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The Effect of Sowing Date on the Nutritional Quality of Kernels of Various Maize Varieties in Northeast China

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Abstract: Suitable sowing dates are crucial in plant production to cope with climate change and ensure high-quality crop production. We hypothesize that the analysis of the effect of sowing date and climatic resources on maize kernel nutritional quality (KNQ) (crude fiber, starch, crude fat, and crude protein) might contribute to selecting appropriate sowing dates according to different production requirements and meteorological conditions. The study was based on five main local varieties in three experimental stations (early-maturing variety: Zengyu1317, Hongshuo298, Keyu15; medium-maturing variety: Xianyu335; late-maturing variety: Danyu405) in Northeast China from 2018 to 2021. The results showed that: (1) the average starch content (67.7%) and crude protein content (9.1%) of early-maturing variety maize and the crude fiber content (3.3%) and crude fat content (3.6%) of late-maturing variety maize were the highest in Northeast China; (2) the sowing date had no significant effect on the starch content, but significantly affected the crude protein and crude fiber contents, the kernel protein content of early-maturing variety maize was the highest when the sowing date was delayed for 5 days (9.8%), and the crude fiber content of medium-maturing and late-maturing variety maize (4.3% and 5.39%, respectively) was the highest when the sowing date was advanced by 10 days; (3) during the reproductive growth stage, the more light and heat resources, the less starch content and crude protein content and the more crude fat content; when the diurnal temperature range increased by 1 °C, the crude fat content decreased by 0.28%, and the crude protein content increased by 0.77%; for every 100 mm more precipitation, crude fiber and crude protein content decreased by 0.68% and 0.73%, respectively, and fat content increased by 0.15%. Our results provide a meaningful reference for maize production to cope with climate change and improve kernel quality.

Keywords: fat; fiber; maize; nutritional quality; protein; starch; sowing date

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1. Introduction

Maize is one of the most important crops in China, with the total amount sown gradually increasing since the 20th century. In 2022, the total planted area and production of Chinese maize reached 43.07 million hm^2 and 277 million t, respectively [1]. Maize is a crucial crop for food, economy, and feed because of its high nutritional content and numerous uses [2,3]. Maize kernels are abundant in starch, proteins, fats, and water-soluble polysaccharides, vitamins, minerals, and other nutrients [4–6]. Among them, starch is an important nutritional component, accounting for about 65–70% of the entire endosperm [7–9]. Maize starch, an environmentally friendly and biodegradable natural polysaccharide material with low cost, is widely used in food, medicine, the chemical industry, papermaking, and textiles [10]. Protein is a component of organisms and is involved in energy metabolism, and the protein content in maize kernels is about 8–11% [11]. Humans and animals maintain their normal activities by consuming appropriate amounts of protein [12]. The crude fiber component of maize kernels prevents intestinal and cardiovascular diseases, changes the microbial flora in the intestines, and accelerates the excretion of toxic substances [13]. The fat content is approximately 4–6% and can be processed into maize oil, a well-known healthy cooking oil [14,15]. With improvements in living standards and changes in the dietary structure, there is an increasing demand for the nutritional quality of maize. Therefore, researching the nutritional quality of corn kernels is important not only for enhancing the comprehensive utilization value of corn in the food, feed, and processing industries but also for ensuring national food security and improving the quality of life for residents [16].

Northeast China (NEC) is a major maize-producing region. The maize planted area (grain yield) in NEC accounts for more than 30% of the national maize planted area (grain yield) [1], and is crucial for ensuring high-quality maize production in the country. Genetic and environmental factors determine nutritional quality in maize kernels. Studies on maize genotypes showed that the contents of soluble sugar and starch of maize varieties in China 2010s were higher than those of varieties in the 1970s and 1990s. This is mainly because the dry matter accumulation and transfer volume per plant after flowering of the new genotypes were significantly higher than those of the old [17]. Against the background of climate change, NEC has become the most significant warming area in China, with a noticeable trend of earlier sowing and tasseling of maize, as well as a delayed maturation period. Thermal resources significantly increased during the entire growth. As an important factor affecting the growth and development of maize, this change in climate resources will have a non-negligible effect on the quality of maize kernels [18]. Adjusting the sowing date can affect the formation of crop kernels by altering the crop's growth process and the distribution of climate resources during the growth period. This makes it an important measure for crop production to cope with climate change and a common method for studying the effect of climate resources on crop kernel quality. The nutritional content of kernels is an important indicator of nutritional quality. Previous studies have shown that the sowing date significantly affects the nutritional content (such as crude protein, crude starch, and soluble protein) and physicochemical properties of maize kernel starch [18–21]. Both the sowing date and maize variety can affect the relative contents of protein, crude fiber, starch, and lysine in glutinous maize kernels [20,21]. Experiments on different sowing dates in Shanxi Province, China, indicated that appropriately advancing the sowing date of mid–late-maturing maize increased the protein content of the kernels, whereas delaying the sowing date increased the crude fiber and starch content of the kernels [22]. Suitable early sowing in NEC is conducive to accumulating crude protein and improves maize kernel quality and yield [19]. In the hilly areas of Sichuan, late sowing increases the risk of loss of protein content and bulk density. In addition, adequate rainfall after emergence is beneficial for fat formation. Lu et al. [21] showed that drought would reduce the content of starch and increase the content of crude protein. However, Wang et al. [23] concluded that drought had no significant effect on starch content. This may be caused by different varieties and growing environments of maize. Wang et al. [24] claimed that by selecting appropriate sowing dates and varieties with different growth periods, one might coordinate the effects of pre-flowering accumulated temperature, post-flowering average temperature, and post-flowering accumulated temperature on kernel nutritional quality. During the kernel-filling stage of maize, high temperatures, prolonged durations of sunshine, and low rainfall benefit kernel protein formation. The converse conditions favor the formation of crude starch. In addition, high temperatures and low rainfall during the kernel filling stage promote the formation of crude kernel fats [25]. However, few studies have evaluated the effect of the sowing date on the kernel nutritional quality of main maize varieties in this region.

