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Effects of Sowing Time and Growing Density on Agronomic Traits, Grain Yield, and Grain Quality of Waxy Sorghum Cultivar Hongliangfeng 1

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Abstract

The aim of this study was to determine the effects of sowing time and growing density on the yield and quality of grain in waxy sorghum (*Sorghum bicolor* L. Moench). The main plots were two sowing time: early sowing (5 April) and late sowing (20 April), and the subplots were three growing densities: 0.8×10^5, 1.1×10^5, and 1.4×10^5 plants/ha. Results showed that sowing time and growing density had significant effects on grain yield and grain quality of waxy sorghum cultivar Hongliangfeng 1. Grain yield, plant height, spike length, culm diameter, grain number per spike, grain weight per plant, 1000-grain weight, protein content, starch content, and amylopectin content were reduced by a delay of sowing time, while the tannin content and amylose content were increased by a delay of sowing time. Grain yield, plant height, spike length, culm diameter, grain number per spike, grain weight per plant, 1000-grain weight, protein content, starch content, and amylopectin content increased and then decreased with the increase of growing density, while the tannin content and amylose content decreased and then increased with the increase of growing density. These results hinted that appropriate sowing time and growing density are key cultivation measures to ensure high yield and good quality in waxy sorghum production.

Keywords: growing density, sowing time, grain yield, grain quality, sorghum

1. Introduction

Sorghum (*Sorghum bicolor* L. Moench) is the world's fifth-largest food crop after corn, wheat, rice, and barley, which is widely planted in tropical and semi-arid regions of the world (Awika et al., 2003; Borrell et al., 2014). It is also one of the earliest cultivated cereal crops in China (Ding et al., 2015). Sorghum has gradually become a model crop of cereal crops genome research due to its wide adaptability to environment, strong resistance, and relatively small genome (Paterson et al., 2009; Mace et al., 2013). In general, sorghum is divided into three types, sweet sorghum, forage sorghum, and grain sorghum according to its different purposes (Bibi et al., 2012). Waxy sorghum belongs to grain sorghum, which is the main raw material for brewing Moutai flavor liquor and plays a crucial part in the development of China's regional economy (Wang et al., 2017a; Wang et al., 2017b). With the rapid development of the Moutai flavor liquor industry, the demand for waxy sorghum yield is increasing and the demand for waxy sorghum quality is becoming more and more strict (Zhou et al., 2008; Peng, 2011). Thus, how to improve the grain yield and quality of waxy sorghum is the key to the development of the Moutai flavor liquor industry.

In general, sorghum yield and quality are strongly dependent on climate conditions, fertilization, sowing time, growing density, irrigation, and soil types (Townend et al., 1996; Chipanshi et al., 2003; Ekeleme et al., 2011; Han et al., 2011; Jahanzad, 2013). Sowing time and growing density are two important factors for successful implementation of management measures in sorghum production (Almodares & Mostafafi Darany, 2006; Marsalis et al., 2010). Sowing time is an essential practice of crop management, which could be manipulated to better control sorghum growth (Ekeleme et al., 2011). Early sowing exposes the seeds to low soil temperatures which could destroy the seed integrity and reduce the germination rate of sorghum (Harris, 1996). Late sowing exposes the plants to drought risks and destroys the normal growth and development of plants that reduces the yield and quality of grain in sorghum (Petrini et al., 1993). Thus, the purpose of sowing time research is to increase grain yield and quality of sorghum by ensuring that the germination rate and accumulated temperature needed for growth, and development of plants are adequate. Reasonable growing density is an important prerequisite for high yield and good quality of sorghum (Berenguer & Faci, 2001; Marsalis et al., 2010; Wang et al., 2013). Low growing density results in big spike and high grain weight per plant because of large nutrient area per plant, full development of single spike, and good ventilation and light transmittance (Carmi et al., 2006; Godsey et al., 2011). However, low growing density leads to some problems such as low grain yield per unit area due to less plant number per unit area and insufficient photosynthesis area (Al-Bedairy et al., 2013). Conversely, high growing density leads to fierce competition among plants and increases the potential for cooperation, thus creating usable differences in the performance of individuals and groups, and results in low grain yield and poor grain quality because of poor ventilation and light transmittance, small nutrient area per plant, and underdeveloped single spike (Mosavi et al., 2009; Wang et al., 2016). Therefore, reasonable growing density can coordinate the relationship between groups and individuals, make individuals grow strong without premature aging, and ensure a certain number of population, which is advantageous to increase the potentials of grain yield and quality in sorghum.

