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Research Article

Gradual Application of Potassium Fertilizer Elevated the Sugar Conversion Mechanism and Yield of Waxy and Sweet Fresh-Eaten Maize in the Semiarid Cold Region

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Fresh-eaten maize (*Zea mays* L.) is favored by consumers for its unique flavor, good health, and medical effects. Heilongjiang province is a semiarid cold region with the annual output of 3.35 billion ears, and the demand for fresh eaten maize is increasing in the region. Therefore, improving its yield and quality is urgently needed in this area. In this study, two of thirty varieties (waxy maize Jin-262 and sweet maize Jingke-183) were used and five proportions of potassium (K_2O, 120 kg/ha) were applied at sowing, jointing, and large trumpet stages to identify the high yield and quality of fresh-eaten maize under a semiarid cold ecological condition in Daqing, Heilongjiang province, China, during 2017-2018. The results from the screening of eighteen maize varieties showed that waxy maize Jin-262 and sweet maize Jingke-183 had higher starch content and soluble sucrose contents than those of other varieties. While the potassium proportions application during the sowing (20%), jointing (40%), and large trumpet stages (40%) had further significantly increased the starch content, soluble sugar content, sucrose content, and sucrose metabolic enzymes activities of Jin-262 and Jingke-183, however, the yields of Jin-262 and Jingke-183 had increased by applying potassium fertilizer during the sowing stages (50%) and jointing stages (50%). Considering the overall higher maize quality, we recommended the waxy maize Jin-262 and sweet maize Jingke-183 varieties along with application of 20% (sowing), 40% (jointing), and 40% (large trumpet stages) of 120 kg/ha potassium fertilizer for the improvement of grain quality of maize planting in the semiarid cold region. Otherwise, reasonable gradual potassium fertilization might be a wiser option.

1. Introduction

Potassium fertilizer (K) helps the formation and convertion of energy and sugar that the crops need for their development through photosynthesis process [1], which plays a crucial role in improving the quality and yield of crops [2]. Many countries have been actively promoting and applying balanced fertilizer application with the appropriate amounts and proportions of K [3]; balanced crop nutrient management is a key factor for improving crop productivity [4]. Heilongjiang province is a cold and semiarid region in China; imbalanced use of chemical fertilizers is one of the major reasons of low maize productivity under semiarid condition [5]; K application under semiarid climates condition not only improves crop tolerance to drought stress [6] but also improves crop growth and dry matter partitioning and increases yields significantly [7]. Potassium application is beneficial for promoting carbohydrate and nitrogen (N) metabolism; K ions significantly promote the absorption and utilization of N and P by crops in the form of compensation charges, thus improving the quality of crop products [8, 9]. Potassium is required for efficient transformation of solar energy into chemical energy [10]. Accurate application of K fertilizers can stimulate biomass and carbohydrate of crops [11, 12] which is considered as an important factor in food and industrial usage. Although effect of K fertilizers on other plants is reported [11] but there are few reports regarding the effect of K fertilizers on gradual application of fresh-eaten maize.

Fresh-eaten maize is favored by consumers for its unique flavor effect [10], which increased the consumption. To generate more revenue from agricultural products and make it more attractive for the buyer at marketplace mainly depends on the amount and quality of the product delivered to the market. The amount and quality of the products contributes largely in the income return for the producers. In fact, for some crops, quality plays an increasing role and, in some cases, the dominant role in generating revenue [13]. The fresh-eaten maize kernels quality is determined by its composition and content of carbohydrates; soluble sugar and sucrose influence the taste and sweetness of fresh-eaten maize, respectively [14]; starch is hydrolyzed and converted into monosaccharide, affecting the taste of fresh-eaten maize [15]. The relationship between sugar accumulation and sucrose metabolic enzymes has been previously reported by many researchers and demonstrated that they have important effects on sugar metabolism and accumulation on tomato [16], wheat [17], and common maize [18, 19].

Many studies have highlighted in an aggressive way by mentioning K as a plant nutrient of the role in crop yield and produce quality [20]; the grain weight, single ear weight, and yield of fresh-eaten maize of potassium fertilizer treatments were significantly higher than those of nonpotassium treatments [21]. The rate of soil applied K up to 90 kg/ha can improve growth and maize productivity under semiarid climates [4]. Keeping in mind the importance of the product quality and the crucial role of potassium in quality improvement, this study was accordingly designed to investigate the quality of two different types of fresh-eaten maize including sweet maize (Jingke-183) and waxy maize (Jin-262) under the different potassium fertilizer treatments in a cold semiarid area. The specific aim of this field experiment was to determine the effects of potassium on (i) fruit quality, (ii) enzyme activity, and (iii) grain yield of fresh-eaten maize.

2. Materials and Methods

2.1. Environmental Conditions. The field experiment was conducted at the Experimental Base (46°37′N, 125°11′E), Daqing, Heilongjiang Bayi Agricultural University, in 2017-2018, which is a continental monsoon climate city of the North Temperate Zone in China. The experimental site was meadow soil, and baseline levels in the soil before fertilization were average soil organic matter of 28.9 mg/kg, alkaline hydrolysis nitrogen (N) of 118.3 mg/kg, available P of 16.6 mg/kg, available K of 106.2 mg/kg, and pH 8.3.

Meteorological data during the growing season (April to September in 2017 and 2018) were provided by local weather stations (Figure 1).

2.2. Plant Materials and Experimental Design. A total of 30 fresh-eaten maize varieties (15 waxy maize varieties and 15 sweet maize varieties) were planted manually on 25 May 2017; each plot was 5.2 m × 10.0 m in size having the plant density of 52300 plants/ha. The experiment was conducted in a randomized complete block design (RCBD) with three replications and had 0.650 m row spacing and 0.293 m plant spacing. The irrigation amount was 50 mm before sowing and the N : P : K in the form of N 135 kg/ha (urea), P_2O_5 120 kg/ha (calcium superphosphate), and K_2O 90 kg/ha (potassium sulfate) was applied as base fertilizer, respectively. Additionally, 90 kg/ha of N was applied at jointing stage.