Therefore, in the context of climate change, we focused on the production demand for high-quality maize and selected five maize varieties commonly planted in NEC as the research objects. The objectives of this study were: (i) to clarify the characteristics of main kernel nutritional quality (the content of crude fiber, starch, crude fat, and crude protein) of studied maize varieties; (ii) to reveal the effect of the sowing date on the kernel nutritional quality of studied maize varieties; and (iii) to assess the effects of climatic resources and growth process on the kernel nutritional quality of maize.

2. Materials and Methods

2.1. Study Region

The study region was located in NEC and comprised Heilongjiang Province (north), Jilin Province (center), and Liaoning Province (south). The maize interval sowing experiments were conducted from 2018 to 2021 at Haerbin Station (45°36′ N, 126°49′ E, 142.3 m a.s.l.), Yushu Station (44°51′ N, 126°31′ E, 196.5 m a.s.l.), and Jinzhou Station (121°9′ N, 41°9′ E, 27 m a.s.l.) (Figure 1). Harbin and Yushu stations have a medium temperate semi-humid climate, whereas Jinzhou Station has a warm temperate semi-humid climate. The meteorological data for the experimental years (Haerbin: 2018, 2019, and 2021; Yushu: 2018–2020; Jinzhou: 2018–2021) were obtained from the China Meteorological Science Data Center's daily surface climate data set (V3.0), including daily minimum temperature (°C), maximum temperature (°C), average temperature (°C), precipitation (mm), and sunshine duration (h). The active accumulated temperature, air temperature, total solar radiation, and total precipitation during the maize growing season (April–September) in the experimental years are detailed in Table 1.

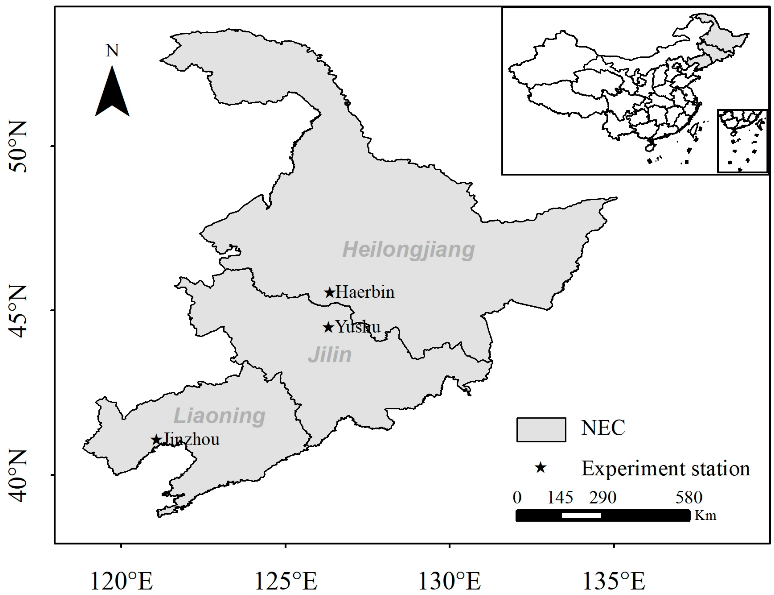

Figure 1. Geographical location of study region and experiment stations.

Table 1. Climatic resources of maize growing season in experiment years for each experiment station.