Numerous studies have reported that sowing time and growing density exerts remarkable impacts on agronomic traits, grain yield, and grain quality of sweet and feed sorghum (Almodares & Mostafafi Darany, 2006; Carmi et al., 2006; Marsalis et al., 2010; Wang et al., 2013). Nevertheless, little is known about the effects of sowing time and growing density on agronomic traits, grain yield, and grain quality of grain sorghum, especially on the waxy sorghum for brewing Moutai flavor liquor. The purpose of this study was to assess the effects of sowing time and growing density on agronomic traits, grain yield, and grain quality and to determine the suitable sowing time and growing density for high yield and good quality in waxy sorghum.

2. Materials and Methods

2.1 Experimental Location

Field experiments were carried out during 2016 and 2017 in Haohuahong Village (26°18′ N and 106°22′ E), Haohuahong Town, Huishui County, Qiannan State, Guizhou Province, China. The village is located 85 km south of Guizhou Academy of Agricultural Sciences at an elevation of 1050 m above sea level. Annual mean temperature is 16.20 °C. Annual precipitation is 1250 mm. The frost-free period is 290 days. The region has a subtropical humid temperate climate.

2.2 Experimental Design

Hongliangfeng 1, a waxy sorghum cultivar specially used to brew Moutai flavor liquor, which was authorized by the Guizhou Provincial Crop Cultivar Certification Committee (Guiyang, Guizhou, China) in 2016. It is widely grown in the sorghum growing region of Guizhou province.

Field experiments were conducted using a split plot design and replicated three times. The main plots were two sowing time: 5 April (early sowing, S1) and 20 April (late sowing, S2). The subplots were three growing density: 0.8×10^5 plants/ha (low, P1), 1.1×10^5 plants/ha (usual, P2), and 1.4×10^5 plants/ha (high, P3). Each plot was 9 m long, 3.5 m wide, about 70 cm apart, and consisted of five rows. There were three protected rows around each plot. Compound fertilizer (containing 15% N, 15% P_2O_5, and 15% K_2O) was used as a basal fertilizer at a dose of 450 kg/ha at sowing time. Final singling was performed at the three-leaf stage. Urea (containing 46.4% N) was used as additional fertilizer at a dose of 300 kg/ha at the jointing stage. The prevention measures of fungicides, pesticides, herbicides were applied to prevent diseases, pests, and grasses in both seasons. No significant occurrence of diseases, pests, or grasses and no impacts on sorghum growth were found in both seasons.

2.3 Determination of Agronomic Traits, Grain yield, and Grain quality

Plant height, spike length, and culm diameter were measured at three days before harvest. Five plants were selected randomly from each plot, excluding the guard rows. Plant height was measured as distance from the base of culm to the top of plant and spike length as distance from the base of spike to the top of spike. Culm diameter refers to the diameter of the 2nd internode at the bottom, and was determined by a vernier caliper (Forgestar 7D-01150, Shanghai, China). At maturity, all plants were hand-harvested. Grain number per spike was measured with an automatic particle meter (Dacheng SLY-C, Hangzhou, China). For grain weight per plant, 1000-grain weight, and grain yield, seeds were determined after being dried for seven days.

Seed samples were refrigerated until grain quality analyses were conducted. The contents of protein, tannin, starch, and amylopectin were determined using a FOSS grain quality analyzer (NIRSystem TR-3750, Shanghai, China) according to the method of Xiao et al. (2004). The amylose content was calculated as starch content minus amylopectin content.

2.4 Data Analyses

Data collected were entered in Microsoft Excel 2013. Analysis of variance was conducted by DPS v3.01. Significant means were separated by LSD method. Figures were drawn by SigmaPlot 10.0.

3. Results

3.1 Basic Information of Experimental Site

The soil was silty loam with a pH of 7.68 and rape (*Brassica napus* L.) was the preceding crop. The organic content was 33.68 g/kg, the total N, P, and K concentrations were1.27, 1.08, and 9.54 g/kg, and the available N, P, and K concentrations were 123.36, 46.33, and 437.65 mg/kg in the 0-200 mm soil horizon, respectively. The meteorological data during the growing period are shown in Figure 1.

