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Sowing Date Regulates the Growth and Yield of Broomcorn Millet (*Panicum miliaceum* L.): From Two Different Ecological Sites on the Loess Plateau of China

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Abstract: A two-year experiment was conducted to determine the optimal combinations of sowing date and variety maturity using four broomcorn millet (*Panicum miliaceum* L.) varieties. The results showed that sowing dates had significant effects on the leaf net photosynthesis (Pn) and chlorophyll fluorescence and multivariate analysis showed that the effects of variety, sowing date, measuring stage and their interactions were significant in both sites. The days from seeding to maturity were strongly decreased (6–35 d) and the ratios of reproductive growth to vegetative growth were increased in V2 and V4 and decreased in V1 and V3 in Baoji and increased in all varieties in Yulin. The highest yield was Jinshu 5 in Baoji and Shaanmei 1 in Yulin, and the total average yield of Yulin (2408.3 kg ha^{-1}) was higher than that of Baoji (1385.2 kg ha^{-1}) and the average yield was reduced by 12.4% and 27.2% compared to BJ1 in Baoji and 15.5%, 3.6% and 12.7% compared to YL1 in Yulin. Correlation analysis showed that the key meteorological factors which limit the growth and yield of broomcorn millet were different for the two sites. Moreover, linear fitting analysis indicated that the accumulated temperature and the number of growth days in the reproductive growth stage (R^2 = 0.5306 and 0.5139) and accumulated temperature during the whole growth period (R^2 = 0.4323) were the top three factors affecting the yield in Baoji and precipitation (R^2 = 0.386) affected the yield in Yulin. Overall, the results of this study determined that the varieties of broomcorn millet with a short growth period should have delayed sowing, while those with a longer growth period are suitable for early sowing in the semi-arid area.

Keywords: broomcorn millet; sowing date; growth performance; yield; meteorological factor

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1. Introduction

Broomcorn millet (*Panicum miliaceum* L.), one of the annual warm-season crops with a 60–90-day growing cycle, has been grown in Northern China for at least 10,000 years [1]. As an important staple food, the main production area is along the Great Wall in China and Russia, Korea, Pakistan, India and other parts of Eurasia [1,2]. With its characteristics of high photosynthetic efficiency, low nutritional requirements and strong tolerance to abiotic stresses, such as drought [3], salt [4] and alkali [5], broomcorn millet is regarded as an important catch crop when other crops have been damaged by natural disasters. Meanwhile, broomcorn millet is regarded as a healthy diet food due to unique nutritional benefits: it features alkaline protein contents [6], which are higher than the levels in wheat and rice, an abundance of easily absorbable amino acids, mineral elements (calcium, iron, magnesium, zinc, etc.) and rich dietary fiber which helps to prevent disorders, such as diabetes and cardiovascular problems [7]. Moreover, with the readjustment of China's agricultural structure, broomcorn millet has been gaining increasing popularity.

The Loess Plateau of China, one of the most eroded areas in the world, is typically rainfed. This region comprises 341 counties, with a total area of 648,700 km^2 and a total cultivated land area of approximately 150,000 km^2. Because of higher water surface evaporation capacity (1500–2000 mm) and concentrated precipitation (from July to September), spring droughts are common, which impedes seed germination and seedling growth and can lead to crop failures [8]. Therefore, determining the optimal sowing date, improving crops yield and reducing water useless consumption play critical roles in food and water safety for the Loess Plateau of China. Baoji city (33° N, 106° E) is characterized by warm temperate semi-humid climate, and the annual average temperature, precipitation and sunshine duration are 11.9 °C, 626 mm and 2066.6 h, respectively. In contrast, Yulin city (38° N, 109° E) belongs to a semi-arid area with a temperate continental monsoon climate, and the annual average temperature, precipitation and sunshine duration are 8.3 °C, 400 mm and 2818.5 h, respectively. These data demonstrate that there are distinct climatic differences between these two areas.

Yield is a complex quantitative index that is strongly influenced by the environment. Many field experimental studies have shown that the sowing date is one of the most important factors in determining productivity [9–11]. Optimal planting date and the number of growth days for the same variety vary across regions due to different climate conditions. Even within the same growth environment or region, there is controversy in whether adjusting the sowing date could achieve greater water use efficiency and yield. Furthermore, as the global climate changes, such as the increase in annual temperature, the plant's optimum sowing dates may be different from the past. Although some researchers have attempted to shed light on this issue by using different sets of data and analyses [12,13], they do not provide actionable information to decision-makers to cope with the predicted climate volatility. Therefore, it is particularly critical to carry out relevant research in the field.

Sowing in an appropriate period benefits individual plant and group canopy development. This avoids cold temperatures at sowing and harvesting and heat stress in key growth stages, which increases the likelihood of a high yield [14,15]. Li et al. [16] reported that the late planting of middle- to late-maturing cultivars could increase rainfed potato yield in North China. However, a decrease in the final numbers of leaves and the individual leaf area from delayed sowing resulted in less light interception [17]. Generally, early-maturing cultivars could achieve a higher yield than late-maturing cultivars under terminal drought conditions; in contrast, late-maturing cultivars would improve crop yield if the temperature and precipitation during the growth seasons could meet the crop growth requirement [18,19]. However, information about the relationship between the sowing date and canopy development, especially at the level of an individual leaf of crops in a semi-arid environment, is not available.

Although the northwest of China is a major producing area of minor grain crops, up to now, few studies have focused on the effect of the planting date on rainfed broomcorn millet yield and yield stability. Therefore, in this study, two main areas on the Loess Plateau of China were selected to investigate the effects of sowing date on the agronomic traits and growth of broomcorn millet. We hypothesize that reasonable sowing time was beneficial to obtain a high yield of broomcorn millet, depending on the characteristics of different varieties. The objectives of this study were to: (i) evaluate the performance of sowing data in simulating the growth and development of broomcorn millet; (ii) investigate the effect of the planting date and variety maturity on broomcorn millet yield and yield variability; and (iii) select suitable sowing dates and broomcorn millet varieties for two main ecological types in northwest China. Our results will provide support for the efficient cultivation of broomcorn millet and further contribute to the development of the broomcorn millet industry.

2. Material and Methods

2.1. Experimental Site

A field experiment was conducted in the Baoji Academy of Agricultural Sciences, Shaanxi (34°37′ N, 109°21′ E, 669 m above sea level and lou soil) in 2019 and Yulin Modern Agriculture Demonstration Garden, Shaanxi (37°56′26″ N, 109°21′46″ E, 1120 m above sea level and loess soil) in 2020. Baoji and Yulin had different average air temperatures and precipitation rates, which were 13.1 °C and 637 mm and 10 °C and 440 mm, respectively. The forecrop in Baoji and Yulin was winter wheat and maize, respectively. Additionally, the properties of soil before sowing are presented in Table 1. Furthermore, the daily average temperature and precipitation from April to October for the two sites are displayed in Figure 1. Additionally, the accumulated temperature and sunshine duration for the different growth periods and precipitation during the whole growth period for the two sites are shown in Figure S1.