Station	Year	Active Accumulated Temperature (°C·d)	Mean Temperature (°C)	Maximum Temperature (°C)	Minimum Temperature (°C)	Solar Radiation (MJ·m^{-2})	Precipitation (mm)
Haerbin	2018	3268.8	18.1	23.4	13.1	3149.6	593.7
	2019	3092.0	17.6	23.2	12.6	3276.9	575.9
	2021	3160.1	18.1	23.1	13.4	3216.5	546.7
Yushu	2018	3278.6	18.2	23.8	12.8	3114.7	448.2
	2019	3089.5	17.7	23.6	12.3	3324.1	725.7
	2020	3080.5	17.4	23.0	12.5	3222.0	620.7
Jinzhou	2018	3832.3	21.1	26.2	16.9	3547.6	362.4
	2019	3838.3	21.2	26.4	16.5	3611.1	546.5
	2020	3705.5	20.7	25.7	16.3	4242.1	421.1
	2021	3680.8	20.2	24.8	16.3	3140.7	859.8

2.2. Experiment Design

Local varieties and maturities where each station was located were selected for the experiments. In Haerbin station, the early-maturing varieties Zengyu1317, Hongshuo298, and Keyu15 were selected in 2018, 2019, and 2021, respectively. The medium-maturing variety Xianyu335 and the late-maturing variety Danyu405 were selected for Yushu and Jinzhou station, respectively. The actual planting date of the local field was taken as the limit, and four sowing dates were set as follows: 10 d in advance (S1), common sowing date (S2), 10 d in delay (S3), and 20 d in delay (S4). The maize experimental stations and corresponding varieties, sowing years, and dates are shown in Table 2. Each experimental station had one maize variety and four sowing treatments per year, with four replicates per treatment. The planting density and depth were 6 plants per m^2 and 5 cm, respectively. The distribution of plots was designed using a standard Latin square, with a plot area of 30 m^2 and a 0.5 m protection interval between plots. The trial plots were level and without significant shade, and maize was planted on the periphery of the plots to avoid the influence of the farmland microclimate. Field management, including irrigation and fertilization, was consistent with local agricultural practices. Compound fertilizer ($N:P_2O_5:K_2O$ = 26%:14%:5%) was applied at the rate of 830 kg ha^{-1}. Insects and diseases were controlled using pesticides to avoid biomass and yield losses.

Table 2. Maize experimental stations and corresponding varieties, sowing years, and dates.

Sowing Station	Maturity/Variety	Year	Sowing Date
Haerbin	Early-maturing Zengyu1317	2018	4/25 5/5 5/15 5/24
	Early-maturing Hongshuo298	2019	4/25 5/5 5/15 5/24
	Early-maturing Keyu15	2021	4/25 5/5 5/16 5/25
Yushu	Medium-maturing Xianyu335	2018–2020	4/21 5/1 5/11 5/21
Jinzhou	Late-maturing Danyu405	2018–2021	4/20 4/30 5/10 5/20

2.3. Measurements and Calculations

2.3.1. Maize Measurements

The observation method for developmental progress was a parallel observation, mainly recording the prevalent dates of emergence, jointing, tasseling, and maturation stages of maize. The kernel nutritional quality (KNQ) of maize, including the content of crude fiber (KFI), starch (KSC), crude fat (KFA), and crude protein (KPC), was determined after harvesting. The acid–base boiling method (Chinese national standard GB/T 5009.10-1985) [26], polarimetry method (Chinese national standard GB/T 5009.9-2003) [27], Soxhlet extraction method (Chinese national standard GB 5009.6-2016) [28], and Kjeldahl method (Chinese national standard GB/T 5009.5-2003) [29] were used for determination. All nutritional contents were expressed as percentages (%).

2.3.2. Growth Stage Division

Research on the maize growth process and climatic resources during the growth period was based on three growth stages: the vegetative growth stage (VGP), the vegetative and reproductive growth stage (VRP), and the reproductive growth stage (RGP). The VGP lasts from sowing to jointing, the VRP lasts from jointing to tasseling, and the RGP lasts from tasseling to maturity.

2.3.3. Total Solar Radiation

The total solar radiation during the growth period of maize was obtained by accumulating the daily solar radiation Q ($MJ \cdot m^{-2}$):

$$Q = Q_0 \left(a + b\frac{n}{N}\right) \quad (1)$$

$$Q_0 = \frac{TI_0}{\rho^2(\omega sin\mu sin\delta + cos\varphi cos\delta sin\omega)} \quad (2)$$

where n is the actual sunshine duration (h); N is the maximum possible sunshine duration (h); and a and b are empirical coefficients related to the geographical location and atmospheric quality, respectively, representing the proportion of extraterrestrial radiation reaching earth on overcast days. Previous studies have reported a and b values of 0.143 and 0.585 in eastern China and 0.185 and 0.595 in western China, respectively [30,31]. Because the experiment stations were in the eastern part of China, values of 0.143 and 0.585 were selected for a and b, respectively. Q_0 is the astronomical radiation ($MJ \cdot m^{-2}$); T is the number of times in a daily cycle, taking 24×60 min; I_0 is the solar constant ($0.082\ MJ \cdot m^{-2} \cdot min^{-1}$); ρ^{-2} is the revised coefficient of the Earth's orbital eccentricity; μ is the latitude (rad); δ is the solar declination (rad); and ω is the sunset hour angle (rad) [30–32].