2.3. Growth- and Yield-Related Parameters. Data collection was carried out for the seedling emergence rate, plant heights, kernels per ear, fresh ear weight, and bald length in all the thirty varieties of sweet maize. Based on these parameters, 12 varieties were eliminated from analysis because of their poor performance. The remaining 18 varieties were selected for further study.

2.4. Measurement of Starch Content, Total Soluble Sugar, and Residue Ratio. Five middle ears of maize in each plot were harvested at 18, 21, 24, 27, 30, and 33 days after flowering (DAF) with a filigree length of 2-3 cm. Grains were collected, oven-dried at 75°C for 7 days up to constant weight, and ground and sieved through 100 mesh. The total soluble sugar contents and starch contents of these samples were analyzed by the anthrone-colorimetry method, while the sucrose contents were measured by the resorcinol method [22], and the residue ratio was determined by following the previous protocol [23].

2.5. Field Adaptability Test Based on the Quality Parameters. Eighteen fresh-eaten maize varieties with high adaptability in the field were harvested at 24 DAF and cooked in boiled water for 30 individuals of different ages and genders for the tasting experiment to determine the cooking taste qualities of flavor, color and luster, sweetness, tenderness, pericarp thickness, sensory quality, and taste quality [23].

Based on the results of screening experiment in 2017, two varieties, Jin-262 (waxy maize; Jinniu Seed Industry Ltd.) and Jingke-183 (sweet maize; Beijing Academy of Agriculture and Forestry Sciences) were selected for further experiment in 2018. The field experimental procedure was consistent with that in 2017. However, K_2O 120 kg/ha was supplied as five potassium fertilizer treatments: K1, K2, K3, K4, and K5 (Table 1).

2.6. Measurement of Sucrose Metabolism Enzyme Activities. Samples from the middle of the ear were collected at 18, 21, 24, 27, 30, and 33 DAF and stored at −80°C in a refrigerator for further analysis. Each sample of maize grains was weighted (0.5 g) and grinded in mortar with liquid nitrogen to analyze the sucrose metabolic enzyme activity. The sucrose metabolism enzymes activities (sucrose synthase and sucrose phosphate synthase) were determined by detection kits (Solarbio Life Sciences Ltd., Beijing, China).

2.7. Yield and Yield Components. A total of 10 representative ears (error less than 0.05 kg) were sampled from the middle of each plot to measure the grain yield (kg) and yield

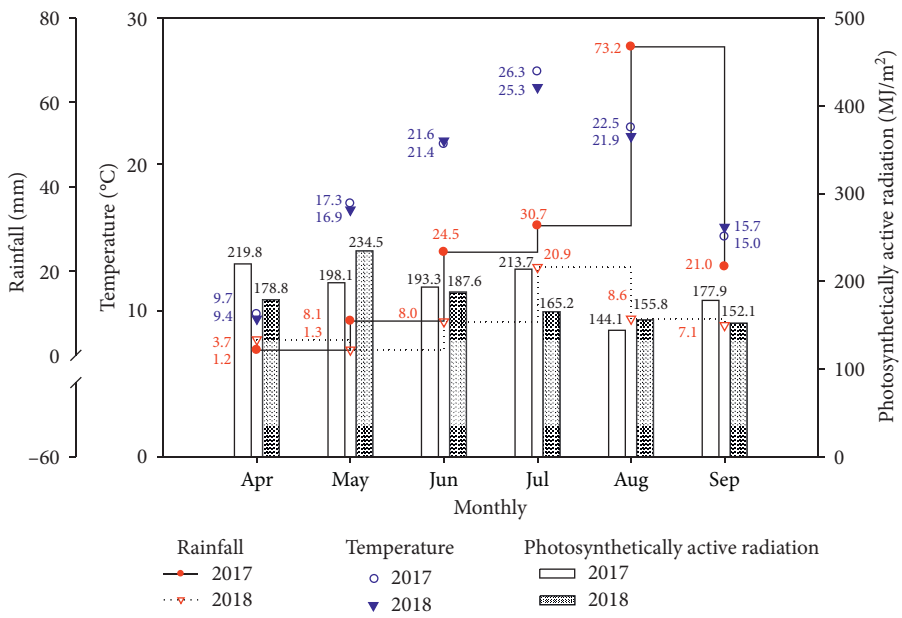

Figure 1: Monthly temperature, rainfall, and photosynthetically active radiation (PAR) average in 2017 and 2018.

Table 1: Schedule, proportion, and amount of potassium fertilizer applied.

Stages	K treatments (kg/ha)				
	K1	K2	K3	K4	K5
Basal	0% (0)	100% (120)	50% (60)	50% (60)	20% (24)
Jointing	0% (0)	0% (0)	50% (60)	0% (0)	40% (48)
Big trumpet	0% (0)	0% (0)	0% (0)	50% (60)	40% (48)

components according to the grain moisture content of fresh-eaten maize and converted to yield (14% moisture content).

2.8. Statistical Analysis. All data were subjected to one-way ANOVA analysis using SPSS 21.0 software [24]. Means of all treatments and genotypes were compared by performing Duncan's multiple comparison tests at $p < 0.05$. Graphs were generated using SigmaPlot 10.0 (SPSS Inc., Chicago, IL).

3. Results and Discussion

3.1. Growth and Yield Component of Waxy and Sweet Maize. The growth and yield component related parameters for both waxy and sweet maize varieties are presented in Tables 2 and 3, respectively.

Among waxy maize varieties, the seedling emergence rates of Lvyuhuang (49.02%), Lv-5 (49.02%), and Lv-2 (46.08%) were the lowest and plant height of these three maize varieties was less than 160 cm (Table 2). Jin-262 had significantly higher ($p < 0.05$) seedling emerging rates (100%), kernels per ear (602 kernels/ear), and fresh ear weight (0.36 kg/ear) as compared with other varieties. The bald length of Jin-262 was 0.36 cm, which was significantly lower than that of Kennian-1 ($p < 0.05$). However, there were no significant differences between the grain yield and spike length of Jin-262 and Kennian-1 ($p < 0.05$), however higher than other varieties of the same group.

