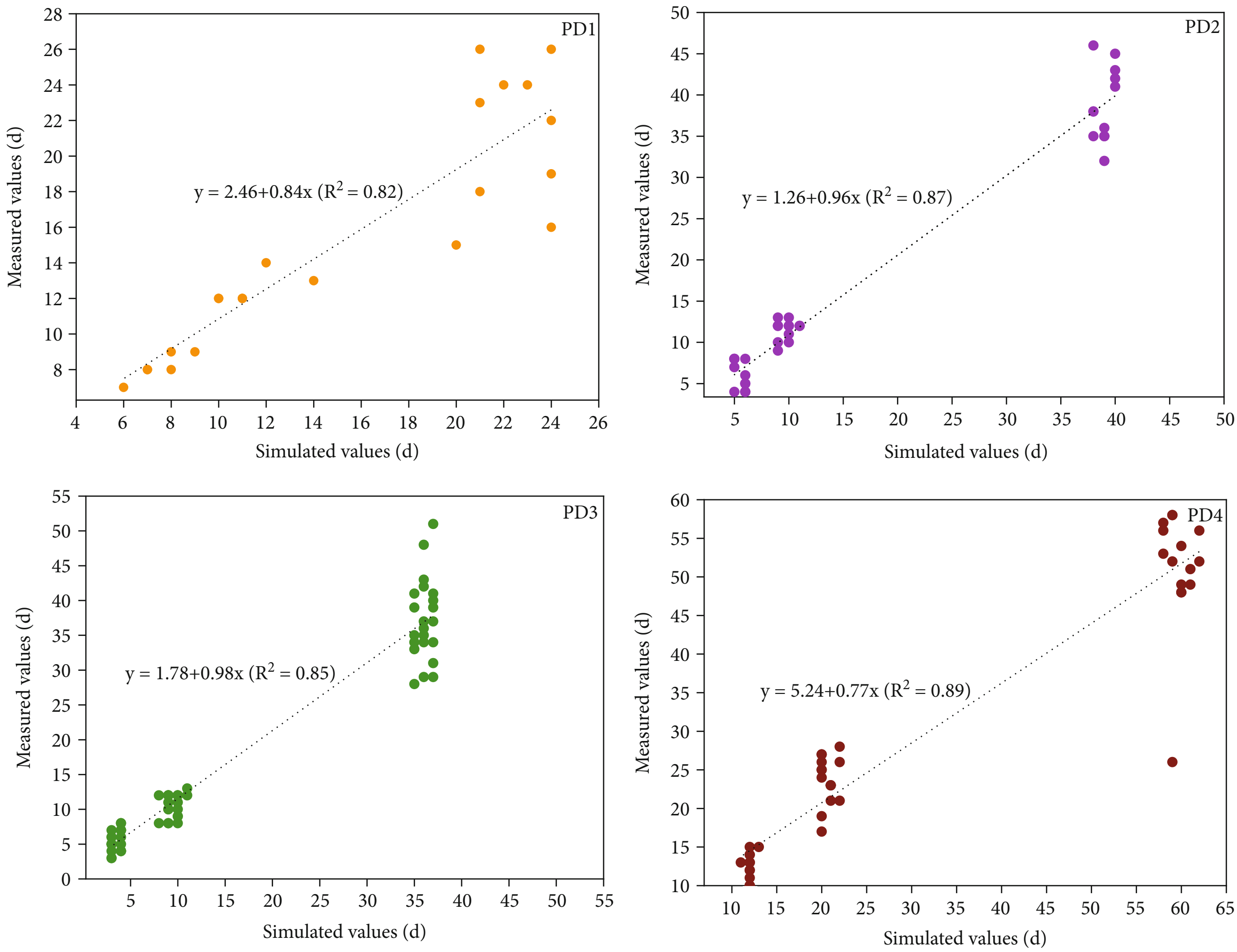


Figure 6: Correlation analysis between simulated and measured values of the number of days elapsed for different physiological maturation periods down to the target moisture content.

mean value was 30%, indicating that there were differences between varieties in the seed water content at physiological maturity and no significant differences at different maturity stages.