Table 1. The soil nutrient data before planting for the two sites.

Location	Total Nitrogen ($g \cdot kg^{-1}$)	Total Phosphorus ($g \cdot kg^{-1}$)	Total Potassium ($g \cdot kg^{-1}$)	Available Nitrogen ($mg \cdot kg^{-1}$)	Available Phosphorus ($mg \cdot kg^{-1}$)	Available Potassium ($mg \cdot kg^{-1}$)	Organic Matter ($g \cdot kg^{-1}$)
Baoji	1.24	1.05	20.2	87.1	32.8	158.8	21.0
Yulin	0.34	0.59	19.8	87.9	48.8	114.2	5.3

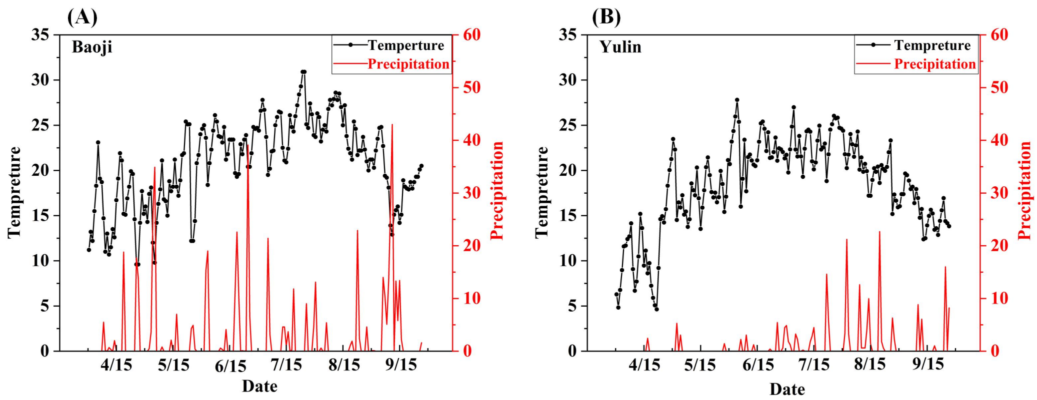

Figure 1. Daily average temperature and precipitation from April to October in Baoji (**A**) and Yulin (**B**).

2.2. Experimental Design

We used four varieties of broomcorn millet (*Panicum miliaceum* L.) with different maturities for both years: Shaanmei 1 (V1), Yumei 2 (V2), Yumei 3 (V3) and Jinshu 5 (V4). Baoji is a winter wheat-summer maize rotation area and Yulin is a one-harvest area, so the sowing date variation fits the local planting date. Therefore, three sowing dates were conducted in 10-day intervals in Baoji city, 4 June (BJ1), 14 June (BJ2) and 24 June (BJ3) in 2019. Similarly, four sowing dates were selected for 15-day intervals in Yulin city, 13 May (YL1), 28 May (YL2), 11 June (YL3) and 24 June (YL4) in 2020. The usual local sowing time was 14 June in Baoji and 11 June in Yulin. The experiment adopted a split zone design, with varieties as the main zone and sowing date as the subzone. Each experimental plot had an area of 10 m^2 (5 m × 2 m) with three replicates, row planting was carried out with 33 cm spacing, seedlings were at the three and five leaf stages and the plant spacing was 10 cm. Despite the sowing dates, both locations had similar field management methods, fertilizer management was carried out according to local traditional fertilization and no artificial irrigation was applied during the growing period. The plants were not chemically protected and bird nets were only erected after the heading stage.

2.3. Sampling and Measurements

2.3.1. Photosynthetic Characteristics

At the heading stage (S1), flowering stage (S2), filling stage (S3) and maturity stage (S4) of each treatment, three individual broomcorn millet plants were selected, and the leaf net photosynthesis (Pn, μmol CO_2 m^{-2} s^{-1}) was measured between 09:00 and 11:00 am on sunny days with the CIRAS-3 portable photosynthesis system (PP system, Amesbury, MA, USA). The flag leaves of broomcorn millet were assessed under photosynthetically active radiation of 1400 μmol m^{-2} s^{-1}. All measurements were conducted at an atmospheric CO_2 level of 400 μmol mol^{-1}.

2.3.2. Chlorophyll Fluorescence

At the four growth stages, similar plants were randomly selected from each plot, the maximum photochemical efficiency of PSII (Fv/Fm) and non-photochemical quenching coefficient (NPQ) were measured using MINI-PAM 2000 (WALZ, Germany). The calculation formula of actual photochemical efficiency of PSII (Φ_{PSII}) is presented in Equation (1) [20]:

$$\Phi_{\mathrm{PS}II} = \frac{Fv}{Fm} \times qP \tag{1}$$

where Φ_{PSII} is the actual photochemical efficiency, Fv/Fm is the maximum photochemical efficiency of PSII and qP is the photochemical quenching coefficient of PSII.

2.3.3. Plant Growth Period and Meteorological Factors during the Growth Period

During the whole growth period across the two sites, the specific date of each treatment corresponding to the growth stage was recorded, and the days and proportion of vegetative growth and reproductive growth were calculated using Equations (2)–(4):

$$\text{Vegetative growth ratio } = \frac{D_H}{D_M} \times 100\% \tag{2}$$

$$\text{Reproductive growth ratio } = \frac{D_M - D_H}{D_M} \times 100\% \tag{3}$$

$$\text{Ratio of reproductive to vegetative } = \frac{Reproductive\ growth\ ratio}{Vegetative\ growth\ ratio} \times 100\% \tag{4}$$

where D_H represents the days (d) from seedling to heading, D_M represents the days (d) from seedling to maturity and $D_M - D_H$ represents the days (d) from heading to maturity.

The meteorological data were obtained from local test bases, and the hours of sunshine duration and accumulated temperature of the whole growth period, vegetative growth period and reproductive growth period (S_M, S_{VG}, S_{RG}, T_M, T_{VG} and T_{RG}, respectively) and precipitation during the whole growth period were calculated for both sites.

2.3.4. Plant Morphology Traits, Yield and Yield Compositions

Before harvest, three representative plants were randomly selected from each plot to determine the morphological indexes of the plants, including plant height, stem diameter, stem tillers and branches, spike length, spike stalk length and the number of spikes, the number of first-level spike branches and the number of second-level spike branches. The plots were harvested and the yield was recorded according to the actual harvested area. Meanwhile, the 1000-grain weight was measured using a multifunctional automatic particle counting meter (DC-3) and a one percent balance.

2.3.5. Grain Size

We used an automatic species test analysis and 1000-grain weight system (SC-G, Wanshen, China) to measure the grain size, including grain width, length, diameter and length/width, roundness, circumference and area.