In sweet maize varieties, the seedling emergence rates of WSC-1701, WSC-1702, WSC-1703, Syngenta-wangchao, Syngenta-kupula, Syngenta-cuiwang, Syngenta-double color honey, T1, and W625 were less than 50%. For instance, the emergence rates of tumor black powder of Syngenta-kupula, Syngenta-cuiwang, and Syngenta-double color honey seedling were 42.49%, 45.95%, and 43.47%, respectively (Table 3). The grain yield of Jingke-183 was 54258 ears/ha, which was significantly higher than those of other varieties ($p < 0.05$). Surprisingly, the bald length (0.05 cm) of Jingke-183 was significantly lower than those of other varieties ($p < 0.05$).

3.2. Quality of Fresh-Eaten Maize Grains. In the waxy maize varieties, the increased amount of grain starch content was in order Jin-262 > Bai-998 > other varieties. In detail, grain starch content was 54.91% in Jin-262 and 53.68% in Bai-998 variety (Table 4). The total soluble sugar content of Jin-262 was significantly higher than that of Bai-998 ($p < 0.05$). There was no significant variation between the residue ratios of Bai-998 and Jin-262 ($p < 0.05$). The scores of order flavor, color and lustre, waxy, sweetness, tenderness, skin thick and thin, sensory quality, and taste quality in averages of Jin-262, Jingke-623, Jingke-2010, Jingke-569, Jingk-928, and Kennian-1 were 77.38, 75.63, 76.38, 71.25, 77.25, and 77.38, respectively, which were significantly higher than those of other varieties ($p < 0.05$). The color and luster of Jingke-623, Jingke-569, and Jingke-928 were significantly lower than those of other varieties ($p < 0.05$). The tenderness of Jingke-2010, Jingke-569, and Kennian-1 was significantly lower than that of other varieties ($p < 0.05$). The pericarp thickness of Jingke-569 was significantly lower than that of other varieties ($p < 0.05$). There was no significant difference in the flavor and sweetness among varieties ($p < 0.05$).

Table 2: Growth and yield of waxy maize during 2017.

Varieties	Seedling emergence rate (%)	Tumor black powder (%)	Plant height 160 cm (%)	Grain yield (ears/ha)	Kernels per ear	Spike length (cm)	Fresh ear weight (kg/ear)	Bald length (cm)
Bai-998	98.04ab	0.00b	2.97b	40020de	575bcd	20.09b	0.34ab	0.61cde
Hua-3	97.06ab	0.00b	0.00c	39443e	739a	22.32a	0.39a	1.20bcd
Jin-262	100.00a	0.00b	0.00c	45215ab	602bc	19.30b	0.36ab	0.36de
Jing-318	95.10ab	0.00b	0.00c	42329cd	614bc	16.97c	0.34ab	1.70b
Kennian-7	99.02ab	0.00b	3.95b	26744f	614bc	21.91a	0.39a	1.52bc
Jingke-623	95.10ab	0.00b	0.00c	44253b	556cd	18.52bc	0.33ab	0.03e
Jingke-2010	100.00a	0.00b	0.00c	40982de	640bc	18.26bc	0.33ab	0.81bcde
Jingke-2016	99.02ab	0.00b	0.00c	41367d	630bc	18.20bc	0.36ab	0.02e
Jingke-569	95.10ab	1.96a	0.00c	43868bc	544cd	19.17b	0.33ab	1.18bcd
Jingke-928	96.08ab	0.00b	0.00c	43483bc	606bc	18.28bc	0.33ab	0.00e
Yinsenianhua	94.12b	0.00b	0.00c	40597cd	667ab	19.64b	0.37a	0.90bcde
Lvyuhuang	49.02c	0.00b	100.00a	*	*	*	*	*
Lv-5	49.02c	0.00b	100.00a	*	*	*	*	*
Lv-2	46.08c	0.00b	100.00a	*	*	*	*	*
Kennian-1	98.04ab	0.00b	0.00c	45984a	500d	19.53b	0.28c	2.88a

The different lowercase letters in the same column are significantly different at the 5% level. *Inadequate for field growth.

Table 3: Growth and yield of sweet maize during 2017.

Varieties	Seedling emergence rate (%)	Tumor black powder (%)	Plant height 160 cm (%)	Grain yield (ears/ha)	Kernels per ear	Spike length (cm)	Fresh ear weight (kg/ear)	Bald length (cm)
Jingke-183	99.02a	1.96de	0.00c	54258a	586b	19.56bc	0.28c	0.05c
Zheng-66	95.10ab	5.15bcde	0.00c	40405c	566b	21.01ab	0.23d	0.23b
WSC-1701	47.06c	6.00bcde	8.23a	*	*	*	*	*
WSC-1702	46.08cd	8.47bc	6.39ab	*	*	*	*	*
WSC-1703	49.02c	9.95bc	9.72a	*	*	*	*	*
Syngenta-wangchao	42.16de	4.60cde	2.38bc	*	*	*	*	*
Syngenta-kupula	39.22ef	42.49a	2.38bc	*	*	*	*	*
Syngenta-overland	96.08ab	5.11bcde	0.00c	39635c	659ab	22.52a	0.31bc	0.23b
Hetian-1	94.12b	8.34bc	0.00c	37326c	579b	21.07ab	0.31bc	0.33ab
Hetiannuo-1	98.04ab	0.00e	0.00c	40790c	641ab	20.82ab	0.37a	0.39a
Syngenta-mige	98.04ab	3.98cde	0.00c	45792b	695a	22.73a	0.35ab	0.27b
Syngenta-cuiwang	49.02c	45.95a	0.00c	*	*	*	*	*
Syngenta-double color honey	45.10cd	43.47a	0.00c	*	*	*	*	*
T1	36.27f	8.12bcd	2.56bc	*	*	*	*	*
W625	35.29f	11.11b	0.00c	*	*	*	*	*

The different lowercase letters in the same column are significantly different at the 5% level. *Inadequate for field growth.

