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The variability of maize kernel drying: sowing date, harvest scenario and year

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Abstract

The extent of the reduction of maize (*Zea mays* L.) kernel moisture content through drying is closely related to field temperature (or accumulated temperature; AT) following maturation. In 2017 and 2018, we selected eight maize hybrids that are widely planted in Northeastern China to construct kernel drying prediction models for each hybrid based on kernel drying dynamics. In the traditional harvest scenario using the optimal sowing date (OSD), maize kernels underwent drying from 4th September to 5th October, with variation coefficients of 1.0–1.9. However, with a latest sowing date (LSD), drying occurred from 14th September to 31st October, with variation coefficients of 1.3–3.0. In the changed harvest scenario, the drying time of maize sown on the OSD condition was from 12th September to 9th November with variation coefficients of 1.3–3.0, while maize sown on the LSD had drying dates of 26th September to 28th October with variation coefficients of 1.5–3.6. In the future harvest scenario, the Fengken 139 (FK139) and Jingnongke 728 (JNK728) hybrids finished drying on 20th October and 8th November, respectively, when sown on the OSD and had variation coefficients of 2.7–2.8. Therefore, the maize kernel drying time was gradually delayed and was associated with an increased demand for AT $\geqslant$ 0°C late in the growing season. Furthermore, we observed variation among different growing seasons likely due to differences in weather patterns, and that sowing dates impact variations in drying times to a greater extent than harvest scenarios.

Introduction

Maize (*Zea mays* L.) kernel drying is affected by genetic characteristics of hybrids and environmental factors (Troyer and Ambrose, 1971; Hunter *et al*., 1979), in which temperature and wind speed mainly affected before physiological maturity (PM), while temperature and relative humidity mainly affected after PM (Gao *et al*., 2018). The growth and development of maize in the field are mainly influenced by temperature, solar radiation and photoperiod, not only temperature mainly affects the growth process of maize, but it also determines the rate and duration of kernel drying, therefore, temperature is the main force of grain drying under drying period (Warrington and Kanemasu, 1983). The base temperature of 8 or 10°C were often used to calculate the thermal time of a crop during growth and development (Jones and Kiniry, 1986; Otegui *et al*., 1996; Capristo *et al*., 2007), and generally, the growing degree-day is used interchangeably with thermal time (Yang *et al*., 1995). However, when the temperature is above 0°C, the kernel moisture diffuses into the atmosphere (Muchow, 1990; Stewart *et al*., 1998; Tsimba *et al*., 2013), and it is usually expressed as accumulated temperature (AT). The kernel drying process can be divided into two different stages of moisture transfer, such as capillary action (constant-rate drying) and intracellular action (falling-rate period), which have different physiological activities due to diffusion (Brooking, 1990). In this study, kernel drying as a physical process was predicted with a base temperature of 0°C.

In Northeastern China, there are abundant heat resources for drying maize and the suitable harvest period is long, which is advantageous for mechanical harvesting (Li, 2017). In order to meet the huge market demand for maize with limited farmlands, selecting relatively late-maturing hybrids and making full use of heat resources has been used as a strategy to increase maize yield in Northeastern China in the past few decades (Chu *et al*., 2020). Maize usually reaches PM just a few days before the first frost in the autumn. Around this time, there is commonly a high kernel moisture content (KMC ~ 30%) at harvest, which is also an important factor influencing kernel quality and post-harvest management (Jennings, 1974; Chai *et al*., 2017). Many farmers prefer to harvest after the first frost. On the one hand, high KMC can provide a high yield (Dwyer *et al*., 1994), but on the other hand, high KMC maize can be used as an animal feed or material for ethanol production, which is the traditional harvest scenario (THS) in Northeastern China. As labour costs rise, mechanical kernel harvesting, which is widely used in developed countries, is becoming extensive in China (Baute *et al*., 2002; Li, 2013). Meanwhile, with the emergence of new agricultural entities such as

