RESPONSE OF KERNEL STRUCTURE-RELATED TRAITS TO PLANTING DENSITY AND CULTIVAR IN DIFFERENT PARTS OF THE WAXY CORN EAR

XUE, J. F.[1,2*] – CUI, W. H.[1,2] – LIU, C. B.[1,2] – LIU, K. K.[1,2] – ZHAO, X. H.[3] – GAO, Z. Q.[1,2]

[1]*College of Agriculture, Shanxi Agricultural University, Taigu County, Shanxi Province, 03l0801, China*

[2]*State Key Laboratory of Integrative Sustainable Dryland Agriculture (in preparation), Taiyuan 030031, China*

[3]*College of Life Sciences, Shanxi Agricultural University, Taigu 030800, China*

**Corresponding author*
e-mail: fudange95@163.com

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Abstract. Kernel structure-related traits are important factors that affect the yield and ear appearance of waxy corn (*Zea mays* L. var. ceratina), regulated together by genetic factors and cultivation practices. Two planting densities, 52500 plants/ha and 67500 plants/ha, were established in this study for three major cultivars that are promoted in the local region: Jinnuo 18# (JN18), Jinnuo 20# (JN20), and Jindannuo 41# (JdN41). We measured how the kernel length, width, thickness, volume, 100-kernel weight, and kernel weight of different parts of the waxy corn ear changed with planting density and cultivar. The results showed that planting density did not significantly affect the structure-related traits of kernels in different parts of the waxy corn ear. Most of the kernel structure-related traits in the middle and basal parts were significantly higher than those in the apical part of the waxy corn ear. Compared with planting density, cultivar had a greater influence on kernel structure-related traits in waxy corn. Comparison between different cultivars showed that the kernel structure-related traits in JN18 were better than those in JdN41.
Keywords: *kernel size, kernel shape, kernel volume, traits of kernel structure, kernel morphological traits*

Introduction

Waxy corn (*Zea mays* L. var. ceratina) is commonly consumed in most Asian countries, particularly China, Korea, Tailand, and Vietnam (Lim and Yi, 2019; ÖZata, 2021; Kim et al., 2022). With the fast growth of the economy in China, the average household income is rising rapidly and the quality of life is also improved greatly. Consequently, food consumption patterns rapidly transitioned from one in which grains and vegetables dominated to one having more animal products and more diversification in China (Yuan et al., 2019). Increasingly more people have begun to emphasize healthy eating and nutritional balance. Waxy corn is rich in various amino acids, vitamins, and minerals, giving it extremely high nutrition values and making it favored by many consumers (Xiao et al., 2022). Currently, the planting area of fresh corn has reached 1.34 million hectares, and which has become the largest consumers and producers of fresh corn in the world (Huang et al., 2022; Xiao et al., 2022). Taste is among the important parameters used to evaluate the eating quality of waxy corn. The kernel structure traits (kernel length, width, thickness, and volume) have a major influence not only on the yield but also the taste of waxy corn (Jung et al., 2005). In recent years,

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kernel structure-related traits have become the target of selection by breeders to obtain a higher yield of common corn (Yang et al., 2016; Li et al., 2019, 2022; Qu et al., 2022).

Kernels of corn ear have different shape-related traits due to the influences of genetic factors (Li et al., 2009, 2022; Liu et al., 2020; Pang et al., 2021; Qu et al., 2022) and cultivation practices (Abdelghany et al., 2019; Zhang et al., 2021). Generally, kernel abortion can appear in the apical kernels (Otegui et al., 1995; Shen et al., 2005), causing an increased barren tip length and a decrease in the quality of physical appearance. Furthermore, kernels that develop in different parts of the ear exhibited large differences. In some studies, kernels are divided into apical, middle, and basal sets based on their positions on the ear. The results have shown that the basal kernels exhibited the greatest 100-kernel weight, followed by that of the middle kernels, and the apical kernels had the lowest 100-kernel weight (Zhang, 2010; Xu et al., 2013a, 2015). Moreover, the moisture content of kernels in the apical part of the ear were lower than those in the middle and basal parts during the middle and late stages (Li et al., 2020). Currently, most studies on the kernel structure-related traits at different positions of the ear have been conducted in common corn and have focused more on kernel weight, overlooking kernel length, width, thickness, and volume. Better understanding the differences in kernel structure-related traits between different parts of the corn ear will help improve the eating quality of waxy corn ears.

Currently, kernel structure-related traits have not been widely studied, and such studies are mostly concentrated on common corn with breeding-related purposes, while the impact of cultivation practice has rarely been studied. With the increase in planting density, the 100-kernel weight, kernel length, and kernel width decreased, while the kernel thickness had no significant changes (Wang, 2016). The kernel volume also decreased with the increase in planting density, but the degree of decrease was different in different cultivars for common corn (Xu et al., 2013b). However, there has been little research on the impact of cultivar and planting density on kernel structure-related traits in waxy corn. Currently, the majority of common corn are compact-types of plant with higher planting density (>67500 plants/ha), however, most of waxy corn are flat-type of plant with lower planting density (<52500 plants/ha). Otherwise, there are great difference in kernel morphological characteristics between common corn and waxy corn. Those would result in the difference in kernel formation and its structure-related traits. Elucidating the influences of planting density and cultivar on kernel structure-related traits in waxy corn is important for increasing the yield of fresh waxy corn and improving the eating quality of kernels.