In sweet maize as shown in Table 4, higher amount of sucrose (6.49%), starch content (15.2%), and sweetness was found in Jingke-183 when compared with remaining varieties of sweet maize; however, the soluble sugar content of Jingke-183 was only higher than Zheng-66 and Hetian-1. Furthermore, lower grain quality related parameters were observed in Hetiannuo-1; for example, the flavor, sweetness, sensory quality, taste quality, and quality average of Hetiannuo-1 were significantly lower as compared to other varieties ($p < 0.05$). There was no significant difference in the flavor, color and luster, tenderness, sensory quality, and taste quality among Jingke-183, Syngenta-overland, Hetian-1, and Syngenta-mige ($p < 0.05$).

3.3. Grain Soluble Sugar Content. Subsequently, the soluble sugar content was measured again during 2018 in the grain of Jin-262 and Jingke-183. The result of time course analysis showed that the soluble sugar content of Jin-262 was first increased and then decreased during the flowering stage, and the maximum value was detected at 21 DAF (Figure 2). For example, the soluble sugar contents of K1, K2, K3, K4, and K5 at 21 DAF were 22.91%, 22.09%, 20.34%, 21.93%, and 24.48% which were higher than those of 18, 24, 27, 30, and 33 DAF. There were nonsignificant differences between K1 and K5 ($p < 0.05$) in soluble sugar content at 18 DAF. Furthermore, the higher and lower soluble sugar content were found in treatment K5 and K3, respectively, at 21, 24, and 30

Table 4: Grain and taste quality of fresh-eaten maize during 2017.

Varieties	Grain quality				Fresh ear cooking taste quality							
	Soluble sugar (%)	Sucrose (%)	Starch (%)	Residue ratio (%)	Flavor	Color and lustre	Sweetness	Tenderness	Pericarp thickness	Sensory	Taste	Quality average
Waxy												
Bai-998	16.03f	1.36e	53.68a	30.41d	73abc	69de	61bc	71de	68cde	70bc	70bc	69.38bcd
Hua-3	12.31h	1.14ef	48.90b	32.22c	62d	64e	50c	72cde	73abcd	64c	60de	62.88e
Jin-262	18.53cd	0.43g	54.91a	29.82d	74ab	86a	63abc	77abcd	76abc	79a	77ab	77.38a
Jing-318	19.49b	2.28bcd	47.71bc	29.92d	64cd	67e	65ab	80abcd	78abc	69bc	68bcd	69.88bcd
Kennian-7	13.93g	2.89a	43.92d	34.67b	66bcd	66e	59bc	66e	68cde	65c	62cde	64.25de
Jingke-623	19.06bc	2.41abc	42.54d	32.32c	73abc	70cde	72ab	81abc	79abc	75ab	81a	75.63ab
Jingke-2010	20.65a	1.86d	46.77c	28.11e	79a	79abc	78a	72cde	69bcde	75ab	81a	76.38a
Jingke-2016	17.88e	2.04cd	43.78d	28.01e	65bcd	70cde	73ab	81abc	64de	72abc	69bc	69.75bcd
Jingke-569	18.20de	2.58ab	44.17d	30.54d	74ab	71cde	70ab	74bcde	61e	75ab	74ab	71.25abc
Jingke-928	19.33b	1.22e	38.58e	28.13e	77a	77bcd	73ab	82ab	80ab	76ab	82a	77.25a
Yinsenianhua	18.15de	1.33e	39.37e	27.95e	65bcd	65e	63abc	86a	81a	64c	59e	67cde
Kennian-1	13.59g	0.66fg	48.65b	36.56a	80a	82ab	67ab	75bcde	74abcd	80a	83a	77.38a
Sweet												
Jingke-183	29.71b	6.49a	15.20a	25.55c	71ab	78a	98a	76ab	75a	76a	79a	79.00a
Zheng-66	28.61c	3.26c	12.09c	26.70b	70ab	69b	78b	69c	65ab	75ab	80a	72.29a
Syngenta-overland	37.10a	5.66b	9.17f	22.64e	76a	84a	76b	82a	57b	79a	85a	77.00a
Hetian-1	28.17c	5.22b	10.19e	24.76d	76a	83a	83b	76ab	76a	82a	78a	79.14a
Hetiannuo-1	29.98b	1.64d	13.58b	31.76a	64b	64b	54c	70bc	60b	68b	65b	63.57b
Syngenta-mige	30.36b	3.89c	11.07d	20.56f	76a	86a	76b	81a	74a	81a	74a	78.29a

The different lowercase letters in the same column are significantly different at the 5% level.