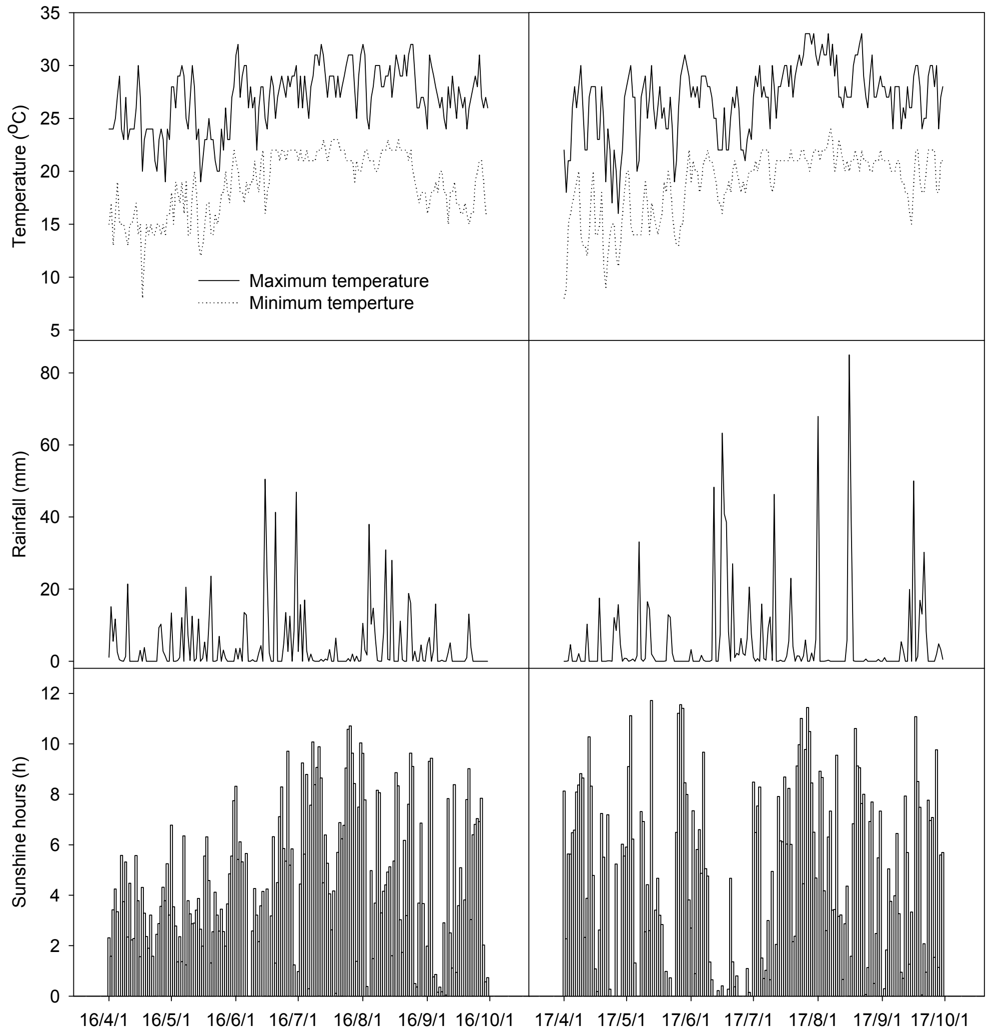

Figure 1. Climate data during the experimental period

3.2 Grain Yield

Grain yield was significantly influenced by sowing time and growing density, but the interactions were not significant in the two years (Table 1). Single factor analysis (Table 2) showed that the grain yield in early sowing was higher than that in late sowing. Compared with late sowing, early sowing increased grain yield by 11.42% in 2016 and 11.53% in 2017. Grain yield significantly increased and then reduced with the increase of the growing density in two years. Interaction between sowing time and growing density (Table 3) showed that the early sowing and growing density of 1.1 × 10^5 plants/ha treatments had the highest grain yield in 2016 and 2017.

3.3 Agronomic Traits

As shown by variance analysis (Table 1), sowing time had significant effect on spike length, culm diameter, grain number per spike, and grain number per plant, while it had no remarkable effect on the plant height and 1000-grain weight in both years. Growing density had significant effect on all agronomic traits in two years. Interaction between sowing time and growing density had significant effect on grain number per spike and grain number per plant, but had no significant effect on plant height, spike length, culm diameter, and 1000-grain weight in both years.