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cooperatives, family farms and trust companies, mass production has become an inevitable trend. Previous studies have shown that when KMC is reduced to around 25%, the harvest quality can be improved and kernel drying costs can be reduced (Li *et al.*, 2017). Currently, this kernel harvest is being promoted on a large scale with the changed harvest scenario (CHS). However, the kernels still need to be heated and dried after harvest. By reviewing the progress of maize production in the United States and European countries, it was found that a system of advanced and efficient maize production has been gradually established centring on mechanical kernel harvest through continuous improvement of hybrids and in-field management (Zhao *et al.*, 2011; Li, 2013). At present, KMC at harvest is largely dependent on weather conditions, production methods and hybrid drying properties and may not ever reach 16%. However, by breeding and planting early or mid-maturing hybrids with high-yield potential, maize kernels can be naturally dried in the field for approximately 30 days before harvest, and KMC can be reduced to 16–17% with the development of agriculture and the progress of science and technology. For future harvest scenario (FHS), the harvested kernels can be directly stored in bags by farmers or directly transported to warehouses by cooperatives and large-scale farms, thereby reducing drying costs and enhancing productivity. In the current study, we evaluated the effects of different sowing dates and harvest scenarios on maize grain drying times by using the historical climate data of the test site over many years and the AT demand of maize grains. This study will provide a theoretical basis for maize growing areas to cope with climate change and for farmers to reasonably choose the corresponding hybrids.

Materials and methods

Experiments and hybrids

The experiments were carried out at an agricultural experiment station in Tieling, Liaoning Province, China, with geographical coordinates 123°63′ E, 42°35′ N, and typical of a temperate continental monsoon climate. The meteorological data of 2017, 2018 and from 1999 to 2018 are listed in Table 1, including average temperature and average precipitation.

Hybrids that are currently planted in Northeast China were selected for this study, including two early-maturing hybrids (EMVs) (FK139 and JNK728) and six mid-late maturing hybrids (MLMVs) (DY311, DK159, DD1331, LD575, TY388 and ZY8911). All seeds were mechanically sown on 28 April 2017 and 4 May 2018 (Table 2). The planting density was 7.0 plants/m^2 with a row spacing of 65 cm. The planting area for each hybrid was at least 667 m^2, and other field management followed local practices. From 20 days after silking (50% of plants) until harvest (in late October), ears from five plants per hybrid line were collected at an interval of approximately 7 days. Entire ears with their surrounding husks were immediately transported to the laboratory. One hundred kernels were hand-picked from the middle of each ear for the determination of fresh weight (FW) and dry weight (DW). The FW was measured with an electronic scale and the DW was determined after drying the kernels in a forced-air oven at 85°C for 48 h (Gao *et al.*, 2021). The KMC (%, wet basis) was calculated as follows:

$$\text{KMC}\ (\%) = \frac{\text{FW} - \text{DW}}{\text{FW}} \times 100\% \quad (1)$$

Simulation of maize kernel drying

To account for the environmental influences on the drying time of maize kernels at different stages of maturation by means of a stable correlation, this study analysed the AT and the KMC after silking (Cross and Zuber, 1972; Daynard, 1972; Russelle *et al.*, 1984), thereby establishing a regression model for the relationship between AT and KMC as a means to estimate the post-silking KMC. In accordance with the scatter-plot distribution of KMC and AT, the logistic power nonlinear growth model was selected to establish the regression model, as shown in Eqn (2):

$$\text{KMC}_\text{P} = 90\left(\frac{b}{b + \text{AT}}\right)^C \quad (2)$$

where KMC_P is the predicted kernel moisture content (%, wb), b and c are regression parameters and AT ($\geqslant$ 0°C) is the accumulated temperature (°C day) starting from silking. It should be noted that the equation does not apply when the average air temperature is below 0°C, as the thermal time will not increase.

Determination of sowing date and harvest scenario

In warmer regions, many maize farmers plant hybrids with longer growth periods. However, early sowing results in seedlings that are prone to frost damage, and delayed sowing can retard maturation, which is detrimental to maize production due to cold damage after sowing and high KMC at harvest time, respectively (Dwyer *et al.*, 1994; Liu *et al.*, 2013). Hence, this study assumed two sowing dates (the optimal sowing date, OSD; and the latest sowing date, LSD) to simulate the process of maize growth and kernel drying in different years. The OSD is the average date at which the temperature reached 10°C for 5 consecutive days from 1999 to 2018, which was 25 April, while the LSD was specified by statistical analysis from the national maize industry system of China (CARS-02-25), which was 10 May.

Based on the current maize production methods and the relevant technical progress in China, the harvesting technology and standards for KMC at harvest will both be improved in the future. In view of the development of maize production in China corresponding to the different development stages of maize harvest technology, three different harvest scenarios were designed in this study, namely, (1) the THS, (2) the CHS and (3) the FHS (Table 3).

With Excel 2016 and Sigma Plot 12.5, the data in this study were analysed, processed and plotted. Curve Expert Professional 2.6 was used for parameter fitting.