The content of seed moisture content tends to decrease around physiological maturity, and a study by Nielsen of Purdue University [12] concluded that the content of seed moisture changes in a linear pattern from approximately 40% to 15% or 20% stage in a field environment, particularly in two linear patterns. The rate of seed dehydration was approximately 0.8 percentage points per day in late August and approximately 0.4 percentage points per day near maturity in mid to late September. Researchers who conducted related studies [13, 14] collected data on the seed moisture content of varieties at four planting dates in the project area, and the analyses showed that the average rate of dewatering throughout the dewatering and drying period was 0.58% per day; however, the rate was not constant, with dewatering proceeding at a rate of 0.69% per day for the first 20 days and then decreasing to 0.44% per day for the next 20 days [15, 16]. This study analyzed the rate of dehydration after physiological maturity in a two-stage linear model at most stages of maturity and again showed a rate of dehydration of 0.85%/d -0.388%/d from early September to early October. These results were consistent with those tested above, and the rate of dehydration from mid-October to early November was from 0.078%/d to 0.051%/d, with a gradual decrease or almost no increase in the water loss from dehydration. PD1-PD4 showed an increasing trend in the number of days required to reduce the moisture content of the seeds to 20% in sequence, with the distribution of days required ranging from 20 d to 59 d. The higher moisture content at harvest not only reduces the quality of the harvest but also increases the cost of postharvest drying, resulting in higher production costs for the growers [17, 18]. Therefore, standing pole drying and selecting the appropriate mechanical grain harvesting period based on the dehydration rate at different maturity stages can reduce the cost to growers and help them to choose timely mechanical grain harvesting times [19, 20].

The correlation analysis between the simulated and measured values of the number of days that elapsed for different physiological maturation time periods down to the target moisture content is shown in Figure 6. The mathematical model developed for the number of calendar days after the maturity of heavy maize was validated by fitting the measured data values of this experiment with the predicted values. It can be seen that the R^2 of maize varieties with different maturity stages of PD1-PD4 is > 0.7, thus, indicating that the mathematical model established in this study can be used as a model for the analysis of seed dehydration characteristics after physiological maturity in Xinjiang.

5. Conclusions

The analysis of the dehydration characteristics of the 52 spring maize varieties after physiological maturity showed that the overall seed moisture content of the 52 varieties after physiological maturity tended to decrease, and the changes in seed moisture content at different maturity stages were in a two-stage linear model, i.e., a rapid dehydration period and a slow one. The differences in content of seed moisture at different physiological maturity stages were not significant.

Through the analysis of two linear models, PD1-PD4 tended to increase. The content of seed moisture during the PD1 maturity period reached 28%, 25%, and 22%, which took 6, 10, and 20 days, respectively, with a span of 14 days. The average number of days to 28%, 25%, and 22% in the PD2 maturity period was 5, 10, and 40 days, respectively, with a span of 25 days. The number of days to 28%, 25%, and 22% of the kernel water content of maize varieties in the PD2 maturity stage was 3, 10, and 37 days, respectively, with a span of 33 days. The number of days to 28%, 25%, and 22% of the kernel water content of maize varieties in the PD4 maturity stage was 12, 20, and 59 days, respectively, with a span of 47 days, and the distribution of the number of days required was 14 d–47 d.

Data Availability

The dataset used in this paper are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding this work.

Acknowledgments

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References

[1] S. A. Ajayi, G. Rühl, and J. M. Greef, "Impact of mechanical damage to hybrid maize seed from harvesting and conditioning," *Seed Technology*, vol. 28, no. 1, pp. 7–21, 2006.

[2] Y. Liu, L. Zhang, X. Yin, X. Zou, and F. Chen, "Influence of climate change and mechanized harvesting on maize (Zea mays L.) planting and northern limits in northeast China," *Journal of the Science of Food and Agriculture*, vol. 101, no. 9, pp. 3889–3897, 2021.

[3] E. Pannacci and F. Tei, "Effects of mechanical and chemical methods on weed control, weed seed rain and crop yield in maize, sunflower and soyabean," *Crop Protection*, vol. 64, pp. 51–59, 2014.

[4] P. Varga, T. Berzy, A. Anda, and K. Ertsey, "Relationship between seed harvesting method and seed physiological quality for a number of Pioneer maize hybrids," *Maydica*, vol. 57, no. 3, pp. 220–225, 2012.