In this study, we analyzed the differences in kernel structure-related traits, including 100-kernel weight, kernel length, width, thickness, and volume, in different parts of the ear of waxy corn of different cultivars at different planting densities. Our goal was to provide a theoretical reference for improving the eating quality of waxy corn ears.

Materials and methods

Experimental site

The experiment was conducted in Luojiazhuang Village, Qingyuan Town, Qingxu County, Taiyuan, Shanxi (37°58’ N, 112°36’ E), which was located in the Eastern Loess plateau. It has a temperate continental climate, with four distinct seasons. The mean annual sunshine duration is 2577.5 h. The mean annual temperature is approximately 9.9 ℃. The mean annual precipitation is approximately 462 mm. The

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mean annual frost-free period is 183 days. The preceding crop at the test site was common corn. Organic matter in the 0-20 cm soil layer was 15.20 g/kg, with alkali-hydrolyzale nitrogen 59.06 mg/kg, available phosphorus 33.76 mg/kg, and available potassium 209.32 mg/kg.

Experimental design

This study used a two-factor randomized block design, three waxy corn cultivars (Jinnuo 18# (JN18, white), Jinnuo 20# (JN20, black), and Jindannuo 41# (JdN41, yellow)), and two planting densities (52500 plants/ha (PD_{52500}, conventional density) and 67500 plants/ha (PD_{67500}, high density)). Each treatment had three replicates in a total of 18 plots, each plot had an area of 50 m^2 (10 m × 5 m). In early April, the test site was watered with flood irrigation. Before sowing, each plot was fertilized with a compound fertilizer (N:P:K = 23:12:5) as the base fertilizer at 600 kg/ha. After rotary tillage, waxy corn were planted with 50 cm of row distance in all plots. The plant distance within a row were 41.67 cm and 32.35 cm in density of 52500 plants/ha and 67500 plants/ha, respectively. Urea was applied at 337.5 kg/ha through ditches at the jointing stage. Seeds were sown on May 17. On May 26 and July 4, a mixture of cypermethrin, chlorpyrifos-phoxim EC, and chlorpyrifos was applied twice to kill pests. At the flowering stage, plants were bagged, and hand pollination was conducted to prevent crossing. The optimal harvest time was different for different waxy corn cultivars. JdN41 and JN18 were harvested on August 21, and JN20 was harvested on August 29.

Kernel structure-related traits in different parts of the ear

At the optimal harvest time, 10 ears were randomly selected from each plot. Here, we divided the ear of waxy corn into three equal parts depending on the length of the ear, including apical (the upper third of the ear), middle (the middle third of the ear), and basal (the lower third of the ear) parts from the top to bottom of the ear. From each ear, kernels were removed and weighed. The kernel weight (g) in each part was recorded. One hundred kernels were randomly selected to measure the 100-kernel weight (g).

Among the kernel samples, 10 kernels were randomly selected from each of the apical, middle, and basal parts. The kernel size parameters such as length, width, and thickness (mm) were measured using a Vernier caliper. The length/width, length/thickness, and width/thickness ratios of each kernel were calculated for the evaluation of kernel shape. In addition, 10 apical, 10 middle, and 10 basal kernels were randomly selected from each plot and placed individually in a 20-mL graduated cylinder with 10 mL distilled water. The cylinder was shaken until the kernels were completely submerged in water. The changes in water volume were taken to be the kernel volume (mL) and converted to single-kernel volume (cm^3). The measurement was repeated 10 times for each plot.

Data analysis

WPS Office 2019 was used for data sorting and graphing. SPSS 16.0 was used for statistical analysis of the data. Duncan’s multiple range test was conducted to analyze the differences among different planting densities and cultivars. Pearson correlation analysis of different parameters was conducted in SPSS 16.0, and R 4.0.3 software (R Core Team, 2020) was used to graph the correlation coefficients.

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Results

The cultivars of waxy corn had a significant effect on most of kernel structure-related traits, e.g., kernel length, width, thickness, kernel length/thickness and width/thickness ratios (*Table 1*). Planting density of waxy corn had no effect on kernel structure-related traits in different ear parts in the study.

Table 1. *Analysis of variance for kernel structure-related traits in different ear parts*

Source of variation	KL			KW			KT		
	Apical	**Middle**	**Basal**	**Apical**	**Middle**	**Basal**	**Apical**	**Middle**	**Basal**
WCC	*	*	*	ns	*	*	**	**	ns
PD	ns	ns	ns	ns	ns	ns	ns	ns	ns
WCC × PD	ns	ns	ns	ns	ns	ns	ns	ns	ns
Source of variation	**KL/WR**			**KL/TR**			**KW/TR**		
	Apical	**Middle**	**Basal**	**Apical**	**Middle**	**Basal**	**Apical**	**Middle**	**Basal**
WCC	*	ns	ns	*	**	*	*	**	**
PD	ns	ns	ns	ns	ns	ns	ns	ns	ns
WCC × PD	ns	ns	*	ns	ns	ns	ns	ns	ns
Source of variation	**KV**			**100-KW**			**KWE**		
	Apical	**Middle**	**Basal**	**Apical**	**Middle**	**Basal**	**Apical**	**Middle**	**Basal**
WCC	ns	ns	ns	ns	ns	ns	ns	ns	ns
PD	ns	ns	ns	ns	ns	ns	ns	ns	ns
WCC × PD	ns	ns	ns	ns	ns	ns	ns	ns	*