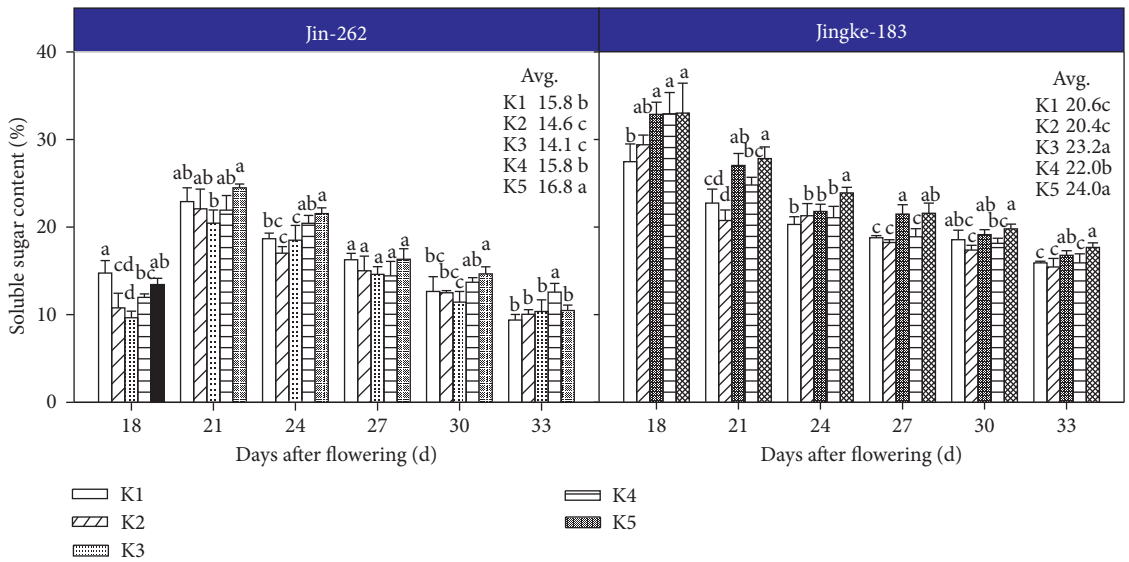

Figure 2: Effects of potassium on the grain soluble sugar content of fresh-eaten maize grains. The different lowercase letters are significant differences at the 5% level; AVG, average; the bars are standard deviation ($n = 5$).

DAF; however, there were nonsignificant differences among all treatments at 27 DAF ($p < 0.05$). At 33 DAF, the significantly higher ($p < 0.05$) sugar content was observed in treatment K4 followed by K5; for instance, the soluble sugar contents of K1, K2, K3, K4, and K5 were 9.38%, 10.4%, 10.36%, 12.56%, and 10.48%, respectively. Taking together, during 18-33 DAF, the mean soluble sugar content of K5 was significantly higher than the remainder treatments ($p < 0.05$).

Similarly, the soluble sugar content of Jingke-183 showed a decreasing trend (Figure 2). The soluble sugar content of K5 was 33.03% at 18 DAF and 17.67% at 33 DAF. Regarding assessment during 18–33 DAF, the average soluble sugar content of K5 was significantly higher than other treatments of the group ($p < 0.05$); however, considering the mean upper values, there was nonsignificant increase between treatment K5 and K3 in the soluble sugar content.

3.4. Grain Sucrose Content. Figure 3 shows the sucrose content in the grain of Jin-262 and Jingke-183. In accordance with the soluble sugar content, the sucrose content of Jin-262 was also first increased and then declined during the flowering stages, and the maximum peak was observed at 21 DAF. In detail, the sucrose contents of K1, K2, K3, K4, and K5 at 21 DAF were 3.69%, 3.06%, 3.33%, 3.42%, and 3.79%, respectively. At 24 DAF, the sucrose content was not significantly different between treatments ($p < 0.05$). Moreover, the sucrose content of only treatment K5 rose again at 27 DAF and then dropped during 30–33 DAF. Regarding average during 18–33 DAF, the average sucrose contents of treatments K1, K4, and K5 were 2.0%, 2.0%, and 2.1%, respectively, and there was no significant difference among them ($p < 0.05$).

The sucrose content of Jingke-183 showed a decreasing trend from the first to the last day of assessment (Figure 3). During 18–33 DAF, the sucrose contents of treatments K1, K2, K3, K4, and K5 declined by 0.53%, 0.45%, 0.50%, 0.49%, and 0.47% per day, respectively. The sucrose content of K5 was 33.03% at 18 DAF and then sharply declined to 17.67% at 33 DAF. Considering the mean upper values, there were nonsignificant differences ($p < 0.05$) between K3 (14.0%) and K5 (14.1%).

3.5. Sucrose Synthase Activity. The time course analysis showed that the sucrose synthase activity of Jin-262 first increased and then decreased during the flowering stages as shown in Figure 4. In general, the sucrose synthase activity started to rise during 21–27 DAF and then declined during the remaining assessment time regardless of treatment. However, among the treatments during 18–21 DAF, the enzyme activity of treatment K5 was significantly higher than those of the other treatments ($p < 0.05$). Time course and treatments data showed that the activity of this enzyme was significantly higher ($p < 0.05$) under treatments K3 at 24 DAF, K5 at 27 DAF, and K2 at 30 DAF in waxy variety Jin-262. Taking the average of all assessment days from 18 to 33 DAF, the average sucrose synthase activity of K5 was significantly higher when compared with remaining treatments ($p < 0.05$).

Similarly, regardless of treatment, the sucrose synthase activity of Jingke-183 was increased during the assessment periods during 21–24 DAF; the highest peak was detected at 24 DAF and then a sharp decline was observed in the activity values (Figure 4). At 18 DAF, the significantly higher and lower sucrose synthase activities were reported for treatments K1 and K4, respectively, compared to those of the other treatments ($p < 0.05$). Under treatments K3 and K5, the enzyme activity was significantly enhanced ($p < 0.05$) during 21–24 DAF relative to other treatments; in addition, there were no differences between K3 and K5; although the decline was observed during the remaining days of flowering under the treatment, it remained significantly higher under