2.4. Data Analysis

SPSS 19.0 (SPSS Inc.; Chicago, IL, USA) was used for the analysis of data variance, multiple comparisons (Duncan's, $p < 0.05$), correlation analysis and the significance of the variety, sowing date and measuring stage effect and its interaction in each year. Origin Pro 2018 was used for figures.

3. Results

3.1. Leaf Photosynthesis Characteristics

Sowing dates had significant effects on the leaf net photosynthesis (Pn) of broomcorn millet (Figure 2 and Figure S2) and multivariate analysis showed that the effect of variety (V), sowing date (D) and measuring stage (S) and their interactions was significant in both sites ($p < 0.001$, Table S1). The detailed variation trend of different measuring stages and significant differences among different sowing dates in each variety were inconsistent for the two sites ($p < 0.05$). First of all, with the delay of the sowing date, the average Pn values significantly increased compared to BJ1 in Baoji (22.2% and 37.2%), which increased in V1 and V3, showed a V-shape trend in V2 and showed an invert-V trend in V4, while the average Pn values significantly decreased compared to YL1 in Yulin (9.1%, 29.8% and 33.4%, respectively), which showed a V shape trend in V1, decreased trend in V2, an invert-V trend in V3 and a Z shape trend in V4. Secondly, with the plant growth, the Pn showed an invert-V trend in both sites. However, the average Pn values peaked at different measuring stages for different varieties. In Baoji, the peaks were at the flowering stage (S2) in V1 and V4 (26.8 and 29.8), at the filling stage (S3) in V3 (32.4) and at both S2 and S3 in V2 (34.1 and 35.7). Additionally, in Yulin, the average Pn peaked at S2 in V1, V2 and V4 (29.9, 31.2 and 25.7, respectively) and at the heading stage (S1) and S2 in V3 (27.4 and 28.6) ($p < 0.05$). In general, the maximum Pn values of broomcorn millet flag leaves were at the flowering stage (S2) in both sites, and that of V2 was significantly higher than other varieties at both sites (Figure S2) ($p < 0.05$).

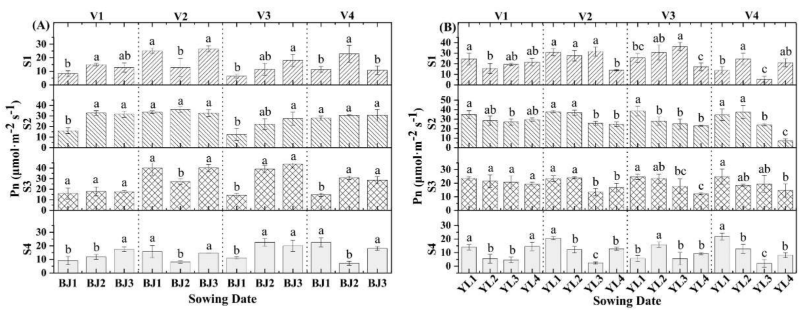

Figure 2. The leaf net photosynthesis (Pn) of broomcorn millet under different treatments in Baoji (**A**) and Yulin (**B**). V and S represent the variety and measuring stage, BJ and YL represent the sowing date in Baoji and Yulin, respectively. This applies to the other figures. The different lowercases in (**A**,**B**) represent the significant differences among treatments in each group at the two sites.

3.2. Leaf Chlorophyll Fluorescence

The chlorophyll fluorescence parameters, which were the maximum photochemical efficiency of PSII (Fv/Fm), non-photochemical quenching coefficient (NPQ) and actual photochemical efficiency of PSII (Φ_{PSII}), of the four broomcorn millet varieties under different sowing dates in the two sites are shown in Figure 3. The results were different from three perspectives: sowing date, variety and measuring stages. In Baoji (Figure 3A,C,E), Fv/Fm, NPQ and Φ_{PSII} had maximum values under BJ2 and the highest Fv/Fm was in V2, while the highest NPQ and Φ_{PSII} were in V1 and Fv/Fm and NPQ showed an inverted V-shape trend with the maximum values at S3 stage. Moreover, the Φ_{PSII} of S4 was significantly higher than that of S1–S3, while the difference among S1–S3 was not significant ($p < 0.05$). In Yulin (Figure 3B,D,F), the results were different from those in Baoji, Fv/Fm, NPQ and Φ_{PSII} had maximum values under YL2, there were no significant differences among the four varieties with regards to plant growth, Fv/Fm and NPQ were significantly decreased and Φ_{PSII} showed an inverted V-shape trend with maximum values at S3 stage ($p < 0.05$, Figure S3).

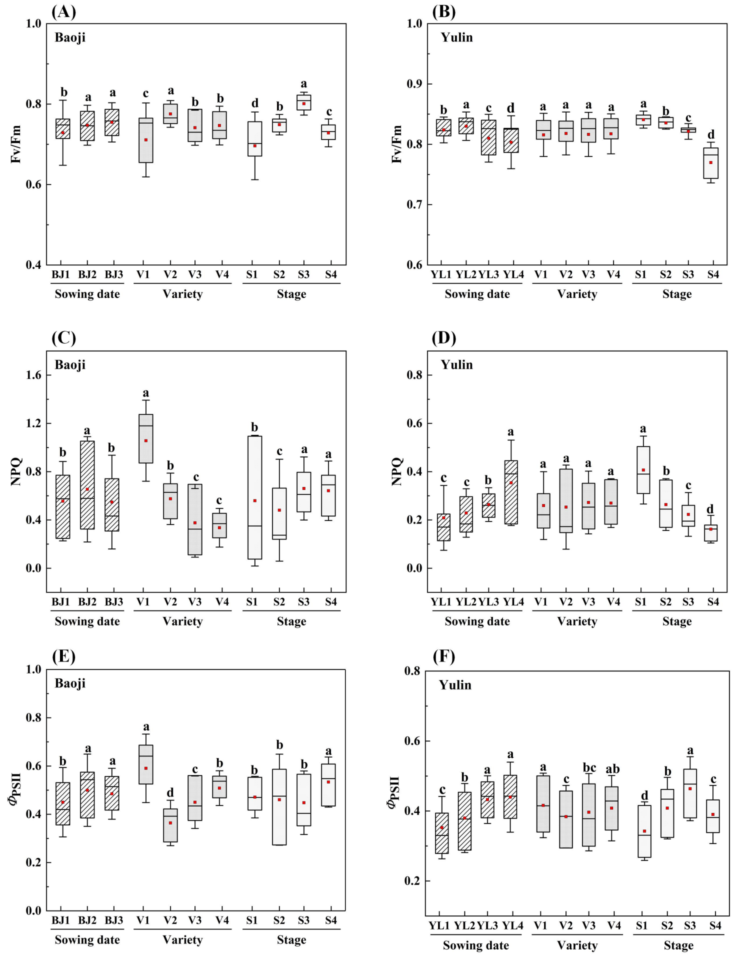

Figure 3. The overall difference in leaf chlorophyll fluorescence characteristics of broomcorn millet in Baoji (Fv/Fm, NPQ and Φ_{PSII}, (**A**,**C**,**E**), respectively) and Yulin (Fv/Fm, NPQ and Φ_{PSII}, (**B**,**D**,**F**), respectively). The different lowercases represent the significant differences among treatments in each group at the two sites.