2.3.4. Active Accumulated Temperature

Active accumulated temperature (ATT, unit °C·d) is an effective parameter for describing the thermal condition for crop growth, which has been widely applied in studying crop physiological ecology [33]. In this study, ATT during different maize growth stages was calculated as follows:

$$ATT = \sum T_i, \text{ for } T_i \geq 10\ ^\circ\text{C}, \quad (3)$$

where T_i is the average air temperature on day i during the growth stage. And $T_i \geq 10$ °C (biological lower limit temperature of maize).

2.3.5. Stable KNQ Index

In this study, the variation coefficient of KNQ was used as the stability index. The greater the variation coefficient, the greater the degree of KNQ fluctuation [33]. According to ranges proposed by Wilding and Drees (1983), $CV < 15\%$ is considered as low; $15\% < CV < 35\%$ is considered moderate, and >35% is considered high [34].

$$CV = \frac{S}{\overline{G}'} \quad (4)$$

where CV is the coefficient of variation of the maize KNQ, S is the standard deviation of the KNQ, and $\overline{G}$ is the mean of the KNQ.

2.3.6. Partial Correlation Analysis

Because different nutrient components of maize kernels would affect each other, second-order partial correlation analysis was used to characterize the relationship between two nutrient component variables by controlling for the other two, and the significance analysis of the partial correlation results was carried out using the *t*-test [35]. The formula used is as follows:

$$R_{ab\cdot cd} = \frac{R_{ab\cdot c} - R_{ad\cdot c}R_{bd\cdot c}}{\sqrt{(1 - r_{ad\cdot c}^2)(1 - r_{bd\cdot c}^2)}} \tag{5}$$

$$t = \frac{R_{ab\cdot cd}}{\sqrt{1 - R_{ab\cdot cd}^2}}\sqrt{n - m - 1} \tag{6}$$

where $R_{ab\cdot cd}$ is the partial correlation coefficient between variables a and b under the influence of control variables c and d; $R_{ab\cdot c}$, $R_{ad\cdot c}$, and $R_{bd\cdot c}$ are the partial correlation coefficients of variables a and b, a and d, and b and d under the influence of control variable c, respectively. n is the number of samples, and m is the number of independent variables.

2.4. Data Analysis

Analysis of variance was used to determine the effects of year, sowing date, and the interaction between the year and sowing date on maize KNQ. Quadratic and linear regressions were used to analyze the effects of the sowing date and growth process on the KNQ of maize. Statistical analyses were performed using Microsoft Excel 365 and IBM SPSS Statistics, version 26. MathWorks MATLAB R2020a was used to calculate the climatic resources of maize during the growth period with different sowing dates during the experimental years.

3. Results

3.1. Variation Characteristics of Maize KNQ of Different Varieties

Figure 2 shows the KNQ of maize of different maturities in the experimental years. Overall, the KSC was higher than the KPC, which was higher than the KFA, whereas the KFI was the lowest. Late-maturing variety (LV) maize had a higher KFI compared to early-maturing (EV) and medium-maturing variety (MV) maize (3.3% and 2.7%, respectively). EV maize had the highest KSC (67.7%), followed by medium (61.3%) and late (60.7%). LV maize had the highest KFA (3.6%), followed by EV (3.4%) and MV (3.1%). EV maize had the highest KPC (9.1%), followed by the MV (8.4%) and LV (7.8%). Among same-maturity maize, KNQ was generally the lowest in 2020 and the highest in 2018. This may be due to the significantly lower active accumulated temperature in 2020 than in other years, whereas the opposite was true for 2018 (Table 1).