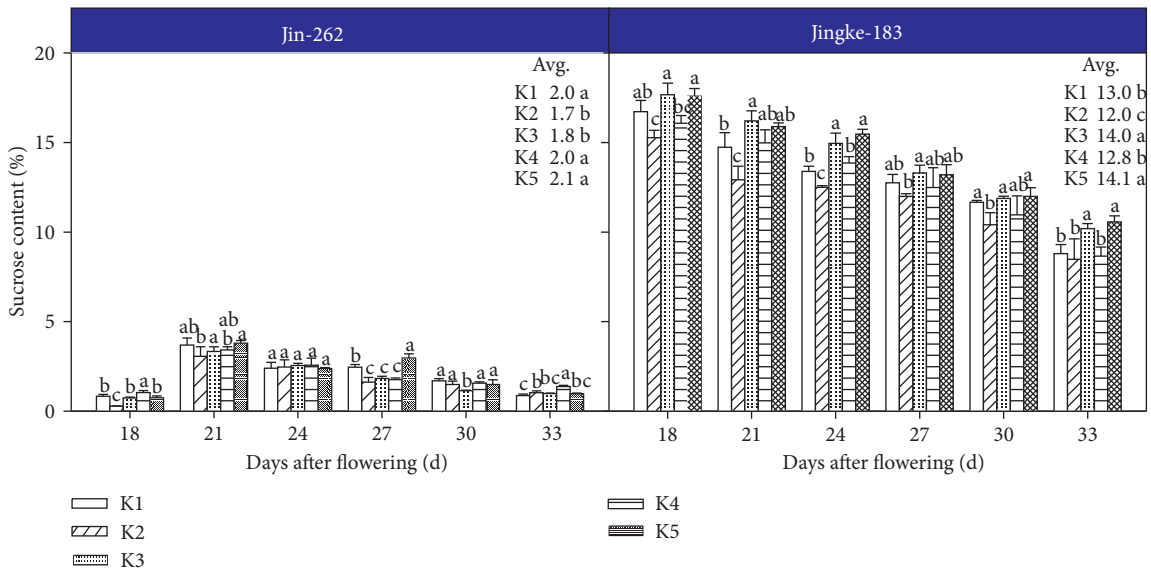

Figure 3: Effects of potassium on the grain sucrose content of fresh-eaten maize kernels. The different lowercase letters are significant differences at the 5% level; AVG, average; the bars are standard deviation ($n = 5$).

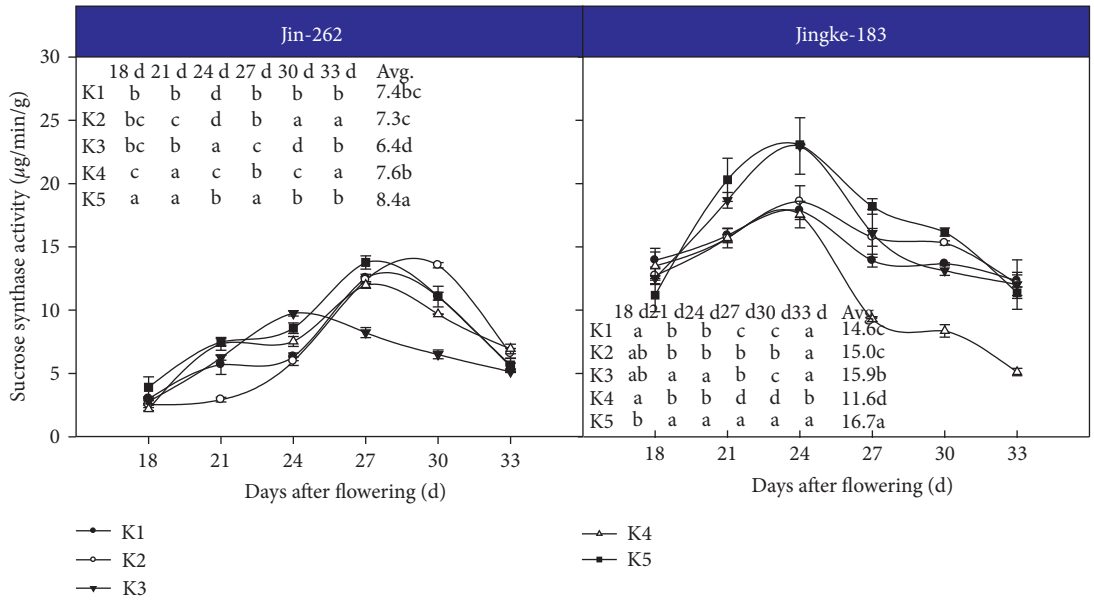

Figure 4: Effects of potassium on grain sucrose synthase activity of fresh-eaten maize kernel fresh weight. The different lowercase letters are significant differences at the 5% level; AVG, average; the bars are standard deviation ($n = 5$).

treatment K5 than other treatments. The results showed that treatment K5 significantly increased the average sucrose synthase activity during 18–33 DAF compared to other treatments ($p < 0.05$).

3.6. Sucrose Phosphate Synthase Activity. The effect of potassium on the sucrose phosphate synthase activity in the grain of fresh-eaten maize varieties (Jin-262 and Jingke-183) is presented in Figure 5. The results show that the enzyme activity value was first increased till 24 DAF and then decreased during the remaining flowering stages. Upon the time course analysis, the sucrose phosphate synthesis activity was highly induced under treatment K5 in both Jin-262 and Jingke-183 relative to remaining treatments, except at 24 DAF; the activity value of treatment K3 was higher than treatment K5 in variety Jin-262. Furthermore, there were no differences of K5 with K2 and K3 at 18 DAF, with K4 at 27 and 33 DAF in Jin-262. Similarly, no differences were reported between K5 and K3 at 21, 30, and 33 DAF in the upper value of Jingke-183.

3.7. Grain Starch Content. The current study showed that all five treatments induced the starch content in an increasing manner under the 6 sampling periods in both