WCC is waxy corn cultivars, PD is planting density, KL is kernel length, KW is kernel width, KT is kernel thickness, KL/WR is kernel length/width ratios, KL/TR is kernel length/thickness ratios, KW/TR is kernel width/thickness ratios, KV is kernel volume, 100-KW is 100-kernel weight, KWE is kernel weight per ear. * and ** indicate significance at the 5% and 1% levels, respectively

Kernel size

Under two planting densities, the average kernel length, width, and thickness in different parts of the ear was 9.56-10.12 mm, 8.53-8.95 mm, and 4.43-4.99 mm, respectively (*Fig. 1 I*, *III*, *V*). The apical, middle, and basal kernels of the waxy corn ear were not significantly different in length, width, or thickness under two planting densities. Analyzing kernel structure-related traits in different parts of the ear revealed that the average length and width of apical kernels were 4.7% and 2.4% less than those of middle kernels, respectively, and 2.8% and 4.4% less than those of basal kernels ($p < 0.05$). Middle kernels were significantly longer by 1.9% than basal kernels, while the average width of middle kernels was significantly lower by 2.1% than that of basal kernels ($p < 0.05$). The average thicknesses of apical and basal kernels were not significantly different, however, they were significantly greater than that of middle kernels, by 4.5% and 6.4%, respectively ($p < 0.05$).

Comparison of kernel structure-related traits among different cultivars showed that the lengths of the apical, middle, and basal kernels followed the order of JN18 > JN20 > JdN41 ($p < 0.05$), with significant differences between cultivars, and that the kernel lengths in JN18 were 4.9-16.4% longer than those in other cultivars (*Fig. 1 II, IV, VI*). The apical, middle, and basal kernels of JN18 were significantly wider than those of JN20 by 5.7-6.7% and JdN41 by 5.4-8.9% ($p < 0.05$), respectively,

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while the difference in kernel width between the latter two cultivars was not significant. The kernel thicknesses were significantly lower in JN18 than those in JdN41 and JN20, by 9.2-15.3% and 9.3-17.9% ($p < 0.05$), respectively, and which were inconsistent in different ear parts of the latter two cultivars.