Multivariate analysis showed that V, D, S and their interactions had significant effects on Fv/Fm, NPQ and Φ_{PSII} in Baoji, expect for S × D ($p < 0.001$). However, in Yulin, V had no significant effect on Fv/Fm and NPQ and V × S had no significant effect on NPQ; in addition, other variation sources had extremely significant effects on Fv/Fm, NPQ and Φ_{PSII} ($p < 0.01$). Meanwhile, the variety had a greater effect on fluorescence parameters in Baoji and the sowing date had a greater effect on fluorescence parameters in Yulin (Table S1).

3.3. Morphological Traits

As shown in Tables 2 and 3, the sowing date has a significant impact on the morphological characteristics of broomcorn millet in both sites. With the delay of the sowing date, the plant height (PH), stem diameter (SD) and number of stem nodes (SN) of broomcorn millet decreased in Baoji ($p < 0.05$) and showed a V-shape in Yulin and the lowest values appeared in YL3. However, the four different varieties responded to the sowing date differently, and their changing tendency was inconsistent for the two sites (Table 2). Moreover, spike length (SL) did not change with the sowing date in Baoji for all selected varieties and V1 and V2 in Yulin and spike stalk length (STL) changed with the sowing date for V2 and V3 in Baoji and V4 in Yulin.

Table 2. Investigation of morphological traits and yield of broomcorn millet under different treatments.