Results

Growth period and AT demand of hybrid maize lines

From 1999 to 2018, during the growing period of maize from April to October, the average temperature was 17.6°C and the average total rainfall was 624 mm. Compared to the average data from 1999 to 2018, the average temperatures were 0.5°C higher in 2017 and 0.8°C higher in 2018 while the average rainfall totals were 138 mm lower and 151 mm lower, respectively. The average temperature from June to August in 2018 was higher than that in 2017, but the rainfall in 2018 was lower than that in 2017 (Table 1). On average, the growth seasons (from emergence to PM) of EMVs were 119 days (from 14th May to 10th September) in 2017 and 121 days (from 27th May to 25th

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Table 1. Average temperature and monthly total precipitation during maize growing seasons in 2017 and 2018

	Average temperature (°C)			Precipitation (mm)		
Month	2017	2018	1999–2018[a]	2017	2018	1999–2018[a]
April	12.0	11.7	10.0	18.5	24.7	30.3
May	17.9	18.4	17.5	62.5	50.2	56.0
June	21.9	22.9	21.1	45.8	98.7	96.1
July	25.7	26.8	24.3	123.6	42.8	165.9
August	22.7	23.9	22.2	175.1	120.1	203.3
September	17.2	16.4	17.1	48.2	93.3	32.4
October	8.8	8.6	9.1	11.8	43.2	39.6
Average/total	18.0	18.4	17.6	485.5	473.0	623.6

[a]Mean values over 20 years from 1999 to 2018.

Table 2. Certification time of tested hybrids used in this study and their characteristics

Type	Hybrids	Year for certification	Parents	Plant height (cm)	Growth period (day)
EMV	Fengken139 (FK139)	2015	FK334♀ × K454♂	283	118
	Jongnongke728 (JNK728)	2017	JingMC01♀ × Jing2416♂	276	121
MLMV	Danyu311 (DY311)	2018	Dan3145♀ × Dan3140♂	312	132
	Dika159 (DK159)	2015	HCL301♀ × F0147Z♂	293	130
	Dongdan1331 (DD1331)	2016	XC2327♀ × XB1621♂	280	129
	Liaodan575 (LD575)	2018	Liao3358♀ × Liao3258♂	299	133
	Tieyan388 (TY388)	2015	TieT0908 ♀ × TieT0809♂	283	132
	Zeyu8911 (ZY8911)	2017	H0908♀ × Z1182♂	299	130

EMV, early-maturing hybrid; MLMV, mid-late maturing hybrid.

Table 3. Harvest method, purpose, KMC and applicative groups in different harvest scenarios

Harvest scenarios	Harvest methods	Harvest purpose	KMC standard (%)	Applicative groups
THS	Mechanical ear harvest	Ethanol materials feedstuff	30	Farmers
CHS	Mechanical kernel harvest	Reduce labour cost, stable	25	Cooperatives
FHS	Mechanical kernel harvest	low drying cost	16	Cooperatives

KMC, kernel moisture content.

September) in 2018. For MLMVs, the growing seasons were 134 days (from 18th May to 29th September) in 2017 and 137 days (from 28th May to 12th October) in 2018. Therefore, the difference in the duration of the growing seasons between 2017 and 2018 was 2 days for EMVs and 3 days for MLMVs. The AT from emergence to PM was 1299°C days for EMVs and 1393°C days for MLMVs in 2017, and 1335°C days for EMVs and 1399°C days for MLMVs in 2018. Overall, the AT for the grain-filling stage accounted for 54.0% of the AT during the growth period, which was 53.6–55.8% with an average percentage of 54.7% in 2017, and 51.3–54.4% with an average percentage of 53.3% in 2018 (Table 4). These results implicate that the AT requirements of maize hybrids at different growth stages were relatively consistent, but that there were slight differences observed between the two years.

Dynamics and modelling of kernel drying of tested hybrid lines

In 2017 and 2018, KMC observations began in late-July and early-August and finished in late-October and early-November, respectively. During these periods, KMC decreased gradually with the increased duration of field exposure (Fig. 1). Due to different maturity stages and dissimilar grain-filling processes, the drying processes of EMVs and MLMVs were significantly different. In both 2017 and 2018, the KMC of the EMVs was lower than that of MLMVs. However, in comparison, the average final KMC was higher in 2018, which was likely due to cooler/wetter ambient conditions.