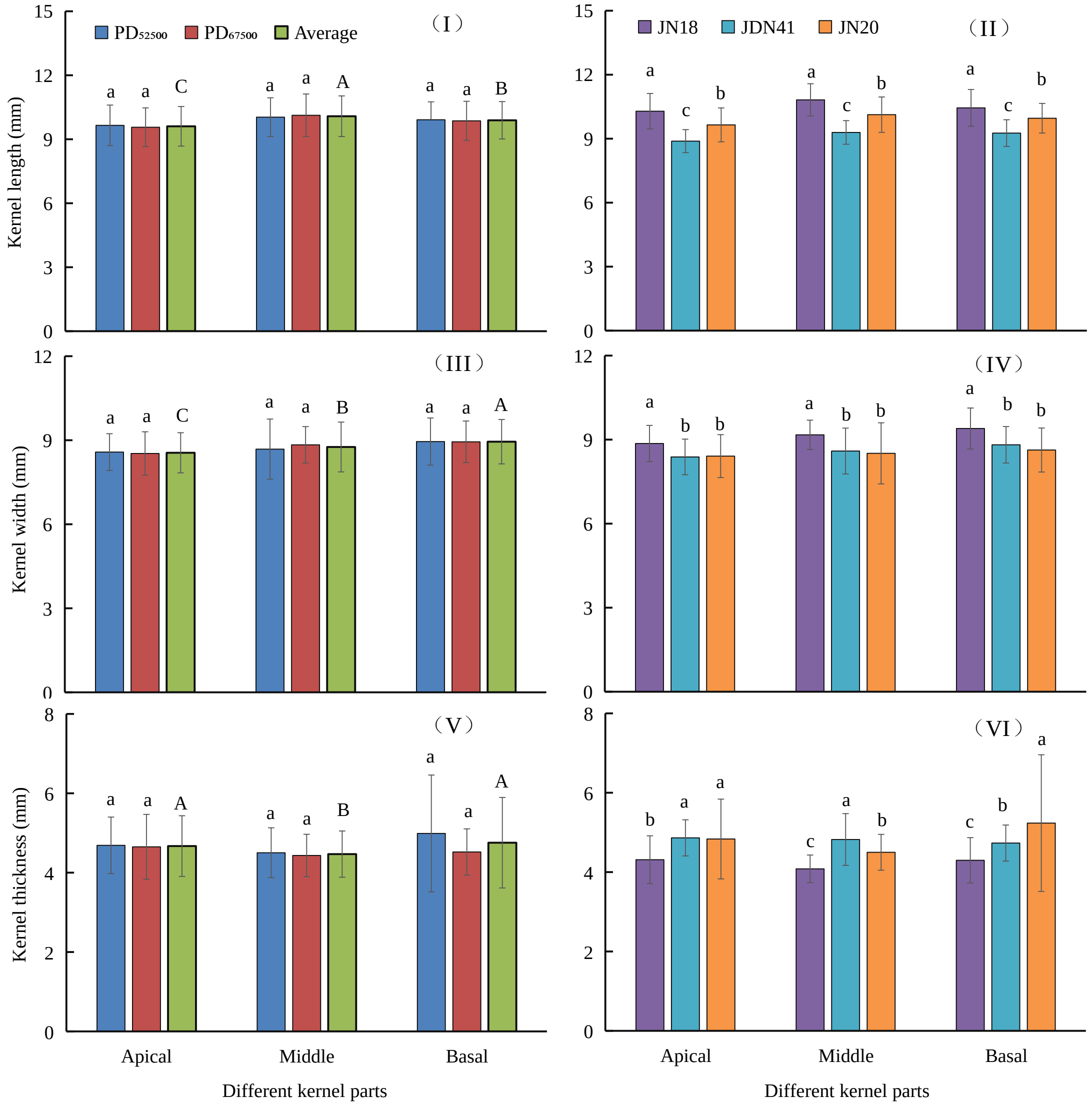

***Figure 1.** Effects of planting density and variety on length, width and thickness in different parts of waxy corn ear. The lowercase letters indicate statistical difference among different planting density or cultivars in the same sample position at p < 0.05. The capital letters in (I), (III), and (V) indicate statistical difference among different parts of waxy corn ear, which are the average value under two planting densities*

Kernel shape

The average kernel length/width, length/thickness, and width/thickness ratios in different parts of the ear under two planting densities were 1.11-1.19, 2.10-2.32, and 1.87-2.02, respectively; there was no significant difference between the two planting densities (*Fig. 2 I, III, V*). Compared with the apical and basal kernels, the middle kernels had a significantly higher average length/width ratio (by 3.7-5.3%) and

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length/thickness ratio (by 6.2-9.0%) ($p < 0.05$). The apical kernels were significantly lower in the width/thickness ratio (by 6.0% and 4.3%, respectively) than the middle and basal kernels ($p < 0.05$); there was no significant difference between the latter two. A comparison between different cultivars showed that compared with JN20, the kernel length/width ratio in the three ear parts of JdN41 was significantly lower by 8.4-12.8% (*Fig. 2 II, IV, VI*, $p < 0.05$). The length/thickness ratio in the three parts of JN18 was significantly higher than those of the other two cultivars ($p < 0.05$). In addition, the length/thickness ratios of the apical and middle kernels were significantly lower in JdN41 than in JN20, however, the length/thickness ratio of the basal kernels was not significantly different between the two cultivars. JN18 had a significantly higher kernel width/thickness ratio in the three parts of the ear than JdN41 and JN20 (by 18.4-25.6%) ($p < 0.05$), while the latter two cultivars had no significant difference.