Table 1. Variance analysis for effects of growing density and sowing time on agronomic traits and grain yield in waxy sorghum cultivar Hongliangfeng 1 (*F*-value)

Year	Source of variation	Degree of freedom	Grain yield	Plant height	Spike length	Culm diameter	Grain number per spike	Grain weight per plant	1000-grain weight
2016	S	1	760.92 **	0.03 ns	47.48 *	38.11 *	23.24 *	20.32 *	11.87 ns
	P	2	7.34 *	5.62 *	13.45 **	17.44 **	30.99 **	187.02 **	87.26 **
	S × P	2	1.32 ns	1.43 ns	0.08 ns	0.61 ns	13.46 **	32.78 **	0.02 ns
2017	S	1	200.68 **	0.01 ns	47.32 *	45.24 *	229.76 **	50.96 **	4.96 ns
	P	2	24.34 **	6.02 *	63.69 **	62.16 **	44.57 **	142.33 **	28.16 **
	S × P	2	2.80 ns	2.16 ns	1.84 ns	2.92 ns	10.26 **	10.96 **	1.41 ns

Note. S, P, and S × P represent sowing time, growing density, and interaction between sowing time and growing density, respectively. * and ** represent significant at $P < 0.05$ and $P < 0.01$, respectively. ns represent not significant.

Table 2. Effects of growing density and sowing time on agronomic traits and grain yield in waxy sorghum cultivar Hongliangfeng 1

Year	Treatments	Grain yield (kg/ha)	Plant height (cm)	Spike length (cm)	Culm diameter (mm)	Grain number per spike	Grain weight per plant (g)	1000-grain weight (g)
2016	S1	5517.57 a	209.75 a	33.15 a	14.56 a	4024.13 a	89.13 a	22.24 a
	S2	4952.21 b	208.86 a	32.24 b	11.95 b	3754.18 b	83.52 b	21.30 a
	P1	5093.82 b	199.92 b	30.33 c	12.02 b	3822.77 b	83.30 b	20.70 c
	P2	5486.08 a	220.30 a	35.13 a	14.94 a	4061.72 a	94.15 a	22.96 a
	P3	5124.78 b	199.92 b	32.62 b	12.81 b	3783.00 b	81.53 c	21.79 b
2017	S1	5692.24 a	211.65 a	33.44 a	14.90 a	4093.12 a	92.31 a	21.96 a
	S2	5103.63 b	211.12 a	30.90 b	12.50 b	3798.30 b	86.17 b	20.94 a
	P1	5207.38 b	204.79 b	30.35 c	12.48 c	3848.74 b	86.15 b	20.18 c
	P2	5717.76 a	222.48 a	34.11 a	15.30 a	4118.98 a	98.68 a	23.01 a
	P3	5268.66 b	206.88 b	32.05 b	13.32 b	3869.41 b	82.89 c	21.17 b

Note. Data are expressed as the mean of three replications (n = 3). Values followed by different letters within a column represent significantly different at $P < 0.05$. S1 and S2 represent sowing time at two levels of 5 April and 20 April, respectively. P1, P2, and P3 represent growing density at three levels of 0.8 × 10^5, 1.1 × 10^5, and 1.4 × 10^5 plants/ha, respectively.

Single factor analysis (Table 2) showed that there were no significant differences in plant height and 1000-grain weight between early and late sowing in both years. Spike length, culm diameter, grain number per spike, and grain number per plant were higher than those in late sowing. Compared with late sowing, early sowing markedly increased the spike length, culm diameter, grain number per spike, and grain number per plant by 5.46%, 20.49%, 7.48%, and 6.92% (mean of 2016 and 2017), respectively. Plant height, spike length, culm diameter, grain number per spike, grain number per plant, and 1000- grain weight increased and then reduced with the increase in growing density in two years. Interaction between sowing time and growing density (Table 3) showed that early sowing and growing density of 1.1 × 10^5 plants/ha treatments had the highest plant height, spike length, culm diameter, grain number per spike, grain number per plant, and 1000-grain weight in both years.