Concerning the kernel dehydration dynamics of each hybrid observed in the field and their corresponding AT requirements, the parameters involved in these metrics were determined to

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Table 4. Growth stages of maize hybrids in 2017 and 2018

Year	Hybrid type	Hybrid name	Emergence date	Silking date	PM date	Em-Sk[a] (°C days)	Sk-PM[b] (°C days)	Rate[c] (%)
2017	EMV	FK139	14 May	8 Jul.	9 Sep.	1259	1588	55.8
		JHK728	14 May	11 Jul.	11 Sep.	1339	1545	53.6
		Average	14 May	9 Jul.	10 Sep.	1299	1567	54.7
	MLMV	DY311	19 May	17 Jul.	1 Oct.	1393	1691	54.8
		DK159	17 May	14 Jul.	20 Sep.	1363	1628	54.4
		DD1331	20 May	19 Jul.	6 Oct.	1423	1706	54.5
		LD575	20 May	18 Jul.	4 Oct.	1395	1708	55.0
		TY388	19 May	16 Jul.	30 Sep.	1365	1706	55.5
		ZY8911	14 May	14 Jul.	23 Sep.	1423	1671	54.0
		Average	18 May	16 Jul.	29 Sep.	1394	1685	54.7
2018	EMV	FK139	25 May	16 Jul.	24 Sep.	1310	1548	54.2
		JHK728	29 May	20 Jul.	26 Sep.	1359	1463	51.8
		Average	27 May	18 Jul.	25 Sep.	1335	1506	53.0
	MLMV	DY311	29 May	22 Jul.	12 Oct.	1393	1593	53.4
		DK159	28 May	20 Jul.	5 Oct.	1359	1586	53.9
		DD1331	30 May	23 Jul.	17 Oct.	1400	1608	53.5
		LD575	30 May	22 Jul.	17 Oct.	1370	1638	54.4
		TY388	29 May	22 Jul.	15 Oct.	1393	1626	53.9
		ZY8911	25 May	22 Jul.	8 Oct.	1480	1559	51.3
		Average	28 May	21 Jul.	12 Oct.	1399	1602	53.4

PM, physiological maturity.
[a]AT, accumulated temperature (⩾0°C) requirement from emergence to silking date.
[b]AT, accumulated temperature (⩾0°C) requirement from silking to PM date.
[c]Rate, the proportion of AT (⩾0°C) at grain-filling stage to the whole growth period.

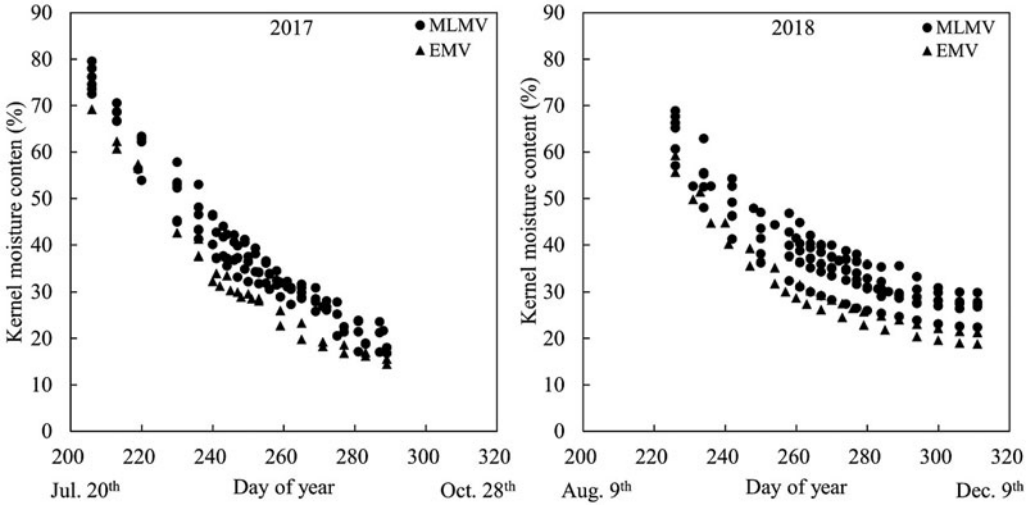


Fig. 1. Kernel drying dynamics of different maize hybrids from silking to PM in 2017 and 2018. EMV, early-maturing hybrid; MLMV, mid-late maturing hybrid.