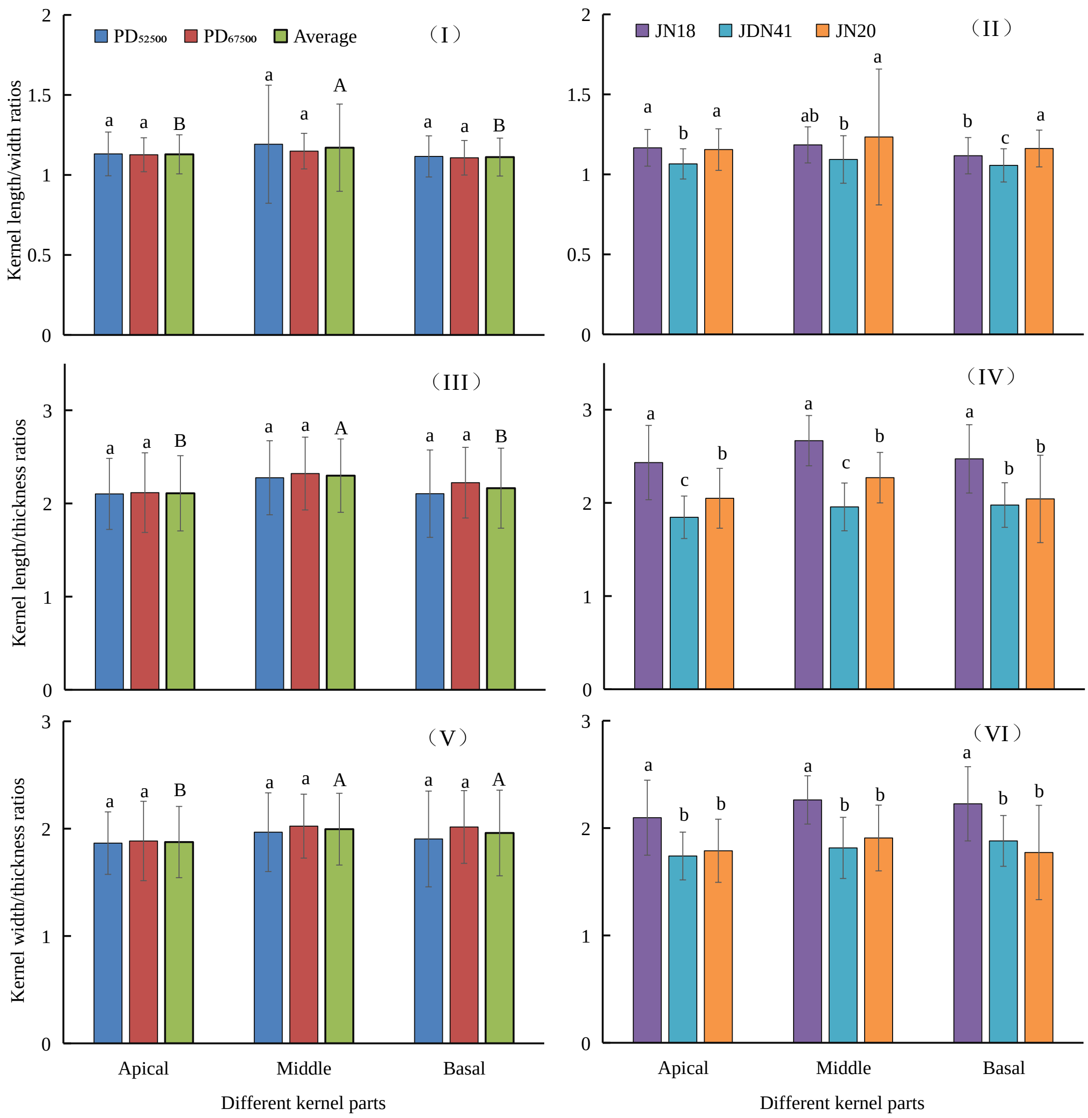

Figure 2. *Effects of planting density and variety on kernel shape in different parts of waxy corn ear. The lowercase letters indicate statistical difference among different planting density or cultivars in the same sample position at p < 0.05. The capital letters in (I), (III), and (V) indicate statistical difference among different parts of waxy corn ear, which are the average value under two planting densities*

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Kernel volume

The single-kernel volume in the apical, middle, and basal parts of the waxy corn ear were 0.28-0.30 cm^3, and there was no significant difference between the two planting densities (*Fig. 3 I*). Single-kernel volume in the apical part was significantly lower by 6.1% and 7.6% than those in the middle and basal parts, respectively ($p < 0.05$). There was no significant difference in kernel volume in the apical part between cultivars (*Fig. 3 II*). The kernel volumes in the middle and basal parts of JN18 were significantly higher by 7.9% and 4.3% than those of JdN41 ($p < 0.05$), respectively, however, which were not significantly different from those of JN20.

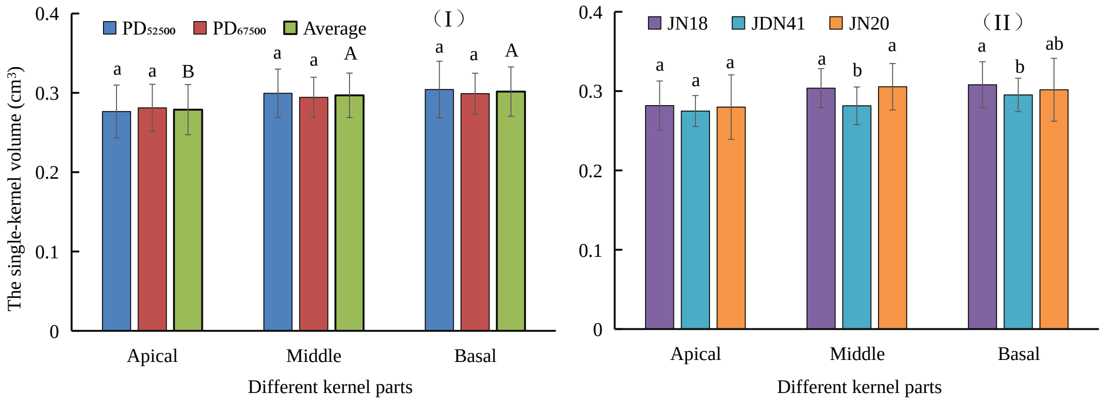

Figure 3. *Effects of planting density and variety on kernel volume in different parts of waxy corn ear. The lowercase letters indicate statistical difference among different planting density or cultivars in the same sample position at p < 0.05. The capital letters in (I) indicate statistical difference among different parts of waxy corn ear, which are the average value under two planting densities*

100-kernel weight

The average 100-kernel weight in the apical, middle, and basal parts of waxy corn ears ranged from 29.90 to 34.31 g, with no significant difference between the two planting densities (*Fig. 4 I*). The 100-kernel weight in the apical part was significantly lower by 10.0% and 10.1% than those in the middle and basal parts, respectively ($p < 0.05$). Comparing the different cultivars (*Fig. 4 II*), the 100-kernel weights of kernels in the apical and middle ear of JdN41 were significantly lower by 1.6% and 4.5% than those of JN20, respectively ($p < 0.05$), however, which exhibited no significant difference in the 100-kernel weight in the basal part. In addition, the 100-kernel weights of kernels in the middle and basal parts of JN18 were both significantly higher than those of JdN41 ($p < 0.05$).