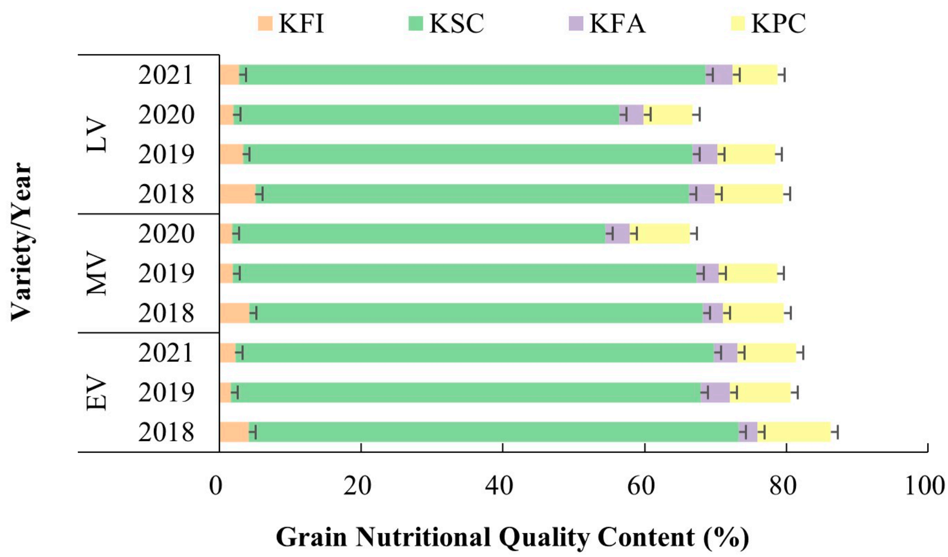

Figure 2. Average maize KNQ of different varieties in 2018–2021.

Partial correlation analysis showed that the KPC of EV maize was significantly positively correlated with KFI and significantly negatively correlated with KSC (Table 3). There was a significant negative correlation between KFI and KFA in MV maize. The KFI of LV maize was significantly and positively correlated with KSC and KPC.

Table 3. Partial correlation coefficient between maize KNQ of different varieties.

Variety	KNQ	KFI	KSC	KFA	KPC
EV	KFI				
	KSC	0.369			
	KFA	−0.479	−0.544		
	KPC	0.676 *	−0.656 *	−0.147	
MV	KFI				
	KSC	−0.057			
	KFA	−0.691 *	−0.540		
	KPC	0.343	−0.363	−0.008	
LV	KFI				
	KSC	0.580 *			
	KFA	0.125	0.352		
	KPC	0.931 **	−0.510	−0.179	

Note: Statistical significance is represented by asterisks (* $p < 0.05$, ** $p < 0.01$).

3.2. Effects of Sowing Date on Maize KNQ of Different Varieties

The effects of sowing date and year on the maize KNQ of different varieties were studied using variance analysis (Table 4). Based on these results, it is evident that the year significantly affected the KNQ of maize. However, the sowing date had no significant effect on the KSC of maize, and the effect of the sowing date on the nutritional components varied among the varieties.

Table 4. The variance analysis (F value) of the effect of sowing date and year on maize KNQ of different varieties.

Variety	Source of Variation	KFI	KSC	KFA	KPC
EV	Year	983.5 **	2.2	238.1 **	70.7 **
	Sowing date	2.3	0.1	2.3	13.9 **
	Year × Sowing date	5.3 **	0.5	3.7 **	10.2 **
MV	Year	1102.5 **	62.8 **	40.6 **	1.7
	Sowing date	14.5 **	1.6	0.7	2.6 *
	Year × Sowing date	9.6 **	2.3 *	3.2 *	1.7
LV	Year	689.6 **	30.2 **	13.1 **	172.4 **
	Sowing date	3.2 *	0.2	4.4 *	1.6
	Year × Sowing date	6.6 **	0.6	5.3 **	4.3 **

Note: Statistical significance is represented by asterisks (* $p < 0.05$, ** $p < 0.01$).

For EV maize, KFI, KFA, and KPC were significantly influenced by year, the interaction between year and sowing date, and KPC was also significantly influenced by sowing date. For MV maize, the KFI, KSC, and KFA were significantly affected by the year and the interaction between year and sowing date, and the KFI and KPC were also significantly affected by the sowing date. Regarding the LV maize, the KFI, KFA, and KPC were significantly affected by the interaction of year and sowing date, and the KFI and KFA were significantly affected by sowing date.

Based on the results of the analysis, significant correlations were observed between the sowing date and KNQ (Figure 3). The KPC of EV maize showed a highly significant quadratic relationship with the sowing date. When the sowing date was delayed by 5 d, the KPC was the highest (9.8%) (Figure 3a). There was a significant quadratic correlation between the KFI of MV maize and sowing date, and the maximum was found at the 10-day advance. There was little difference among the other three sowing dates (Figure 3b). The change in the KFI of the LV maize was similar to that of the MV maize (Figure 3d). There was a significant quadratic correlation between the KPC of MV maize and the sowing date, and the KPC was the smallest when the sowing date was delayed by 20 d (Figure 3c). The KPC of the MV maize was more stable and showed less variation than that of the EV. The KFA of MV maize also showed a significant quadratic relationship with the sowing date, but the differences between the different sowing dates were small.