Table 3. Effects of interaction between sowing time and growing density on agronomic traits and grain yield in waxy sorghum Hongliangfeng 1

Year	Treatments	Grain yield (kg/ha)	Plant height (cm)	Spike length (cm)	Culm diameter (mm)	Grain number per spike	Grain weight per plant (g)	1000-grain weight (g)
2016	S1 × P1	5447.17 b	195.16 c	30.69 bc	13.26 bc	3982.35 b	89.04 b	21.21 c
	S1 × P2	5802.90 a	225.89 a	35.48 a	16.55 a	4281.41 a	96.80 a	23.50 a
	S1 × P3	5302.90 b	208.20 abc	33.29 ab	13.87 b	3808.63 c	81.55 c	22.30 b
	S2 × P1	4740.46 d	204.69 bc	29.98 c	10.77 d	3663.18 d	77.56 d	20.19 d
	S2 × P2	5169.25 bc	214.70 ab	34.79 a	13.32 bc	3842.03 bc	91.51 b	22.42 b
	S2 × P3	4946.92 cd	207.20 abc	31.95 bc	11.75 cd	3757.34 cd	81.50 c	21.29 c
2017	S1 × P1	5508.95 b	200.78 b	31.26 c	13.91 b	4005.92 b	91.31 c	20.43 cd
	S1 × P2	6102.82 a	229.34 a	35.47 a	16.62 a	4333.17 a	102.14 a	23.88 a
	S1 × P3	5464.96 b	204.83 b	33.58 b	14.16 b	3940.29 bc	83.47 d	21.57 bc
	S2 × P1	4905.82 c	208.82 b	29.44 d	11.05 d	3691.57 e	80.99 d	19.92 d
	S2 × P2	5332.71 b	215.61 ab	32.75 b	13.98 b	3904.79 c	95.22 b	22.14 b
	S2 × P3	5072.36 c	208.93 b	30.52 cd	12.48 c	3798.51 d	82.30 d	20.76 cd

Note. Data are expressed as the mean of three replications (n = 3). Values followed by different letters within a column represent significantly different at $P < 0.05$. S1 and S2 represent sowing time at two levels of 5 April and 20 April, respectively. P1, P2, and P3 represent growing density at three levels of 0.8×10^5, 1.1×10^5, and 1.4×10^5 plants/ha, respectively.

3.4 Grain Quality

Sowing time had significant effect on protein content in the two years. Growing density and interaction between sowing time and growing density had significant effects on protein content in 2017, while it had no effects on protein content in 2016 (Table 4). As shown by single factor analysis (Table 5), protein content in early sowing was higher than that in late sowing. Compared with late sowing, early sowing significantly increased protein content by 4.83% in 2016 and 9.49% in 2017. There were no significant differences in protein content among the three growing densities in 2016. Protein content increased and then reduced with the increase in growing density in 2017. Interaction between sowing time and growing density (Table 6) showed that early sowing and growing density of 1.1×10^5 plants/ha treatments had the highest protein content in the two years.

Table 4. Variance analysis for effects of growing density and sowing time on grain quality in waxy sorghum cultivar Hongliangfeng 1 (F-value)

Year	Source of variation	Degree of freedom	Protein content	Tannin content	Starch content	Amylopectin content	Amylose content
2016	S	1	27.14 *	43.73 *	13.60 ns	37.59 *	135.32 **
	P	2	1.37 ns	654.42 **	29.73 **	70.20 **	2.36 ns
	S × P	2	0.63 ns	16.44 **	1.49 ns	2.12 ns	2.54 ns
2017	S	1	40.17 *	36.33 *	29.64 *	9.92 ns	6.11 ns
	P	2	115.01 **	101.59 **	116.55 **	45.49 **	4.76 *
	S × P	2	42.59 **	12.40 **	4.71 *	0.37 ns	2.39 ns

Note. S, P, and S × P represent sowing time, growing density, and interaction between sowing time and growing density, respectively. * and ** represent significant at $P < 0.05$ and $P < 0.01$, respectively. ns represent not significant.

Tannin content was significantly influenced by sowing time, growing density, and their interaction in the two years (Table 4). Single factor analysis (Table 5) showed that tannin content in early sowing was lower than that in late sowing. Compared with late sowing, early sowing significantly decreased the tannin content by 7.71% in

2016 and 8.48% in 2017. Tannin content reduced and then increased with the increase of growing density in both years. Interaction between sowing time and growing density (Table 6) showed that early sowing and growing density of 1.1×10^5 plants/ha treatments had the lowest tannin content in the two years.

Growing density had significant effect on starch content in the two years. Sowing time and interaction between sowing time and growing density had no significant effects on starch content in 2016, while it had significant effects on starch content in 2017 (Table 4). Single factor analysis (Table 5) showed no significant differences in starch content between early and late sowing in 2016. Early sowing increased the starch content by 1.08% compared with late sowing in 2017. Starch content increased and then reduced with the increase in growing density in both years. Interaction between sowing time and growing density (Table 6) showed that early sowing and growing density of 1.1×10^5 plants/ha treatments had the highest starch content in the two years.