Kernel weight per ear

The apical, middle, and basal kernels of waxy corn ears weighed 50.38-69.89 g, and there was no significant difference between the two planting densities (*Fig. 5 I*). Kernel weight in different parts of the ear followed the order of basal > middle > apical; the differences between each part were significant (*Fig. 5 I*, $p < 0.05$). Compared with JN18 (*Fig. 5 II*), JdN41 and JN20 were significantly lower by 12.6-16.9% and 15.3-18.2% in kernel weight in the apical and middle parts of the ear, respectively ($p < 0.05$), while the

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differences between the latter two cultivars were not significant. There was no significant difference in kernel weight in the basal part of the ear between JN18 and JN20, however, they were both significantly higher than that in JdN41 ($p < 0.05$).

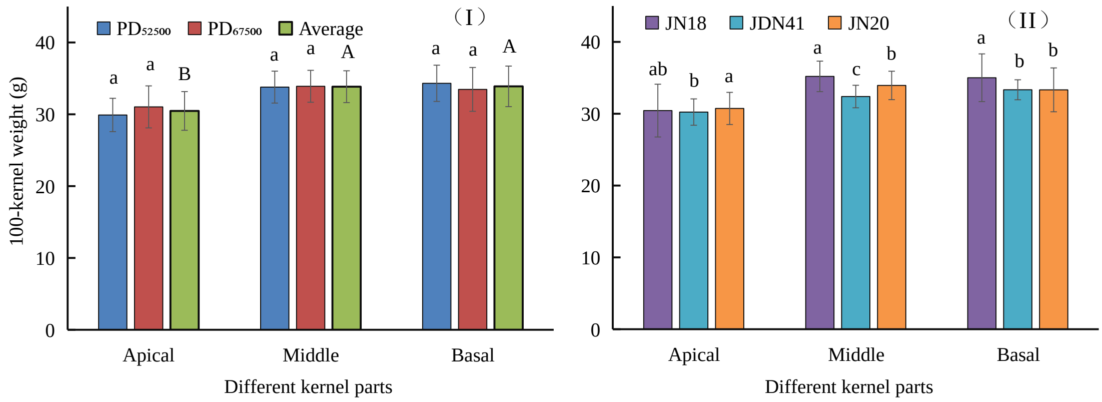

Figure 4. *Effects of planting density and variety on hundred-grain weight of waxy corn in different parts of ear. The lowercase letters indicate statistical difference among different planting density or cultivars in the same sample position at p < 0.05. The capital letters in (I) indicate statistical difference among different parts of waxy corn ear, which are the average value under two planting densities*

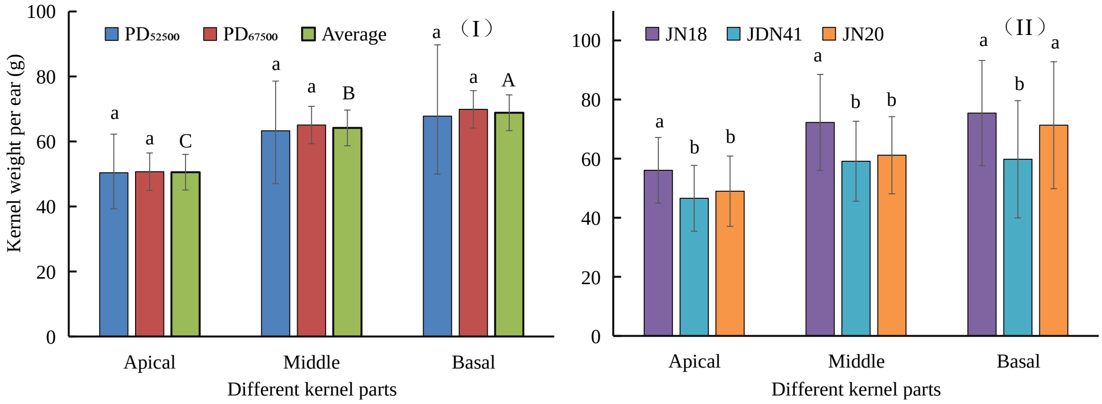

Figure 5. *Effects of planting density and variety on weight of grain per ear of waxy corn. The lowercase letters indicate statistical difference among different planting density or cultivars in the same sample position at p < 0.05. The capital letters in (I) indicate statistical difference among different parts of waxy corn ear, which are the average value under two planting densities*

The correlation among kernel structure-related traits

The correlation among kernel structure-related traits of waxy corn were shown in *Figure 6*. Positive correlation between kernel length and kernel width were presented ($p < 0.001$). However, negative correlation between kernel thickness and kernel length ($p < 0.001$) was observed, similar trend was showed between kernel thickness and kernel width ($p < 0.01$). Moreover, there were positive effects of kernel length and kernel width on 100-kernel weight and kernel weight per ear ($p < 0.001$), while on

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which were negative effects of kernel thickness. In addition, kernel length/thickness and width/thickness ratios had significant positive effects on kernel volume, 100-kernel weight and kernel weight per ear.