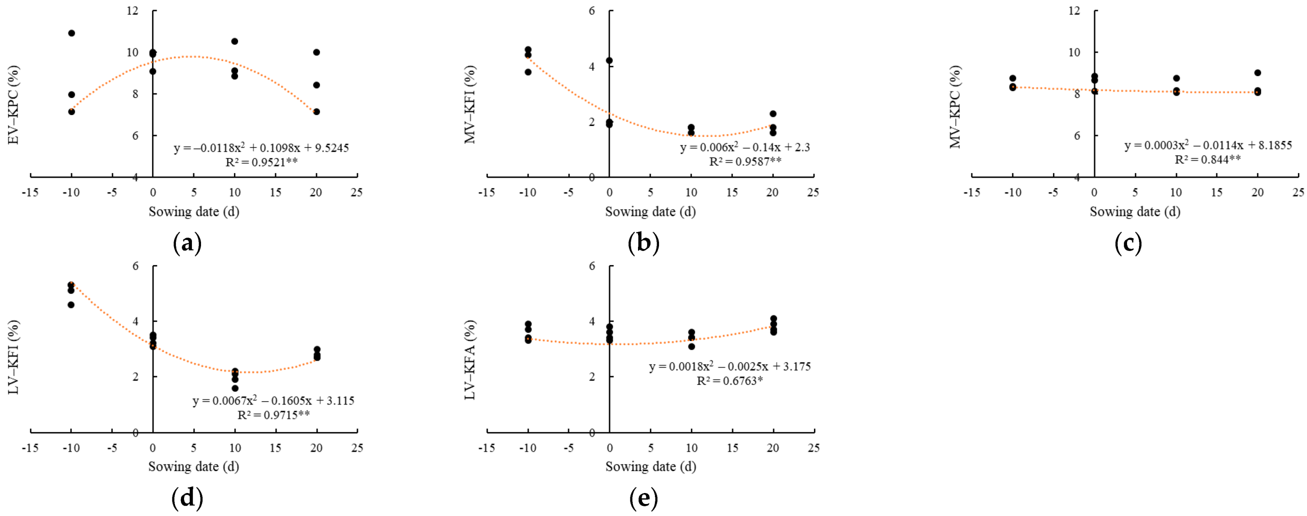

Figure 3. Effects of sowing date on KPC of EV (**a**), KFI of MV (**b**), KPC of MV (**c**), KFI of LV (**d**), and KFA of LV (**e**). Note: The horizontal and vertical coordinates represent the changes in sowing dates and KNQ relative to the common sowing date, respectively. The orange dotted lines represent the fitted regression trend line. Statistical significance is represented by asterisks (* $p < 0.05$, ** $p < 0.01$).

Figure 3 illustrates that the variation rate of KNQ varied with the sowing date. Therefore, we conducted further analyses to determine how the sowing date influenced the stability of KNQ by examining the coefficient of variation (CV) of KNQ (Figure 4). The stability of the KSC was the highest, with an average CV of 0.074, whereas that of the KFI was the lowest, with an average CV of 0.473. The mean CV of the KNQ for EV, MV, and LV was 0.221, 0.195, and 0.189, respectively. This indicates that the KNQ stability of EV maize was the worst, and that of LV maize was the best. The stability of the KFI was ranked as follows: LV > EV > MV. The stability of the KSC was ranked as follows: EV > LV > MV. The stability of the KFA was ranked as follows: LV > MV > EV. The stability of the KPC was ranked as follows: MV > EV > LV.

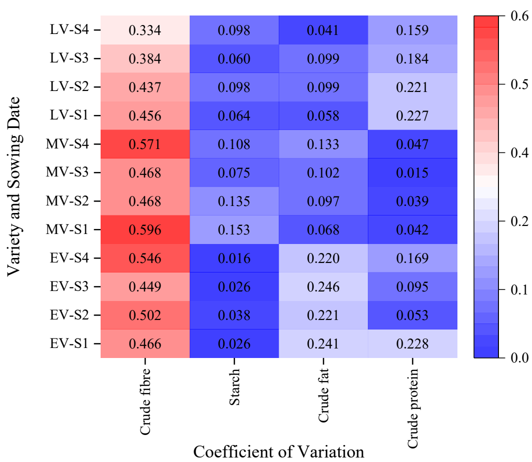

Figure 4. Coefficient of variation of KNQ for different maize varieties at different sowing dates.

3.3. Relationship between KNQ and Climatic Resources and the Length of Growth Stages

The effect of the sowing date on the KNQ of maize was achieved through its influence on the developmental process and climatic resources during the maize growth stage. Based on this, we analyzed the relationship between KNQ and the days of different growth stages and climatic resources using experimental and meteorological data (Table 5). From the perspective of RGP, more solar radiation and thermal resources resulted in decreased KSC and KPC and increased KFA levels; a greater diurnal temperature range resulted in decreased KFA (0.28% per 1 °C increase) and increased KPC (0.77% per 1 °C increase); more precipitation resulted in decreased KFI and KPC (0.68% and 0.73% per 100 mm increase, respectively) and increased KFA (0.15% per 100 mm increase).