Table 5. Effects of growing density and sowing time on grain quality in waxy sorghum cultivar Hongliangfeng 1

Year	Treatments	Protein content (%)	Tannin content (%)	Starch content (%)	Amylopectin content (%)	Amylose content (%)
2016	S1	11.40 a	1.46 b	80.09 a	72.44 a	7.65 b
	S2	10.87 b	1.59 a	79.33 a	70.68 b	8.65 a
	P1	11.01 a	1.54 b	78.35 c	69.82 c	8.53 a
	P2	11.24 a	1.41 c	80.84 a	73.27 a	7.57 a
	P3	11.16 a	1.63 a	79.94 b	71.59 b	8.36 a
2017	S1	11.95 a	1.38 b	80.40 a	72.88 a	7.96 a
	S2	10.91 b	1.51 a	79.54 b	71.51 a	8.86 a
	P1	11.06 b	1.47 b	78.81 c	70.36 c	8.98 a
	P2	12.06 a	1.32 c	81.12 a	73.97 a	7.85 b
	P3	11.17 b	1.54 a	79.98 b	72.26 b	8.39 ab

Note. Data are expressed as the mean of three replications (n = 3). Values followed by different letters within a column represent significantly different at $P < 0.05$. S1 and S2 represent sowing time at two levels of 5 April and 20 April, respectively. P1, P2, and P3 represent growing density at three levels of 0.8×10^5, 1.1×10^5, and 1.4×10^5 plants/ha, respectively.

Sowing time had significant influence on amylopectin content in 2016, but it had no significant influence in 2017. Growing density had significant influence on amylopectin content in both years. Interaction between sowing time and growing density had no significant influences on amylopectin content in the two years (Table 4). Compared with late sowing, early sowing increased the amylopectin content by 2.49% in 2016, while it had no differences in amylopectin content between early and late sowing in 2017 (Table 5). Amylopectin content increased and then reduced with the increase in growing density in both years. Interaction between sowing time and growing density (Table 6) showed that early sowing and growing density of 1.1×10^5 plants/ha treatments had the highest amylopectin content in the two years.

Sowing time had significant influence on amylose content in 2016, but it had no significant influence in 2017. Growing density had no significant influence on amylose content in 2016, but it had significant influence in 2017. Interaction between sowing time and growing density had no significant influences on amylose content in the two years (Table 4). Compared with late sowing, early sowing decreased amylose content by 11.63% in 2016, while it no differences in amylose content were found in 2017 (Table 5). There were no significant differences in amylose content among the three growing densities in 2016. Amylose content reduced and then increased with the increase in growing density in 2017. Interaction between sowing time and growing density (Table 6) showed that early sowing and growing density of 1.1×10^5 plants/ha treatments had the lowest amylose content in the two years.

Table 6. Effects of interaction between growing density and sowing time on grain quality in waxy sorghum cultivar Hongliangfeng 1

Year	Treatments	Protein content (%)	Tannin content (%)	Starch content (%)	Amylopectin content (%)	Amylose content (%)
2016	S1 × P1	11.35 ab	1.47 c	78.82 c	70.40 c	8.43 abc
	S1 × P2	11.43 a	1.34 d	81.44 a	74.17 a	7.27 c
	S1 × P3	11.42 a	1.58 b	80.01 b	72.76 b	7.25 c
	S2 × P1	10.66 c	1.61 b	77.88 c	69.25 d	8.63 ab
	S2 × P2	11.06 abc	1.48 c	80.23 b	72.37 b	7.86 bc
	S2 × P3	10.91 bc	1.67 a	79.88 b	70.42 c	9.46 a
2017	S1 × P1	11.87 ab	1.36 c	79.14 d	70.85 cd	8.75 abc
	S1 × P2	12.21 a	1.29 c	81.81 a	74.76 a	7.64 cd
	S1 × P3	11.75 b	1.48 b	80.24 b	73.03 b	7.48 d
	S2 × P1	10.24 c	1.57 a	78.47 e	69.86 d	9.22 ab
	S2 × P2	11.90 ab	1.35 c	80.43 b	73.18 b	8.06 bcd
	S2 × P3	10.59 c	1.60 a	79.72 c	71.49 c	9.31 a

Note. Data are expressed as the mean of three replications ($n = 3$). Values followed by different letters within a column represent significantly different at $P < 0.05$. S1 and S2 represent sowing time at two levels of 5 April and 20 April, respectively. P1, P2, and P3 represent growing density at three levels of 0.8×10^5, 1.1×10^5, and 1.4×10^5 plants/ha, respectively.