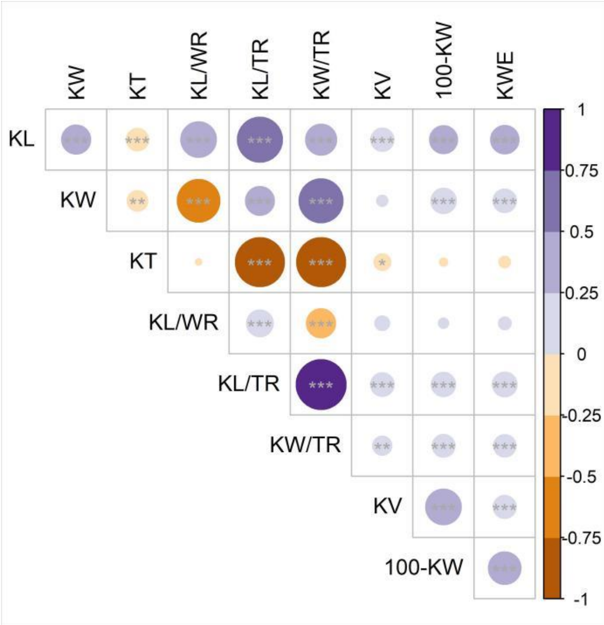

Figure 6. *The correlation coefficient plot among kernel structure-related traits. Significant correlation at *0.05, **0.01, and ***0.001 levels. KL is kernel length, KW is kernel width, KT is kernel thickness, KL/WR is kernel length/width ratios, KL/TR is kernel length/thickness ratios, KW/TR is kernel width/thickness ratios, KV is kernel volume, 100-KW is 100-kernel weight, KWE is kernel weight per ear*

Discussion

Analysis of kernel structure-related traits in different parts of the waxy corn ear

The differences in the development of kernels in different parts of the ear could lead to differences in kernel structure-related traits. So far, researches on kernel structure-related traits in different parts of the ear have mostly concentrated on common corn and on studying kernel weight (Wei et al., 2019; Yin et al., 2021), however, which in waxy corn are rarely studied. Most studies have shown that the 100-kernel weight in different parts of the ear follows the order of basal > middle > apical (Zhang, 2010; Xu et al., 2013a), while some studies showed that the distribution of ^{14}C-assimilates followed the order of middle > basal > apical (Xu et al., 2015). In this study, we found that kernel length, width, volume, 100-kernel weight, and kernel weight in the apical part of the ear were all significantly lower than those in the middle and basal parts. Moreover, the length/width and length/thickness ratios in the apical part of the ear were significantly lower than those in the middle part of the ear. Generally, floret development, silking, and pollination occur earlier in the middle and basal parts of the ear than in the apical part, which could inhibit the growth of florets in the apical part (Cárcova et al., 2000). Thus, compared with the kernels in the middle and basal parts, kernels in the apical part exhibit worse grain-filling and lower kernel weight and therefore are inferior kernels (Zhang, 2010). The volume and size of kernels in the apical part is also inhibited to a certain extent. Focusing on the breeding of a cultivar with good kernel shape in the

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apical part of the ear is necessary for increasing waxy corn yield and improving its physical appearance.

In recent years, kernel structure-related traits in corn have gradually become the target of selection by breeders (Li et al., 2009). Some results showed that kernel length exhibits a high positive correlation with yield in common corn (Li et al., 2009; Veldboom et al., 1994; Veldboom et al., 1996), however, relevant information in waxy corn is scarce. Moreover, the correlation between kernel structure-related traits and yield in waxy corn has not been reported. There has been very little study of the relationship between kernel structure-related traits and yield components. The correlation analysis conducted in this study found that the kernel weight and 100-kernel weight in waxy corn exhibited positive correlations with kernel length, width, and volume (*Fig. 6*).

The mechanism of the interaction between kernel weight and kernel structure-related traits remains unclear. Some researchers used common corn and synchronous hand pollination to eliminate the influence of the timing of pollination on floret development in different parts of the ear. The kernels in the top 3-13 kernel rings of the ear were apical kernels, and the kernels in the middle and basal 23-33 rings were middle and basal kernels. These studies showed that kernel weight, number of endosperm cells, sucrose, and total sugar in the middle and basal kernels of the ear were higher than those in the apical kernels. The difference in the assimilate-holding capacity of kernels and the imbalance of the supply of assimilates may be one reason for the differences in kernels between different parts of the ear (Shen et al., 2005; Zhang et al., 2010). Differences in kernel structure-related traits in different parts of the ear could also be related to the type and cultivar of the corn and how different parts of the ear are divided (Xu et al., 2015).