Location	Variety	Sowing Date	PH (cm)	SD (mm)	SN	T	B	SL (cm)	STL (cm)	NS	NSB1	NSB2	1000 G (g)	Y (kg ha^{-1})
Baoji	V1	BJ1	145.00 ± 7.00 a	6.60 ± 0.42 a	7.00 ± 1.00 a	1.00 ± 0.00 a	1.33 ± 2.31 a	41.00 ± 4.58 a	22.17 ± 12.00 a	2.00 ± 0.00 a	22.33 ± 2.52 a	108.67 ± 15.53 a	8.25 ± 0.01 a	2263.50 ± 45.90 a
		BJ2	119.00 ± 7.30 b	5.93 ± 0.63 a	5.00 ± 0.82 b	2.25 ± 2.22 a	0.75 ± 0.96 a	41.50 ± 4.80 a	23.75 ± 5.38 a	3.75 ± 2.75 a	19.00 ± 1.83 ab	94.00 ± 14.45 a	7.70 ± 0.07 b	1658.67 ± 39.35 b
		BJ3	138.50 ± 3.00 a	6.26 ± 0.42 a	5.25 ± 0.50 b	0.75 ± 0.96 a	0.00 ± 0.00 a	42.50 ± 7.85 a	17.63 ± 5.31 a	1.75 ± 0.96 a	17.75 ± 2.22 b	88.00 ± 15.66 a	7.39 ± 0.09 c	1278.90 ± 23.65 c
	V2	BJ1	147.00 ± 5.27 a	6.57 ± 0.54 a	5.33 ± 0.58 a	1.00 ± 0.00 a	0.00 ± 0.00 a	38.67 ± 5.03 a	29.67 ± 0.76 a	1.00 ± 0.00 b	20.33 ± 2.52 a	97.33 ± 10.69 a	8.15 ± 0.07 a	1402.33 ± 31.00 b
		BJ2	125.00 ± 4.36 b	5.18 ± 0.33 b	4.67 ± 0.58 a	0.67 ± 0.58 a	1.67 ± 0.58 a	36.67 ± 1.53 a	32.67 ± 1.15 a	3.33 ± 0.58 a	14.67 ± 0.58 b	57.67 ± 6.81 b	7.63 ± 0.06 c	1733.00 ± 28.35 a
		BJ3	110.67 ± 8.02 c	4.75 ± 0.39 b	4.33 ± 0.58 a	0.67 ± 0.58 a	1.33 ± 1.53 a	38.33 ± 2.52 a	17.83 ± 7.52 b	3.00 ± 1.00 a	17.33 ± 1.15 ab	89.00 ± 4.00 a	8.03 ± 0.09 b	1043.56 ± 23.11 c
	V3	BJ1	114.67 ± 3.79 a	4.75 ± 0.33 a	4.33 ± 0.58 b	1.00 ± 0.00 b	0.33 ± 0.58 b	37.00 ± 4.58 a	14.00 ± 2.65 b	2.33 ± 0.58 b	16.33 ± 1.53 a	92.67 ± 3.51 a	5.83 ± 0.04 c	1122.22 ± 11.11 a
		BJ2	107.33 ± 2.31 a	4.35 ± 0.09 a	5.33 ± 0.58 a	0.67 ± 1.15 b	2.00 ± 1.00 a	33.67 ± 2.52 a	24.50 ± 2.00 a	3.00 ± 1.00 b	17.00 ± 1.00 a	81.00 ± 3.61 b	5.92 ± 0.07 b	785.11 ± 14.89 c
		BJ3	91.00 ± 5.29 b	3.43 ± 0.14 b	4.00 ± 0.00 b	2.67 ± 0.58 a	0.33 ± 0.58 b	35.00 ± 1.73 a	28.33 ± 2.89 a	6.00 ± 2.00 a	13.00 ± 0.00 b	60.00 ± 1.00 c	6.15 ± 0.02 a	637.33 ± 20.67 b
	V4	BJ1	133.00 ± 3.97 a	6.23 ± 0.14 a	5.00 ± 0.00 a	0.00 ± 0.00 b	0.00 ± 0.00 b	33.83 ± 3.40 a	29.67 ± 0.58 a	1.00 ± 0.00 b	16.33 ± 0.58 a	69.33 ± 3.51 b	5.79 ± 0.05 b	1267.33 ± 12.67 b
		BJ2	125.67 ± 5.69 a	5.12 ± 0.44 b	5.67 ± 0.58 a	0.00 ± 0.00 b	3.00 ± 1.00 a	37.67 ± 3.51 a	29.17 ± 3.62 a	4.00 ± 1.00 a	15.33 ± 2.08 a	74.33 ± 5.03 b	5.55 ± 0.12 c	1743.56 ± 66.89 a
		BJ3	116.83 ± 11.75 a	4.89 ± 0.49 b	5.33 ± 0.58 a	2.33 ± 1.15 a	1.00 ± 1.00 b	34.33 ± 1.53 a	27.17 ± 3.62 a	4.33 ± 2.08 a	17.00 ± 1.00 a	87.33 ± 2.31 a	5.96 ± 0.03 a	1686.56 ± 19.89 a
Yulin	V1	YL1	180.33 ± 11.68 a	7.95 ± 0.77 a	7.67 ± 0.58 a	3.00 ± 1.00 a	0.00 ± 0.00 b	41.67 ± 1.53 a	30.33 ± 3.79 a	4.00 ± 1.00 a	23.33 ± 0.58 a	128.00 ± 2.00 a	7.43 ± 0.16 c	3220.00 ± 70.00 a
		YL2	183.67 ± 5.51 a	7.00 ± 0.14 b	8.00 ± 1.00 a	2.67 ± 0.58 a	0.00 ± 0.00 b	39.00 ± 2.65 a	29.00 ± 3.61 a	3.67 ± 0.58 ab	21.33 ± 0.58 a	119.67 ± 2.52 b	8.30 ± 0.12 b	2290.00 ± 105.36 c
		YL3	161.00 ± 6.56 b	4.95 ± 0.02 c	7.00 ± 0.00 a	0.00 ± 0.00 b	1.33 ± 0.58 a	36.00 ± 1.00 a	24.33 ± 2.31 a	2.33 ± 0.58 bc	18.00 ± 2.00 b	54.67 ± 7.37 d	8.65 ± 0.04 a	3186.67 ± 96.09 a
		YL4	160.33 ± 3.79 b	5.10 ± 0.29 c	5.33 ± 0.58 b	1.00 ± 1.00 b	0.00 ± 0.00 b	40.33 ± 5.03 a	28.67 ± 3.21 a	2.00 ± 1.00 c	16.67 ± 0.58 b	93.67 ± 1.15 c	8.39 ± 0.03 b	2686.67 ± 90.74 b
	V2	YL1	160.33 ± 4.62 ab	6.78 ± 0.31 b	7.33 ± 0.58 ab	1.33 ± 0.58 b	2.00 ± 0.00 a	36.33 ± 2.89 a	24.33 ± 1.15 a	8.00 ± 1.00 a	21.33 ± 1.53 a	111.33 ± 4.16 b	9.01 ± 0.14 c	2950.00 ± 108.17 b
		YL2	172.67 ± 5.13 a	8.16 ± 1.21 a	8.00 ± 1.00 a	1.67 ± 0.58 b	0.33 ± 0.58 bc	33.67 ± 1.53 a	25.33 ± 6.66 a	4.00 ± 1.73 b	22.67 ± 0.58 a	129.67 ± 2.52 a	9.15 ± 0.07 b	2646.67 ± 123.42 c
		YL3	151.33 ± 12.9 b	5.22 ± 0.42 c	7.00 ± 0.00 ab	0.00 ± 0.00 c	1.67 ± 1.53 ab	38.33 ± 5.13 a	28.00 ± 1.73 a	2.67 ± 1.53 b	21.67 ± 1.53 a	93.00 ± 8.19 c	9.33 ± 0.07 a	3133.33 ± 60.28 a
		YL4	156.33 ± 4.04 b	6.48 ± 0.17 b	6.33 ± 0.58 b	2.67 ± 0.58 a	0.00 ± 0.00 c	37.67 ± 1.53 a	26.67 ± 2.08 a	3.67 ± 0.58 b	19.00 ± 1.00 b	86.67 ± 6.03 c	9.41 ± 0.02 a	2566.67 ± 41.63 c
	V3	YL1	101.00 ± 9.17 b	5.98 ± 0.04 a	7.00 ± 1.00 a	2.67 ± 1.15 a	1.00 ± 1.00 b	27.33 ± 4.04 b	18.83 ± 2.57 a	4.00 ± 1.00 b	18.67 ± 2.31 a	108.67 ± 6.66 a	5.93 ± 0.14 c	1186.67 ± 30.55 c
		YL2	125.33 ± 6.11 a	5.10 ± 0.11 b	5.67 ± 0.58 ab	2.33 ± 1.15 a	1.00 ± 1.00 b	38.33 ± 5.51 a	23.67 ± 2.31 a	8.33 ± 3.21 a	16.33 ± 1.15 a	85.67 ± 4.93 b	6.73 ± 0.06 b	1280.00 ± 10.00 b
		YL3	84.33 ± 7.02 c	3.27 ± 0.18 c	5.67 ± 0.58 ab	0.00 ± 0.00 b	3.67 ± 1.53 a	26.50 ± 0.87 b	22.67 ± 3.06 a	5.00 ± 1.00 ab	11.33 ± 1.15 b	31.67 ± 2.89 c	6.78 ± 0.05 ab	1363.33 ± 20.82 ab
		YL4	122.67 ± 5.13 a	4.85 ± 0.53 b	4.33 ± 0.58 b	2.67 ± 0.58 a	1.00 ± 1.00 b	38.00 ± 2.65 a	21.67 ± 3.21 a	4.67 ± 1.53 ab	17.00 ± 2.65 a	91.00 ± 4.58 b	6.88 ± 0.06 a	1426.67 ± 83.27 a
	V4	YL1	138.00 ± 5.20 b	6.18 ± 0.30 a	6.67 ± 0.58 a	2.67 ± 0.58 a	0.00 ± 0.00 b	32.33 ± 2.31 a	19.00 ± 2.65 b	3.67 ± 0.58 a	18.00 ± 2.65 ab	79.33 ± 12.90 a	5.97 ± 0.06 c	2506.67 ± 85.05 a
		YL2	153.33 ± 3.06 a	5.45 ± 0.99 a	7.00 ± 0.00 a	1.67 ± 2.08 ab	1.00 ± 0.00 b	35.00 ± 2.00 a	28.00 ± 3.00 a	4.00 ± 2.65 a	21.33 ± 3.21 a	92.33 ± 6.66 a	6.48 ± 0.17 b	2116.67 ± 107.86 b
		YL3	102.00 ± 2.65 c	2.77 ± 0.17 b	5.67 ± 0.58 b	0.00 ± 0.00 b	2.67 ± 1.15 a	24.67 ± 1.53 b	24.33 ± 0.58 ab	3.67 ± 1.15 a	16.00 ± 1.00 b	55.67 ± 5.03 b	6.49 ± 0.03 b	1810.00 ± 30.00 c
		YL4	140.67 ± 3.06 b	5.46 ± 1.15 a	5.67 ± 0.58 b	2.33 ± 0.58 a	0.00 ± 0.00 b	36.00 ± 1.73 a	24.00 ± 4.58 ab	3.33 ± 0.58 a	17.67 ± 1.53 ab	86.33 ± 6.35 a	6.63 ± 0.05 a	1926.67 ± 109.7 c

Mean ± SD, n = 3, and different lowercases represent significant differences among sowing date treatments in the same variety, $p < 0.05$. PH plant height, SD stem diameter, SN stem nodes, T number of stem tillers, B number of stem branches, SL spike length, STL spike stalk length, NS number of spikes, NSB1 number of first-level spike branches, NSB2 number of second-level spike branches, 1000G 1000-grain weight, Y yield. These apply to other tables and figures.