Table 5. The correlation coefficient of KNQ with climatic resources and growing period days.

Growth Period	Influence Factor	KFI	KSC	KFA	KPC
VGP	ATT	0.323 *	0.505 **	−0.635 **	0.557 **
	days	0.049	0.367 *	−0.478 **	0.394 *
VRP	ATT	0.036	−0.418 **	0.443 **	−0.397 *
	days	−0.040	−0.464 **	0.501 **	−0.427 **
RGP	ATT	0.307	−0.333 *	0.291	−0.204
	Mean temperature	0.178	−0.349 *	0.365 *	−0.417 **
	Maximum temperature	0.231	−0.359 *	0.308	−0.377 *
	Minimum temperature	0.112	−0.347 *	0.394 *	−0.452 **
	Total solar radiation	0.211	−0.435 **	0.174	−0.191
	Total precipitation	−0.569 **	−0.214	0.323 *	−0.584 **
	Diurnal temperature range	0.268	0.201	−0.471 **	0.482 **

Note: Statistical significance is represented by asterisks (* $p < 0.05$, ** $p < 0.01$).

Notably, KNQ was significantly correlated with the active accumulated temperature and days of both the VGP and VRP (Table 5). For every 10-day increase in the number of days of VGP, the KSC and KPC increased by 2.1% and 0.5%, respectively, whereas the KFA decreased by 0.23%. For every 10-day increase in the number of days of the VRP, the KSC and KPC decreased by 5.7% and 1.2%, respectively, whereas the KFA increased by 0.5% (Figure 5). It can be concluded that the effect of the VRP on the KNQ was greater than that of the VGP.

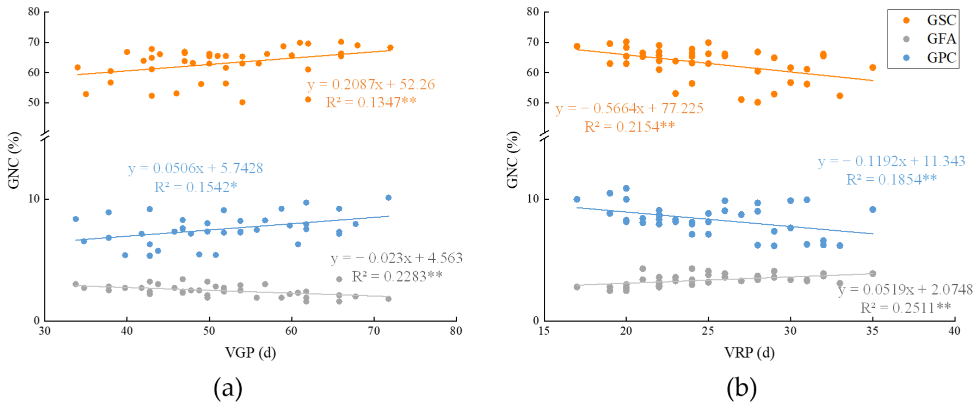

Figure 5. The relationship between (**a**) VGP and VRP and (**b**) VGP and KNQ. Note: The lines represent the fitted regression trend line. Statistical significance is represented by asterisks (* $p < 0.05$, ** $p < 0.01$).

The correlation between the length of the growth stage and the KNQ of maize was analyzed using KFA and KPC as examples (Figure 6). EV and MV maize had long VGP, averaging 57 days, and short VRP, averaging 23 days. They had low KFA and high KPC.

LV maize had short VGP, averaging 44 days, and long VRP, averaging 30 days. In addition, it had high KFA and low KPC. Thus, the differences in KNQ of different varieties of maize may be caused by the different lengths of the VGP and VRP.