establish the kernel drying models for the tested hybrids. The coefficients between post-silking AT and KMC were determined to have R^2 values in the range of 0.956–0.982 in all tested hybrids. With high reliability, the prediction model can be used to calculate the KMC of each hybrid under different AT conditions (Table 5). Accordingly, our prediction model was used to calculate the AT for three harvest KMC levels (30, 25 and 16%) and the ATs from the sowing to silking stages (recorded during in-field observation) were determined. By adding the sowing to silking and post-silking AT values together, these values were

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Table 5. KMC models and AT (⩾0°C) requirements of the tested hybrids used in different harvest scenarios

	Model coefficient			THS	CHS	FHS
Hybrid name	*b*	*c*	R^2 ($P < 0.01$)	AT to 30% KMC (°C days)	AT to 25% KMC (°C days)	AT to 16% KMC (°C days)
DY311	970.5	1.4	0.956**	3391	3716	4685
DD1331	1005.6	1.5	0.957**	3529	3822	4655
DK159	975.3	1.7	0.965**	3196	3439	4123
FK139	1019.9	2.3	0.967**	2971	3137	3575
JHK728	1048.5	1.7	0.982**	3106	3232	3779
LD575	1127.6	1.7	0.967**	3422	3715	4563
TY388	1054.2	1.6	0.956**	3396	3675	4468
ZY8911	967	1.6	0.966**	3253	3354	4119

R^2 indicates the coefficient of determination, and *b* and *c* are parameters.
AT, accumulated temperature (⩾0°C); KMC, kernel moisture content.

used to determine the kernel-drying required ATs of all tested hybrids in different harvest scenarios. The AT requirements for hybrids were 2971–3529°C days in THS, 3137–3822°C days in CHS and 3575–4685°C days in FHS. It can be seen that when a certain harvest scenario calls for a relatively lower KMC, there is a larger difference among hybrid AT requirements.

The drying period of all tested hybrids in three harvest scenarios with different sowing dates

Inter-annual climate variation has caused variable maize harvest scenarios during different periods. By calculating the required AT and kernel dehydration for hybrid growth and development with the support of regional meteorological data in recent years (1999–2018), the inter-annual drying period difference of tested hybrids in different harvest scenarios was analysed.

Using OSD and LSD conditions, the inter-annual drying period variations of hybrids in THS, CHS and FHS are shown in Fig. 2 and Table 6. Under the THS, assuming that farmers sow on the OSD, the tested hybrids were determined to be able to be harvested at the earliest on 4th September and at the latest on 5th October, with a variation coefficient of 1.0–1.9. When sowing on the LSD, farmers needed to postpone the harvest date to a period from 14th September to 31st October, with a variation coefficient of 1.3–3.0. Under the OSD conditions, the tested hybrids were harvested from 12th September to 9th November, with a variation coefficient of 1.3–3.0. However, under LSD conditions, only FK139, JNK728, ZY8911 and DK159 could be harvested between 26th September and 28th October, with a variation coefficient of 1.5–3.6. Other hybrids could not be harvested regularly in the CHS. Under the OSD and LSD conditions, the average harvest dates of different hybrids in the CHS varied over a range of 14–35 days. In the FHS under the OSD conditions, only FK139 and JNK728 could be harvested from 22nd October to 8th November. Moreover, all of the tested hybrids could not be harvested in the FHS under the LSD conditions.

Relationships between yield and AT

We found that the AT required for drying is closely related to yield, and the relationship between them can be fitted by a linear regression model. Although the drought in 2018 significantly reduced the total yield, a very significant positive correlation between AT and yield was observed (Fig. 3, $P < 0.01$). Based on these analyses, we identified hybrids with higher AT requirements for maturation and drying that have better yield performance, and this trend was consistent for both years.

Discussion

Previous studies have shown that maize kernel drying was affected by genotype and environment (Schmidt and Hallauer, 1966; Daynard and Duncan, 1969; Carter and Poneleit, 1973; Borrás *et al.*, 2009; Elmore and Abendroth, 2010). Neuffer *et al.* (1968) and Kang *et al.* (1978) studied different types of maize hybrids and found that late-maturing maize hybrids had higher KMCs during harvest and slower kernel drying rates during maturation. Crane *et al.* (1959) compared the changes in kernel drying under field drying conditions and suggested that there were obvious differences among maize hybrids. Hillson and Penny (1965) and Nass and Crane (1970) also investigated that the physiological characteristics of different hybrids, and found differences in the rate of kernel drying after maturity, and that these differences were heritable. Daynard and Kannenberg (1976) also reported that crop heat units (CHUs) were significantly correlated with kernel drying rates, and proposed using the following equation to first predict the grain drying rate and then the grain moisture content at harvest:

$$y = c + dx^2 \tag{3}$$

In the above equation, y is the KMC, c is the initial KMC, d is the maize kernel drying rate (percentage decrease in grain moisture content per CHU) and x is the accumulated CHU after silking. We also demonstrated that under ideal crop management, there were significant differences in AT requirements among tested maize hybrids at each of their growth and developmental stages (sowing, silking, ripening, kernel drying and different harvest scenarios). After PM, the kernel is isolated from the plant at the black layer stage. The drying of kernels then becomes a physical process of water loss. Due to the short duration of plant growth, EMVs can enter this drying stage earlier, which was also demonstrated in this study. For example, under the OSD conditions, FK139 is traditionally harvested from 1st to

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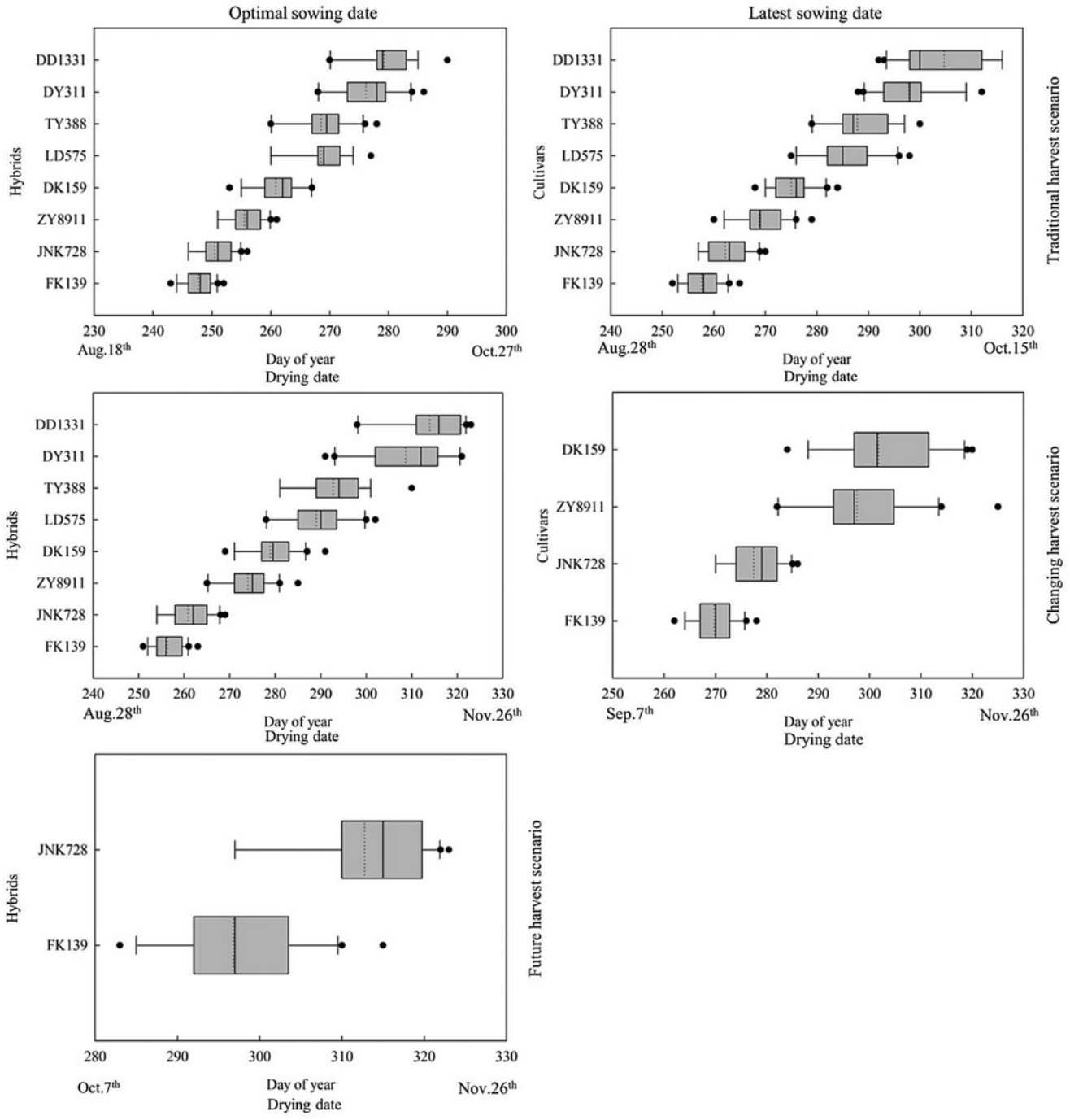


Fig. 2. Inter-annual variation of the drying date of maize in THS, CHS and FHS, under OSD/LSD conditions. Hybrids are defined in Table 1. The solid and dotted lines in the box plots are the medium and the mean, respectively. The black circles represent outliers.