Table 3. The ANOVA results of morphological traits and yield of broomcorn millet under different treatments.

Location	Variation Source	PH (cm)	SD (mm)	SN	T	B	SL (cm)	STL (cm)	NS	NSB1	NSB2	1000 G (g)	Y (kg ha^{-1})
Baoji	Variety (V)	41.847 ***	38.732 ***	8.97 ***	2 ns	0.491 ns	6.727 **	3.774 *	2 ns	9.869 ***	7.331 **	3584.452 ***	259.858***
	Sowing date (D)	37.406 ***	27.857 ***	6.091 **	2.542 ns	7.342 **	0.046 ns	3.553 *	11.625 ***	11.225 ***	12.468 ***	65.239 ***	88.746 ***
	V × D	6.228 ***	2.162 ns	4.515 **	6.542 ***	1.833 ns	0.678 ns	4.207 **	3.768 **	4.768 **	9.74 ***	67.612 ***	67.296 ***
Yulin	V	53.764 ***	53.219 ***	21.105 ***	21.255 ***	17.046 ***	10.976 ***	2.264 ns	4.616 **	14.598 ***	174.039***	3550.121***	202.815***
	D	217.187 ***	31.58 ***	14.649 ***	0.706 ns	5.92 **	15.695 ***	8.87 ***	6.906 **	21.626 ***	63.164 ***	210.301 ***	23.553 ***
	V × D	7.013 ***	4.186 **	1.924 ns	1.778 ns	2.211 *	5.087 ***	1.896 ns	3.449 **	4.274 **	21.649 ***	16.935 ***	13.955 ***

ns represents no significant difference; *, ** and *** represent significant effects at the levels of $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.

The average tallest plant was V1 among the varieties and BJ1 among the sowing dates in Baoji, and the PH, SD, SL and STL were 134.2 cm, 6.26 mm, 41.7 cm and 21.2 cm and 134.9 cm, 6.03 mm, 37.6 cm and 23.9 cm, respectively. Similarly, it was V2 and YL1 in Yulin, and those were 158.8 cm, 6.43 mm, 36.5 cm and 26.5 cm and 171.3 cm, 6.25 mm, 39.3 cm and 28.1 cm, respectively. Generally, the averages of morphological parameters in Yulin were larger than those in Baoji, except for the SL.

Multivariate analysis showed that V, D and their interaction had significant effects on PH, SN in both sites, and had significant effects on SL in Yulin ($p < 0.001$). Moreover, D had no significant effect on the number of stem tillers (T) in both sites and V had no significant effect on T and number of stem branches (B) in Baoji and STL in Yulin ($p < 0.05$).

3.4. Plant Growth Days and the Meteorological Factors during Each Growth Period

The number of growth days during each growth period and the hours of sunshine and accumulated temperature during the whole growth period (S_M and T_M), vegetative growth period (S_{VG} and T_{VG}) and reproductive growth period (S_{RG} and T_{RG}) and precipitation (P) during each growth period of all treatments at the two sites are shown in Table 4. With the postponement of the sowing date, the days between seeding to emergence were shortened and the days from seedling to maturity (D_M) were decreased (4–11 d in Baoji and 10–31 d in Yulin), whichever the days of vegetative growth (D_{VG}, 3–6 d in Baoji (except V1) and 20–28 d in Yulin) or reproductive growth (D_{RG}, 2–6 in Baoji and 7–11 in Yulin (except V3)) of all selected varieties in both sites. The reduction in D_{VG} was greater, resulting in an increased ratio of reproductive growth to vegetative growth ($R_{R/V}$). However, the response of the four varieties to the sowing date was different in the two sites. In Baoji, with the delay of the sowing date, the R_{RG} of varieties with relatively longer (V1) and shorter (V3) growth periods decreased, while the R_{RG} of varieties with intermediate growth periods (V2 and V4) increased. In Yulin, the R_{RG} increased with the delay of the sowing date, and the most obvious increase was shown in V3 (59.02% up to 125%). On average, the growth period of V1, V2 and V4 was longer than that of V3, which suggested that the varieties with a longer growth period were more affected by the sowing date.

Table 4. The growth period of broomcorn millet and the meteorological factors under different sowing dates in the two sites.

Location	Variety	Sowing Date	D_E	D_{VG}	D_{RG}	D_M	R_{VG} (%)	R_{RG} (%)	$R_{R/V}$ (%)	S_M	S_{VG}	S_{RG}	T_M	T_{VG}	T_{RG}	P
Baoji	V1	BJ1	8	37	40	77	48.24	51.76	107.32	457.10	164.10	293.00	1903.40	789.20	1114.20	241.30
		BJ2	7	37	38	75	48.78	51.22	105.00	421.90	199.20	222.70	1848.60	800.00	1048.60	210.90
		BJ3	6	37	36	73	49.37	50.63	102.56	413.10	226.30	186.80	1811.50	853.20	958.30	191.70
	V2	BJ1	8	35	42	77	45.88	54.12	117.95	457.10	155.10	302.00	1903.40	736.30	1167.10	241.30
		BJ2	6	35	38	73	46.83	53.16	113.51	421.90	162.30	259.60	1805.60	742.20	1063.40	210.70
		BJ3	6	30	36	66	44.44	55.56	125.00	412.10	177.60	234.50	1655.00	664.10	990.90	162.30
	V3	BJ1	6	34	33	67	52.05	47.95	92.10	382.90	150.50	232.40	1668.00	759.60	908.40	213.00
		BJ2	6	33	30	63	53.62	46.38	86.49	396.70	180.70	216.00	1581.30	742.20	839.10	178.90
		BJ3	6	31	28	59	53.85	46.15	85.71	391.10	214.60	176.50	1505.30	751.00	754.30	157.50
	V4	BJ1	7	35	36	71	50.00	50.00	100.00	425.90	155.10	270.80	1768.00	760.10	1007.90	213.00
		BJ2	6	32	35	67	47.95	52.05	108.57	408.70	153.00	255.70	1674.20	691.30	982.90	203.70
		BJ3	6	29	34	63	46.38	53.62	115.62	391.60	177.60	214.00	1592.30	664.10	928.20	162.10
Yulin	V1	YL1	10	69	37	106	62.93	37.07	58.90	1050.58	662.67	387.92	2285.10	1386.80	898.30	153.30
		YL2	7	62	40	102	57.80	42.20	73.01	983.50	576.33	407.17	2204.10	1288.40	915.70	162.40
		YL3	7	49	40	89	55.21	44.79	81.13	847.00	477.75	369.25	1890.10	1075.40	814.70	161.70
		YL4	6	46	29	75	54.32	45.68	84.09	701.75	385.00	316.75	1574.30	896.70	677.60	160.10
	V2	YL1	10	63	42	105	58.26	41.74	71.64	1041.83	607.25	434.58	2265.60	1251.90	1013.70	153.30
		YL2	7	56	46	102	53.21	46.79	87.93	983.50	522.08	461.42	2204.10	1165.20	1038.90	162.40
		YL3	7	42	47	89	47.92	52.08	108.70	847.00	410.08	436.92	1890.10	908.10	982.00	161.70
		YL4	6	35	40	75	45.68	54.32	118.92	701.75	321.42	380.33	1574.30	739.40	834.90	160.10
	V3	YL1	12	54	31	85	62.89	37.11	59.02	849.92	543.67	306.25	1890.70	1082.20	808.50	119.70
		YL2	7	48	42	90	54.64	45.36	83.02	869.17	478.92	390.25	1993.20	1053.60	939.60	153.30
		YL3	7	36	38	74	50.62	49.38	97.56	701.75	365.75	336.00	1638.60	791.80	846.80	146.60
		YL4	6	34	41	75	44.44	55.56	125.00	701.75	313.83	387.92	1574.30	717.50	856.80	160.10
	V4	YL1	12	58	43	101	56.64	43.36	76.56	997.50	576.92	420.58	2196.30	1155.30	1041.00	153.30
		YL2	7	56	37	93	59.00	41.00	69.49	901.25	530.83	370.42	2044.00	1187.00	857.00	153.30
		YL3	7	43	34	77	54.76	45.24	82.61	733.83	410.08	323.75	1689.40	908.10	781.30	146.60
		YL4	6	37	38	75	49.38	50.62	102.50	701.75	345.92	355.83	1574.30	805.40	768.90	160.10