[5] Z. Chai, K. Wang, Y. Guo et al., "Current status of maize mechanical grain harvesting and its relationship with grain moisture content," *Scientia Agricultura Sinica*, vol. 50, no. 11, pp. 2036–2043, 2017.

[6] Y. Su, T. Cui, G. Xia et al., "Effects of different moisture content and varieties on physico–mechanical properties of maize kernel and pedicel," *Journal of Food Process Engineering*, vol. 44, no. 9, article e13778, 2021.

[7] Y. Wang, L. Li, S. Gao et al., "Evaluation of grain breakage sensitivity of maize varieties mechanically-harvested by combine harvester," *International Journal of Agricultural and Biological Engineering*, vol. 13, no. 5, pp. 8–16, 2020.

[8] S. Li, L. Ren, T. Liu, Y. Zhang, and M. Zhang, "Suitable sunshine and temperature for mechanical grain harvesting of summer maize in the Huang-Huai-Hai Plain," *Zhongguo Shengtai Nongye Xuebao/Chinese journal of eco-agriculture*, vol. 26, no. 8, pp. 1149–1158, 2018.

[9] C. Shen, B. Zhang, J. Huang et al., "Research status and suggestions of mechanical harvesting technology for high-stalk bast-fiber crops," *International Agricultural Engineering Journal*, vol. 29, no. 2, pp. 269–284, 2020.

[10] G. Zhang, C. Liu, C. Xiao et al., "Optimizing water use efficiency and economic return of super high yield spring maize under drip irrigation and plastic mulching in arid areas of China," *Field Crops Research*, vol. 211, pp. 137–146, 2017.

[11] F. Jiang-peng, H. Zheng, J. Biao, L. Zhi, L. Zhen-zhou, and L. Hui-fang, "Effect of integrated fertilization level of water and fertilizer on maize grain filling and dehydration process," *Chinese Journal of Agrometeorology*, vol. 40, no. 12, p. 772, 2019.

[12] R. Nielsen, *Field Drydown of Mature Corn Grain*, Purdue University, West Lafayette, 2011.

[13] L. Li, K. Wang, R. Xie et al., "Corn kernel weight and moisture content after physiological maturity in field," *Scientia Agricultura Sinica*, vol. 50, no. 11, pp. 2052–2060, 2017.

[14] W. Lv, M. Zhang, Y. Wang, and B. Adhikari, "Online measurement of moisture content, moisture distribution, and state of water in corn kernels during microwave vacuum drying using novel smart NMR/MRI detection system," *Drying Technology*, vol. 36, no. 13, pp. 1592–1602, 2018.

[15] L. Hou, K. Wang, Y. Wang et al., "In-field harvest loss of mechanically-harvested maize grain and affecting factors in China," *International Journal of Agricultural and Biological Engineering*, vol. 14, no. 1, pp. 29–37, 2021.

[16] H. Li, Y. Wang, J. Xue et al., "Allocation of maize varieties according to temperature for use in mechanical kernel harvesting in Ningxia, China," *International Journal of Agricultural and Biological Engineering*, vol. 14, no. 1, pp. 20–28, 2021.

[17] R. L. Gu, R. Huang, G. Y. Jia et al., "Effect of mechanical threshing on damage and vigor of maize seed threshed at different moisture contents," *Journal of Integrative Agriculture*, vol. 18, no. 7, pp. 1571–1578, 2019.

[18] Y. Zhang, Y. Hu, Z. Guan et al., “Combined linkage mapping and association analysis reveals genetic control of maize kernel moisture content,” *Physiologia Plantarum*, vol. 170, no. 4, pp. 508–518, 2020.

[19] Z. Huang, J. Xue, B. Ming et al., “Analysis of factors affecting the impurity rate of mechanically-harvested maize grain in China,” *International Journal of Agricultural and Biological Engineering*, vol. 13, no. 5, pp. 17–22, 2020.

[20] Z. Zhang, B. Ming, H. Liang et al., “Evaluation of maize varieties for mechanical grain harvesting in mid-latitude region, China,” *Agronomy Journal*, vol. 113, no. 2, pp. 1766–1775, 2021.