9th September, while DD1331 is traditionally harvested from 25th September to 10th October. However, under the LSD conditions, FK139 can be harvested from 9th to 20th September, and DD1331 can be harvested from 18th October to 10th November. Furthermore, in the CHS, only FK139, JNK728, DK159 and ZY8911 can be harvested under LSD conditions. The main reasons for this restricted harvesting are as follows. Firstly, there are significant differences between the maturation period between hybrids and the drying characteristics of hybrids (Fig. 1). On the contrary, the period for kernel drying under the OSD conditions is longer than that under the LSD conditions (Fig. 4). Additionally, the average temperature during the drying period is also higher. Since the 1980s, the sowing dates during growing seasons have brought forward and the first frost date has been delayed (Ning *et al.*, 2015; Zhao *et al.*, 2015), making AT higher and more available for maize producing areas to not only move northwards but also to expand westwards into non-traditional climate zones. Therefore, in the future, MLMVs will be harvested according to the CHS, while EMVs will be harvested according to the FHS.

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Table 6. Mean values and variation coefficients and kernel harvest dates of tested hybrids in different harvest scenarios sown at different times

		OSD		LSD	
Harvest scenarios	Hybrids	Mean	CV (%)	Mean	CV[a] (%)
THS	FK139	4 Sep.	1.0	14 Sept.	1.3
	JNK728	7 Sep.	1.2	18 Sept.	1.5
	ZY8911	12 Sep.	1.1	25 Sept.	1.8
	DK159	17 Sep.	1.6	1 Oct.	1.5
	LD575	25 Sep.	1.7	11 Oct.	2.3
	TY388	25 Sep.	1.8	14 Oct.	2.1
	DY311	2 Oct.	1.9	24 Oct.	2.3
	DD1331	5 Oct.	1.9	31 Oct.	3.0
CHS	FK139	12 Sep.	1.3	26 Sept.	1.5
	JNK728	17 Sep.	1.7	3 Oct.	1.8
	ZY8911	30 Sep.	2.0	24 Oct.	3.6
	DK159	5 Oct.	2.0	28 Oct.	3.4
	LD575	15 Oct.	2.5		
	TY388	19 Oct.	2.5		
	DY311	4 Nov.	3.0		
	DD1331	9 Nov.	2.6		
FHS	FK139	22 Oct.	2.7		
	JNK728	8 Nov.	2.8		

CV, coefficient of variation.

According to maize harvest research and production experience abroad, when the KMC drops to approximately 30%, a maize combine harvest machine with good performance is selected for harvesting high-quality commercial maize. When the KMC reaches approximately 25%, it is most conducive for harvesting and is a critical stage for coordinating the economic trade-off between harvest quality and drying cost. When the KMC drops to 16%, most farmers can store grain in bags temporarily, and after a short period, be directly transported to warehouses for storage, thereby reducing drying costs. The variable drying characteristics and harvest time of maize hybrids also determine their KMCs at harvest (Li *et al.*, 2010), with the temperature being the main weather factor affecting the rate and extent of kernel drying (Borrás and Westgate, 2006).

A long growth period is generally considered to be required for high yields in maize, but late-maturing hybrids have a high KMC during the harvest period which makes it difficult to meet the requirements of high-quality mechanical kernel harvest

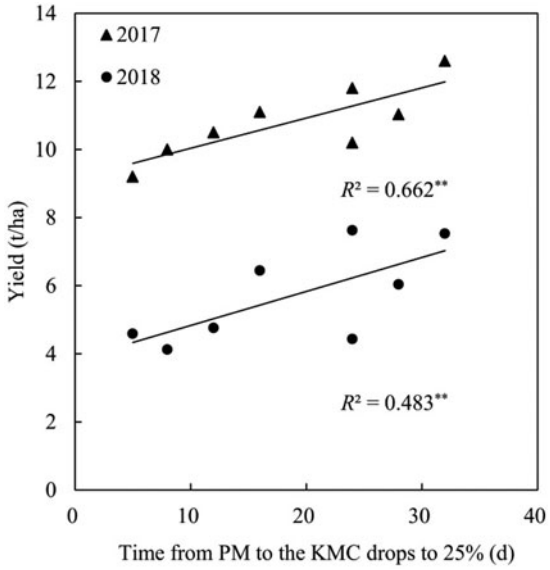


Fig. 3. Relationship between the yield and time from PM to the KMC drops to 25%. **indicates significance at a level of 0.01 ($P < 0.01$). PM, physiological maturity; KMC, kernel moisture content.