D_E represents the number of days from seeding to emergence, D_{VG} stands for the number of days from seedling to flowering, D_{RG} stands for the number of days from flowering to maturity, D_M stands for the number of days from emergence to maturity. R_{VG} represents vegetative growth ratio, R_{RG} represents reproductive growth ratio, $R_{R/V}$ represents the ratio of reproductive growth to vegetative growth. The sunshine duration and accumulated temperature during the whole growth period (S_M and T_M), vegetative growth period (S_{VG} and T_{VG}) and reproductive growth period (S_{RG} and T_{RG}) and precipitation (P) during each growth period, respectively. These apply to other figures and tables.

The averages of S_M, S_{VG}, S_{RG}, T_M, T_{VG}, T_{RG} and P for the two sites were significantly different (Figure S1 $p < 0.05$), 415.0 h, 176.3 h, 238.7 h, 1726.4 °C, 746.1 °C, 980.3 °C and 198.9 mm in Baoji and 850.9 h, 470.5 h, 380.3 h, 1905.5 °C, 1025.8 °C, 879.7 °C and 154.3 mm in Yulin, respectively. The CVs of S_M, S_{VG}, T_M, T_{VG} and T_{RG} in Yulin were larger than those in Baoji. Moreover, the S_M, S_{VG}, S_{RG} and T_{VG} in Baoji were extremely lower than those in Yulin ($p < 0.01$), and the T_{RG} and P in Baoji were significantly higher than those in Yulin ($p < 0.05$).

3.5. Yield and Yield Components

As shown in Table 2, the changing trends of yield and yield components were inconsistent for the different varieties and sites. The yield of broomcorn millet could be affected by the changes in yield components to some extent. The changing trends of yield for different sowing dates were inconsistent in the two sites. In Baoji, the highest yield of V1 and V3 was under BJ1 treatment (2263.5 and 1122.2 kg ha^{-1}), and that of V2 and V4 was under BJ2 treatment (1733.0 and 1743.6 kg ha^{-1}). In Yulin, the highest yield of V1 and V4 was under YL1 treatment (3200.0 and 2506.7 kg ha^{-1}), V2 was under YL3 treatment (3133.3 kg ha^{-1}) and V3 was under YL4 treatment (1426.7 kg ha^{-1}). The differential yield spans of V1 to V4 in different sowing periods in Baoji were 984.6, 689.5, 484.9 and 476.3 kg ha^{-1}, respectively, and in Yulin they were 930.0, 566.6, 240.0 and 696.7 kg ha^{-1}, respectively. In Baoji, the maximum 1000-grain weight of V1 and V2 was under BJ1 treatment (8.25 g and 8.15 g) and that of V3 and V4 was observed under BJ3 treatment (6.15 g and 5.96 g). In Yulin, it was YL3 of V1 (8.65 g) and YL4 of V2, V3 and V4 (9.41 g, 6.88 g and 6.63 g, respectively). Furthermore, the number of spikes, the number of first-level spike branches and second-level spike branches and 1000-grain weight were also affected by the sowing dates in both sites, and there were significant differences among varieties. Notably, multivariate analysis showed that V, D and their interaction had significant effects on the yield and yield components of broomcorn millet ($p < 0.001$, Table 3) (expect for V, which had no significant effect on the number of spikes in Baoji).

3.6. The Grain Size of Broomcorn Millet

The grain size indexes of different sowing dates and varieties for both sites are shown in Figure 4. There were no significant differences in grain length, circumference, area and diameter for the three sowing dates in Baoji. However, with the postponement of the sowing date, the grain length, width, circumference, area and diameter showed an inverted V-shaped changing trend in Yulin, and they were significant differences among sowing dates ($p < 0.05$). The grain length and length/width in Baoji (3.45 mm and 1.45) were higher than that in Yulin (3.28 mm and 1.28). Furthermore, the grain length/width of BJ3 was significantly higher than that of BJ1 and BJ2, and it showed an increasing trend from YL1 to YL4 (Figure S4). Notably, multivariate analysis showed that V, D and their interaction had significant effects on all grain size parameters of broomcorn millet in Yulin ($p < 0.001$), while V and V × D had significant effects on the grain size parameters of broomcorn millet and D had significant effects on the grain length/width and roundness in Baoji ($p < 0.05$, Table S1).

3.7. Correlation Analysis of Plant and Grain Parameters and Meteorological Factors in Each Location

The correlations between plant and grain size parameters, as well as yield and 1000-grain weight, meteorological factors and the number of growth days of the two sites are shown in Figure 5. First of all, the results of the correlation analysis were different for the two sites. At Baoji, the PH, SD and NSB1, as well as 1000-grain weight and yield were positively related to S_M, S_{RG}, T_M and T_{RG}, D_M and D_{RG}; on the other hand, grain width, surface area, diameter and circumference were negatively related to S_M, T_M and D_M (Figure 5A, $p < 0.01$). However, at Yulin, the plant parameters (PH, SD, SN, SL and STL, NSB1 and NSB2) and the leaf characters (Pn, *Fv*/*Fm* and NPQ) were strongly positively related to S_M, S_{VG}, T_M and T_{VG}, D_M and D_{VG}, and grain width, area, length, diameter and circumference, 1000-grain weight and yield were positively related to P (Figure 5B, $p < 0.05$). Moreover, Φ_{PSII} (PSII) was not related to any meteorological factors or growth parameters at either site.