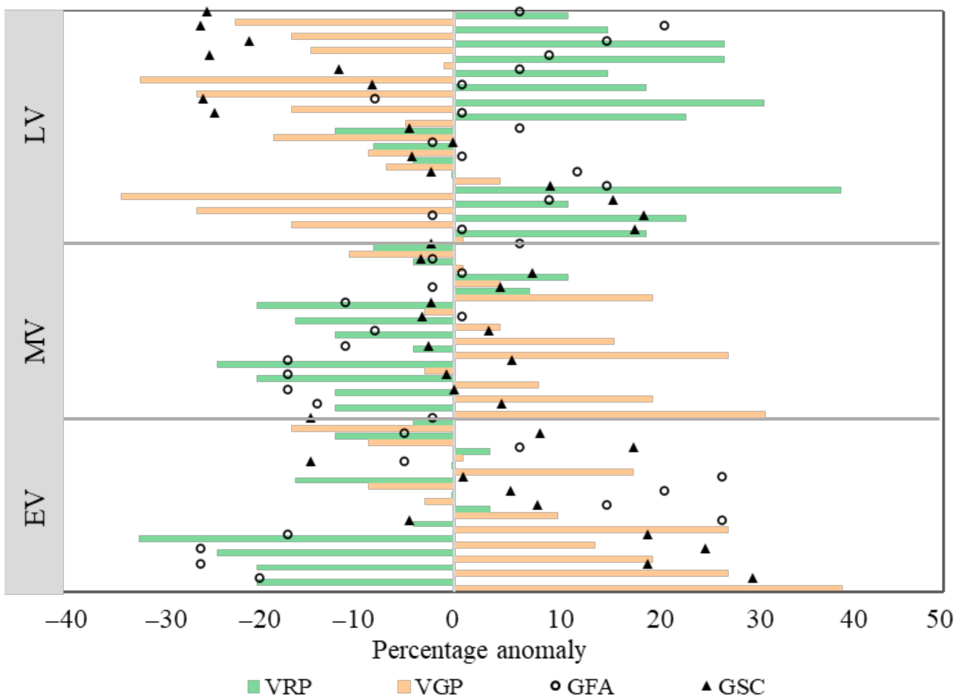

Figure 6. The anomaly percentage of the length of growth stage days, KFA, and KPC of maize with different varieties in the period 2018–2021.

4. Discussion

Genetic and environmental factors determine nutrient formation in maize kernels. Genetic factors refer to the genetic modes and characteristics that determine the traits of maize varieties, whereas environmental factors contain soil conditions, cultivation practices, and meteorological conditions. Among these, genetic factors, soil conditions and cultivation practices are relatively stable, whereas climatic conditions are the main reason for the fluctuation in maize kernel nutritional components. Light, temperature, and water are the basic elements required for the growth and development of maize and the formation of kernel nutrients [36,37]. Light and heat can influence crop growth and development and nutrient transport and distribution, thereby affecting kernel nutrient synthesis and accumulation [38]. In this study, we found that the more light and heat resources during the RGP, the lower the KSC and KPC and the higher the KFA, which is consistent with the results of Wang et al. [24]. However, Butts et al. [39] believed that appropriate low temperature during anthesis to filling period was conducive to the increase in maize KFA, which was different from the result of this study. Based on this, we can find out the key period of the effects of climatic resources on KNQ by refining maize growth stages in the following research. Barutcula [40] found that water stress at the kernel-filling stage had little effect on KPC and KFA, whereas this study suggests that water during RGP significantly affected them. This may be related to the different maize varieties and growth stages.

The results revealed significant differences in KNQ among the different mature varieties of NEC. The KSC and KPC of EV and MV maize were significantly higher than those of LV maize, and the KFA was significantly lower than that of LV maize. Further analysis showed that the VGP was significantly longer in EV and MV maize, whereas the VRP was significantly shorter in LV. Additionally, VGP was significantly positively correlated with KSC and KPC and significantly negatively correlated with KFA, whereas VRP showed the opposite trend. Therefore, the difference in the length of the growth stage of different mature varieties may be one of the reasons for the difference in KNQ. Yu et al., suggested that balancing the use of heat resources before and after flowering in regions with limited heat resources was crucial for achieving sufficient biomass accumulation before flowering, supporting the current study's conclusion [41].

The current study focused on five main maize varieties planted in NEC. Although the number of varieties selected was limited, the maize varieties used in the current study represented the KNQ of the varieties in this region to some extent. Nowadays, the KNQ is very important to people's production and life. For a long time, people have paid more attention to maize yield than KNQ, resulting in less data and research on the KNQ. The mechanism of the effects of sowing dates and climatic resources on maize KNQ is the key and difficult point, so the continuous observation of the dynamic content of KNQ can be added in future research. More maize varieties should also be considered to improve the accuracy of the results for better theoretical value and practical significance. The results of this study can also provide a data basis for model simulations of KNQ in NEC.

5. Conclusions

Based on the field experiments, we concluded that the effect of the sowing date on the KNQ of studied maize varieties was different. Suitably delaying the sowing date increased the KPC of EV maize, and appropriately advancing the sowing date increased the KFI of MV and LV maize. The differences in the KNQ of studied varieties may be due to the lengths of VGP and VRP. Long VGP and short VRP resulted in low KFA and high KPC and KSC. Short VGP and long VRP resulted in high KFA and low KPC and KSC. In the RGP, light and heat resources suppress the KSC and KPC but promote the KFA. The diurnal temperature range negatively affected KFA but promoted KPC. Precipitation may negatively affect KFI and KPC but positively affect KFA.

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