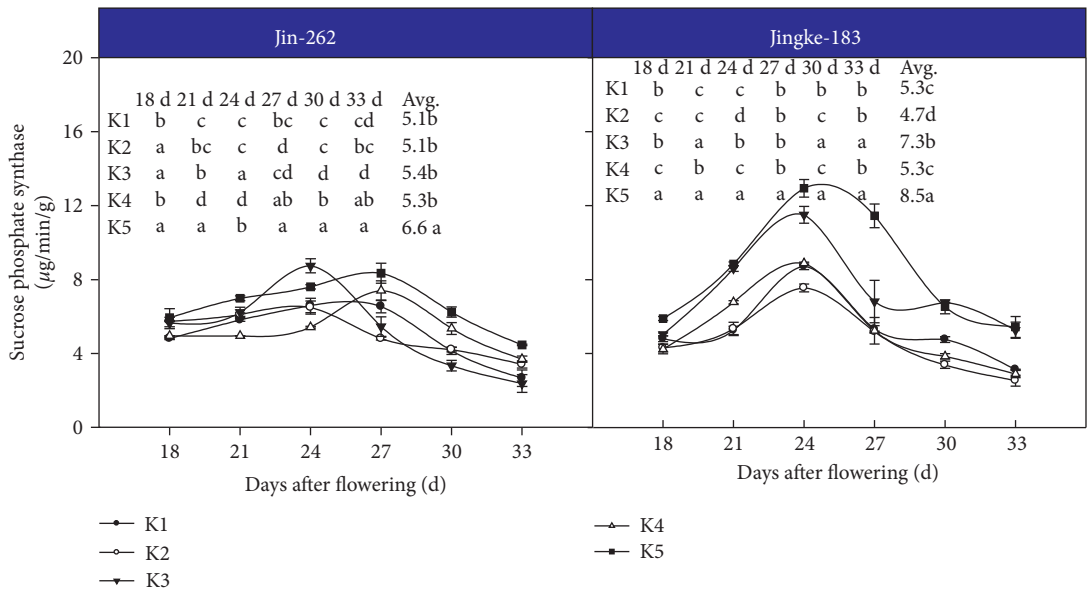

Figure 5: Effects of potassium on grain sucrose phosphate synthase (SPS) activity of fresh-eaten maize kernel fresh weight. The different lowercase letters are significant differences at the 5% level; AVG, average; the bars are standard deviation ($n = 5$).

varieties Jin-262 and Jingke183; however, the extent of increase is smaller in Jingke-183 than that observed in Jin-262 (Figure 6). In detail, considering the upper value, there were no differences in starch content between treatments K1 and K5 at 18 and 24 DAF in waxy maize Jin-262 ($p < 0.05$); however, at 21 DAF differences were found upon imposition of treatment K5. Surprisingly, this study did not report any differences in starch content among the treatments in the 27- and 30-day samplings. On the other hand, in variety Jingke-183, the least starch content was noted under treatment K4 throughout the sampling days, relative to other treatments. Overall, taking the average of all sampling days, from 18 to 33 DAF, the highest starch content was 32.2 and 32 under treatments K1 and K5 in the Jin-262 and 10.6 and 10.2 under treatments K2 and K1 in the variety Jingke-183 which are nonsignificant ($p < 0.05$) from each other, respectively.

3.8. Yield and Yield Components. The effect of potassium on yield and yield component in fresh-eaten maize is presented in Table 5. Grain yield, kernels per ear, and spike length were increased under treatment K3 in both varieties Jin-262 and Jingke-183. In detail, the grain yield (44107.69; 65128.2 ears/ha), kernels per ear (658; 545), and spike length (19.1; 18.8 cm) were noted in Jin-262 and Jingke-183, respectively, which were higher than other treatments. However, there were no significant differences ($p < 0.05$) in the ears per hectare and spike length between treatments K3 and K4, in the kernels per ear between treatments K3 and K5, and in fresh ear weight among treatments K2, K3, and K4 in variety Jin-262. Under the imposed treatments K2 and K3 in variety Jingke-183 and treatment K2 in variety Jin-262, the fresh ear weight was enhanced as compared with the other treatments.

There were no significant differences ($p < 0.05$) in the kernels per ear and spike length among K1, K3, K4, and K5 in variety Jingke-183.

3.9. Discussion. Potassium is an essential nutrient for plant growth and activating several enzymes used as a catalyst in promoting the metabolic processes of the crops, which plays an important role in increasing crop yields and plant growth [25, 26]. This is significantly influenced by various K fertilizer levels in different crops [27]; recent research indicates that K fertilization has increased the yield and carbohydrates content in maize [2, 4], sorghum [12], soybean [2], wheat [28], and mung bean [29]. In the northeast black soil with medium available potassium content of (113.36 mg/kg), the optimal potassium application amount of sweet maize was 107–140 kg/ha K_2O. When the application of K_2O is greater than 200 kg/ha, it is harmful to the growth, yield, and quality of sweet maize [30]. Balance K fertilization applied at the right time of plant development increases maize yield [31]. According to Amanullah et al. [4], early potassium application (vegetative stage) resulted in better growth and higher yield than late potassium application (reproductive stage); from tasseling to maturity, the potassium absorption rate decreases due to nutrient transport and distribution. In this study, we found that the application of 120 kg/ha K_2O had positive effects on the yield and quality of maize varieties at different flowering stages. Notably, the half-half dose application of K on basal and jointing stage (60 kg/ha basal + 60 kg/ha jointing stage; treatment K3) increased the grain yield, kernels per ear, spike length, and fresh ear weight. For instance, the grain yield of Jingke-183 was 65128 ears/ha, which was higher than plant density of 52300 plants/ha; this may be the increase of double ears number per plant under K3 (60 kg/ha basal + 60 kg/ha jointing stage). Similar positive increase in the yield and relative component has also