3.5 Correlation Analysis Among Grain Yield, Amylopectin Content, and Grain Yield Components

Grain yield was significantly and positively correlated with grain number per spike, grain weight per plant, 1000-grain weight, and amylopectin content (Table 7). Similarly, amylopectin content was significantly and positively correlated with grain number per spike, grain weight per plant, and 1000-grain weight.

Table 7. Correlation coefficients among grain yield, amylopectin content, and *grain yield components* in waxy sorghum cultivar Hongliangfeng 1

	Amylopectin content	Grain number per spike	Grain weight per plant	1000-grain weight
Amylopectin content		0.761 **	0.738 **	0.920 **
Grain yield	0.818 **	0.974 **	0.856 **	0.778 **

Note. ** represent significantly correlation at $P < 0.01$.

4. Discussion

Sorghum yield is determined by spike number per growing area, grain number per spike, grain weight per plant, and 1000-grain weight. The spike number per growing area mainly reflects the changing amplitude of population density and the grain number per spike, grain weight per plant, and 1000-grain weight mainly reflect the growth and development status of individuals within a population (Zhou et al., 2016; Zhou et al., 2017). Generally speaking, amylopectin content is the most critical factor for quality assessment of waxy sorghum cultivars grown for liquor production (Cao, 2016; Wang et al., 2017a). In this study, grain yield and amylopectin content were significantly and positively correlated with grain number per spike, grain weight per plant, and 1000-grain weight, which is consistent with reported by Liu et al. (2012). Therefore, greatly expanding the plant's storage capacity (increasing of grain number per spike, grain weight per plant, and 1000-grain weight) is the premise to realize the high yield and good quality of Hongliangfeng 1.

Suitable sowing time is one of the key cultivation measures in sorghum production. As reported by Ekeleme et al. (2011), and Luo et al. (2013), in sorghum, yield and quality are strongly reduced by a delay of sowing time. Similar to our study, compared with early sowing (5 April), late sowing (20 April) significantly decreased the grain yield, spike length, culm diameter, grain number per spike, grain weight per spike, protein content, starch content, and amylopectin content, while significantly increased the tannin content and amylose content. There are two reasons that could be responsible for the decrease in the mean values of agronomic traits, grain yield, and grain quality. The first is that sorghum seeds would have low germination if sown late. The second reason is that late sowing destroys the normal growth and development of sorghum plants due to high temperatures and rainfall occur during later growth development period (Figure 1). In the present study, there were no significant differences in plant height and 1000-grain weight between early and late sowing in both years. However, Yang et al. (2017) concluded that sowing time had significant effects on the plant height and 1000-grain weight, and the plant height and 1000-grain weight were reduced by a delay of sowing time. The reason for this difference requires further study.

Growing density is one of the important factors to coordinate the contradiction between crop groups and individuals. In general, an increase in the number of plants can make the most of the crop grain yield and grain quality reaches a certain limit or threshold, after that, the growing density of further increase or maintain the same output and quality, either to lower yield and quality (Watanabe et al., 2003; Wang et al., 2009; Fang et al., 2018). Similar to our study, the grain yield, plant height, spike length, culm diameter, grain number per spike, grain weight per plant, 1000-grain weight, protein content, starch content, and amylopectin content increased to their maximums at the growing density of 1.1×10^5 plants/ha, while subsequently decreased at the growing density of 1.4×10^5 plants/ha. However, tannin content and amylose content decreased and then increased with the increase of growing density. This might be due to the weak light irradiance to the leaf by shading and strong competition at high growing density (Fang et al., 2018). Based on the present results, it is suggested that appropriate sowing time and growing density could effectively optimize the population structure, reduce the competition between plants, enhance the grain yield, and improve the quality of waxy sorghum.

5. Conclusion

Sowing time and growing density had significant effects on grain yield and grain quality of waxy sorghum cultivar Hongliangfeng 1. Early sowing had a positive on the expression of most agronomic and quality traits. Appropriate growing density need to be identified in order to ensure high yield and good quality in waxy sorghum production.

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