Impact of planting density on kernel structure-related traits in waxy corn

As a consumer product, waxy corn is usually sold as single ears; increasing planting density is important for boosting profits. Kernel structure-related traits in waxy corn are closely related to its taste and its marketability. Studies on kernel structure-related traits have mostly focused on common corn and rarely on waxy corn. Some studies showed that as the planting density increased, the 100-kernel weight, kernel volume, length, and width decreased, while the kernel thickness had no clear pattern of change (Wang, 2016; Peng et al., 2011). Kernel structure-related traits in corn, including 100-kernel weight, kernel length, and kernel width, are not easily influenced by the external environment (Yang et al., 2016; Zhang et al., 2006). In this study, kernel size, shape, volume, 100-kernel weight, and kernel weight in different parts of the ear in waxy corn exhibited no significant difference between the two planting densities. Proper close planting is one of the best ways to increase yield and economic benefits of waxy corn. If the planting density is too low, population spatial structure becomes inappropriate, which would lead to inappropriate soil utilization and a waste of light energy. Too high of a planting density will lead to shading between individuals and competition over resources, including water, fertilizer, air, and heat (Cárcova et al., 2000; Wang et al., 2017) resulting in a yield reduction and worsened quality of physical appearance and edibility. In a literature review, we found that the planting density in recent studies on different waxy corn cultivars was 37,500-75,000 plants/ha (Cao et al., 2018; Tan et al., 2019; Doebley et al., 2006; Borrás and Otegui, 2001). In farmers' actual practice, it is generally 52,500 plants/ha. In this study, the 100-kernel weight, kernel length, and

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kernel width in waxy corn exhibited no significant difference after the planting density was increased to 67,500 plants/ha. This indicated that increasing planting density in waxy corn is feasible to a certain extent. However, it will be influenced by soil fertility and management technologies. Differences in the results may be related to the differences in the gradient of established planting densities, corn type and cultivar, field management, climate conditions, and soil type in different studies. A multiyear, multilocation, comprehensive experiment is needed to study this matter in greater depth.

Impact of cultivar on kernel structure-related traits in waxy corn

Genetic makeup is one of the most important factors that affect kernel structure-related traits in waxy corn. In this study, we found that kernel structure-related traits, including kernel size and shape, exhibited significant differences between different waxy corn cultivars and that cultivar a greater influence than planting density. This also indicated that kernel structure-related traits are influenced more by genetic factors in waxy corn. Particularly, the kernel weight, 100-kernel weight, kernel length, width, length/width ratio, length/thickness ratio, width/thickness ratio in JN18 were significantly higher than those in JdN41 but were similar to those in JN20. JdN41 was approved by the Shanxi Crop Cultivar Approval Committee in 2001, and JN18 and JN20 were approved in 2018 and 2019, respectively. The promotion of JdN41 application in production was earlier, while JN18 and JN20 are newly bred and approved cultivars that may have more advantages in adapting to social needs and might better satisfy consumers' needs.

Kernel structure-related traits in waxy corn and taste

Currently, consumers' demand for waxy corn is increasing, and the requirement for the quality of physical appearance and palatability continues to rise. The yield and the physical appearance of waxy corn are closely related to kernel weight and kernel structure-related traits (Doebley et al., 2006). The 100-kernel weight is one of the major yield components, while kernel volume, size, and shape are related to its physical appearance and palatability. We believe that suitable length, width, and thickness could impact the experience of biting and chewing the kernels. Too long (or short), too wide (or narrow), or too thick (or thin) kernels could cause an uncomfortable eating experience. A brief survey showed that during corn consumption, the taste of kernels in the apical part of the corn was worse than that of kernels in the middle and basal parts. However, there is no available scientific evidence on this topic. In our upcoming work, we are going to evaluate the relationship between taste and different kernel structure-related traits through sensory analysis. In addition, the physical appearance and kernel arrangement may be other important factors that influence consumers' selection of waxy corn, and these factors also need more in-depth investigation. These aspects will provide new ideas and directions for waxy corn breeding, such as using kernel structure-related traits (100-kernel weight, volume, and size) to select waxy corn cultivars (Li et al., 2009).

Limitations

The comparisons and analyses of the samples in this study allow for preliminary but clear conclusions. However, only a one-year field experiment was conducted in one locale in this study. Because of factors such as climate conditions, the reproducibility of

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our results needs to be tested via multiyear, multilocation experiments. Second, this study selected three waxy corn cultivars for comparison, including JN18 (white), JN20 (yellow), and JdN41 (yellow). These three cultivars are promoted well at the local market and are thus representative waxy corn cultivars in the local region. In this study, one representative cultivar was selected from among the waxy corns of each color for comparison. Next, we will increase the number of waxy corn cultivars that have the same color and thoroughly analyze their kernel structure-related traits. Third, we think that kernel structure-related traits in waxy corn are closely related to the eating experience, but there is a lack of in-depth study on this aspect, a subject of our future work. We will also evaluate the consumers' preferences from the perspectives of kernel arrangement, color, and size. Our goal is to provide new directions for the breeding of waxy corn. Moreover, we compared kernel structure-related traits of waxy corn between two planting densities in current study, including the conventional density of 52500 plants/ha and higher density of 67500 plants/ha. We mainly observed the difference in structure-related traits under higher densities than conventional density, not trying to obtain the optimum density. In future studies, we will set up 4~6 more densities to obtain the optimal planting density.

Conclusions

Kernel structure-related traits in different parts of the waxy corn ear exhibited significant differences, these traits being significantly inferior in the apical part compared to the middle and basal parts. Strengthening the breeding of cultivars with better kernel structure-related traits in the apical part has practical significance. In the current study, planting density had no significant impact on kernel structure-related traits in different parts of the waxy corn ear. In contrast, cultivar had a significant impact on kernel structure-related traits.

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