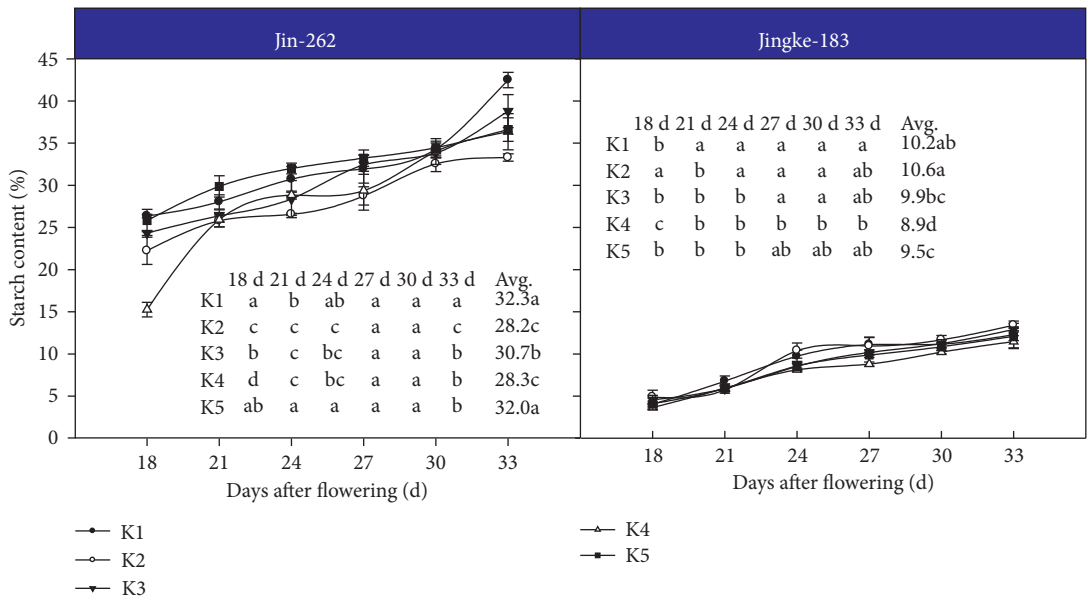

Figure 6: Effects of potassium on the starch content of fresh-eaten maize kernels. The different lowercase letters are significant differences at the 5% level; AVG, average; the bars are standard deviation ($n = 5$).

Table 5: Effect of potassium fertilizer on the yield of fresh-eaten maize during 2018.

Varieties	Treatment	Grain yield (kg/ear)	Kernels per ear	Spike length (cm)	Fresh ear weight (ears/ha)
Jin-262	K1	34354bc	615cd	17.8b	0.24c
	K2	28723c	609d	18.1b	0.29a
	K3	44108a	658a	19.1a	0.26abc
	K4	40508ab	632bc	18.6ab	0.28ab
	K5	36415b	646ab	18.2b	0.25bc
Jingke-183	K1	45641c	511ab	17.7ab	0.14b
	K2	42564c	494b	17.1b	0.16a
	K3	65128a	545a	18.8a	0.16a
	K4	54872b	532a	18.4a	0.15bc
	K5	47692c	522ab	18.1ab	0.15bc

The different lowercase letters in the same column are significantly different at the 5% level.

been observed in others crops such as soybean [2] and wheat [28], where they mentioned that the increase was due to either the increase in the number of pods per plant or the weight of individual kernel.

Sugars function as signals and metabolic intermediates used for growth, energy production, storage, and long-distance transport in plants [32, 33]. The total soluble sugar is used as a proxy for sugar and its higher values are positively correlated with the consumers acceptance [34], which determines the quality of fresh-eaten maize [35, 36]. Sucrose is the main component of soluble sugar, which is also helpful in accumulation and storage of carbohydrates and plays a leading role in sweetness of maize [37] and rice [38]. The K cation directly affects the structure of many enzymes [39], which can improve the sugar content due to the interaction by enzymes [40]. Altered sugar metabolism, together with corresponding changes in the sugar transport system, contributes to growth of plants [41, 42]. The main enzymes that participate in sucrose metabolism are sucrose phosphate synthase and sucrose synthase [37]. The sucrose phosphate synthase activity plays an important role in sucrose synthesis [43]; sucrose synthase is another enzyme initially involved in sucrose breakdown [44]. Sucrose synthase in sucrose metabolism can effectively regulate quality by sucrose synthesis and degradation as mentioned by [30, 45]. Furthermore, sucrose phosphate synthase and sucrose synthase are the key enzymes affecting starch synthesis [46]. Hashida et al. [47] studied that starch synthesis and sucrose phosphate synthase may play an important regulatory role in maintaining the balance between sucrose accumulation and consumption. The amount of sucrose converted to starch in seeds may change through the coordination of sucrose synthase and sucrose phosphate synthase to regulate the supply level of adenosine diphosphate glucose, the substrate required for starch synthesis [48]. Bioinformatic analysis indicates that sucrose phosphate synthase interacts with sucrose phosphate phosphatase, impacting soluble carbohydrate pools and affecting carbon partitioning to starch [49].

Data from this study showed that potassium application induced the soluble sugar content sucrose content, sucrose metabolic enzyme activity, and starch of fresh-eaten maize.

Importantly, the split application of K (24 kg/ha basal + 24 kg/ha jointing + 48 kg/ha big trumpet stage; treatment K5) was beneficial for increasing the soluble sugar content, the sucrose content, sucrose synthase activity, and sucrose phosphate synthase activity in Jin-262 and Jingke-183. The soluble sugar and sucrose content of Jin-262 and Jingke-183 were decreasing during 21-33 DAF, but significantly increased under split potassium fertilizer application (treatment K5; basal fertilizer 20%, jointing stage 40%, and big trumpet stage 40%); so, the increase of soluble sugar and sucrose content might be a reason of fresh-eaten maize's improved quality under the potassium treatment. Furthermore, sucrose content decreased while sucrose phosphate synthase and sucrose synthase activity both increased during 18–24 DAF; this might be because sucrose resolves to fructose and glucose, and the resolve rate is greater than the synthesis rate; the application of potassium effectively improved the decomposition ability of sucrose, rather than increase of synthetic quantity leading to the decrease in sucrose. In this study, the starch content increased, and the sucrose content decreased, indicating that the sucrose content in fresh-eaten maize was continuously transformed into starch by synthesis and degradation.

4. Conclusions

This study revealed the effect of potassium on the grain quality related parameter in two fresh-eaten maize varieties, Jin-262 (waxy maize) and Jingke-183 (sweet maize). The results showed that the gradual potassium fertilizer application (treatment K5; basal fertilizer 20%, jointing stage 40%, and big trumpet stage 40%) increased the quality related parameters such as soluble sugar, sucrose, and sucrose metabolic enzymes activities in the grain of Jin-262 and Jingke-183. However, the yield and related parameters of both varieties were enhanced under treatment K3 (basal 50% and jointing stage 50%). The results of this study showed that treatment K3 (basal 50% and jointing stage 50%) was beneficial for improving the yield and quality of fresh eaten maize; the early application is beneficial for nutrient absorption by crops. Therefore, we suggested that a reasonable application of potassium fertilizer is crucial to improve the quality and yield of fresh-eaten maize in semiarid cold regions.

Data Availability

The original data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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