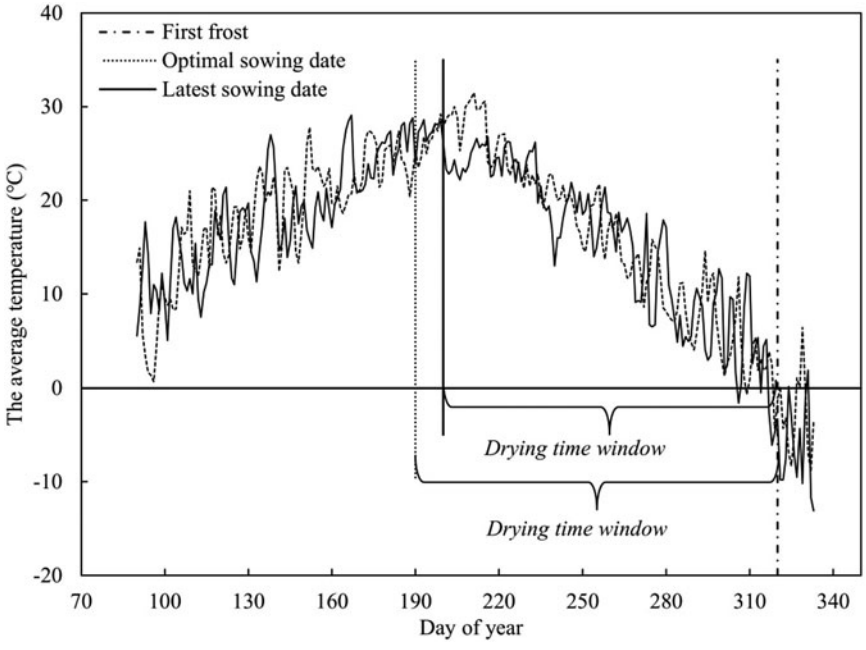


Fig. 4. Average temperature during the maize drying period under OSD (dashed line) and LSD (solid line). The drying time window indicates the number of days from silking until the first frost.

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(Wang and Li, 2017). The AT is significantly positively correlated with yield, where the higher the yield, the greater the AT requirement for hybrids. In order to pursue yield efficiency, the growth period of hybrids used in production is generally long, resulting in a higher KMC during harvest and reduced kernel quality. In addition, the temperature for maize hybrid planting and the initial kernel filling is relatively high, but it drops rapidly after the fall, hence, the heat conditions during the maturation and drying of the kernel are gradually reduced. The results of this study show that, based on the meteorological data of recent years, the estimated harvest time of the tested hybrids can differ by nearly 60 days. When increasing AT as required for hybrids and postponing sowing, kernel maturation and drying are both delayed. Additionally, the drying time for reaching the standard of KMC fluctuated under different meteorological conditions in the years monitored for this study. The later that the drying of mature seeds proceeds, the more impactful are late-season weather factors which then increase the uncertainty of environmental conditions and production. Therefore, from the perspective of production management, it is also reasonable to coordinate the maturation of hybrids with the sowing date. The restructuring of maize production, mechanical operation capacity and labour demand can be performed to reduce the risk of decreasing maize production and improving the efficiency of harvesting machinery. Thus, we identified additional agricultural factors that contribute to the unification of agronomic measures and processes for optimizing hybrid maize yield characteristics and boosting the efficiency of maize production.

Conclusion

The temperature drops sharply during autumn and there is a prominent reduction in heat resources that naturally dry maize kernels in the field. As the demand for AT increases during drying, the variability of kernel drying time gradually increased between sowing dates and harvest scenarios. Hereby, we recommend that farmers in maize production regions choose the OSD to sow hybrid maize hybrids and harvest MLMVs in the CHS and EMVs in the FHS. In addition, maize sowing date and grain drying methods should be taken into full consideration when selecting harvest scenarios under future climate conditions.

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