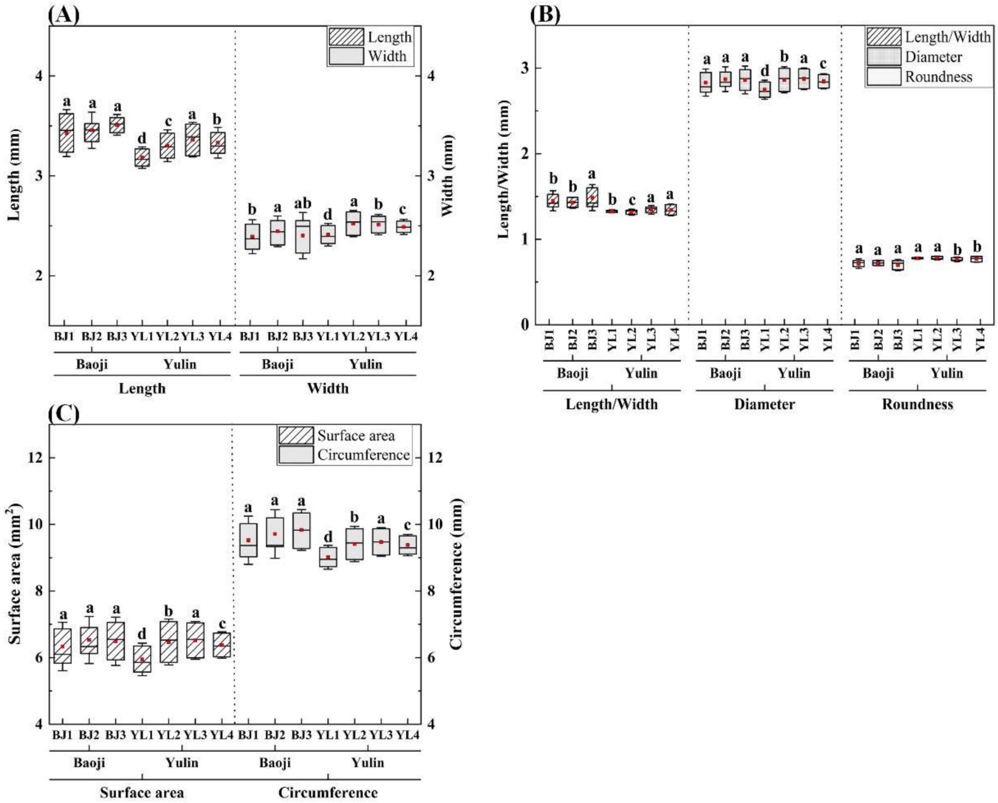

Figure 4. The overall difference in grain size parameters of broomcorn millet (**A**,**B**,**C**). Grain length and width were showed in (**A**), grain diameters indexes (length/width, diameter and roundness) were showed in (**B**) and grain surface area and grain circumference were showed in (**C**). BJ and YL represent for sowing date in Baoji and Yulin, respectively; the different lowercases in (**A**), (**B**), and (**C**) represent the significant differences among treatments in each group at two sites.

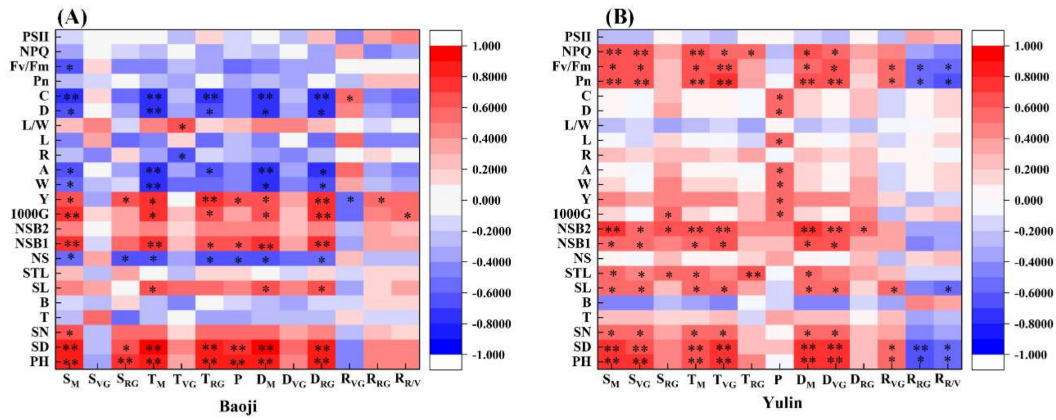

Figure 5. The correlations between plant and grain parameters and meteorological factors and growth periods in Baoji (**A**) and Yulin (**B**). R_{VG} represents the vegetative growth period; R_{RG} represents the reproductive growth period; $R_{V/R}$ represents the ratio of vegetative growth period to reproductive growth period. W width, A grain area, R grain roundness, L grain length, L/W grain length/width, D grain diameter, C grain circumference, respectively. These apply to other figures and tables. * and ** represent significant correlations at the levels of $p < 0.05$ and $p < 0.01$.

The strongest meteorological factors which affected PH and SD was T_M in Baoji ($r = 0.879$ and 0.929, $p < 0.01$) and S_M and T_{VG} in Yulin ($r = 0.723$ and 0.762, $p < 0.01$), respectively. Additionally, the strongest factors that were related to yield was D_{RG} in Baoji ($r = 0.762$, $p < 0.01$) and P in Yulin ($r = 0.723$, $p < 0.05$).

3.8. Fitting Relationship between Yield, Meteorological Factors and Growth Days

The linear fitting relationships between yield and S_M, S_{VG} and S_{RG}, T_M, T_{VG} and T_{RG}, D_M, D_{VG} and D_{RG} and P for the two sites are presented in Figure 6. First of all, the meteorological factors and the number of growth days were positively related to yield in both sites (except for S_{VG} in Baoji). In Baoji, the yield of broomcorn millet was significantly and positively correlated with most of the meteorological factors. According to the R^2 value of the fitted line, these factors were T_{RG} and D_{RG} ($R^2 = 0.5306$ and 0.5139, Figure 6A6, A9), T_M and D_M ($R^2 = 0.4323$ and 0.4288, Figure 6A4,A7), P ($R^2 = 0.3554$, Figure 6A10) and S_{RG} and S_M ($R^2 = 0.3432$ and 0.3348, Figure 6A1,A3) ($p < 0.05$, Figure 6). Additionally, in Yulin, the P was positively related to yield ($R^2 = 0.386$, Figure 6B10); however, there was no significant correlation between yield and other meteorological factors in Yulin.

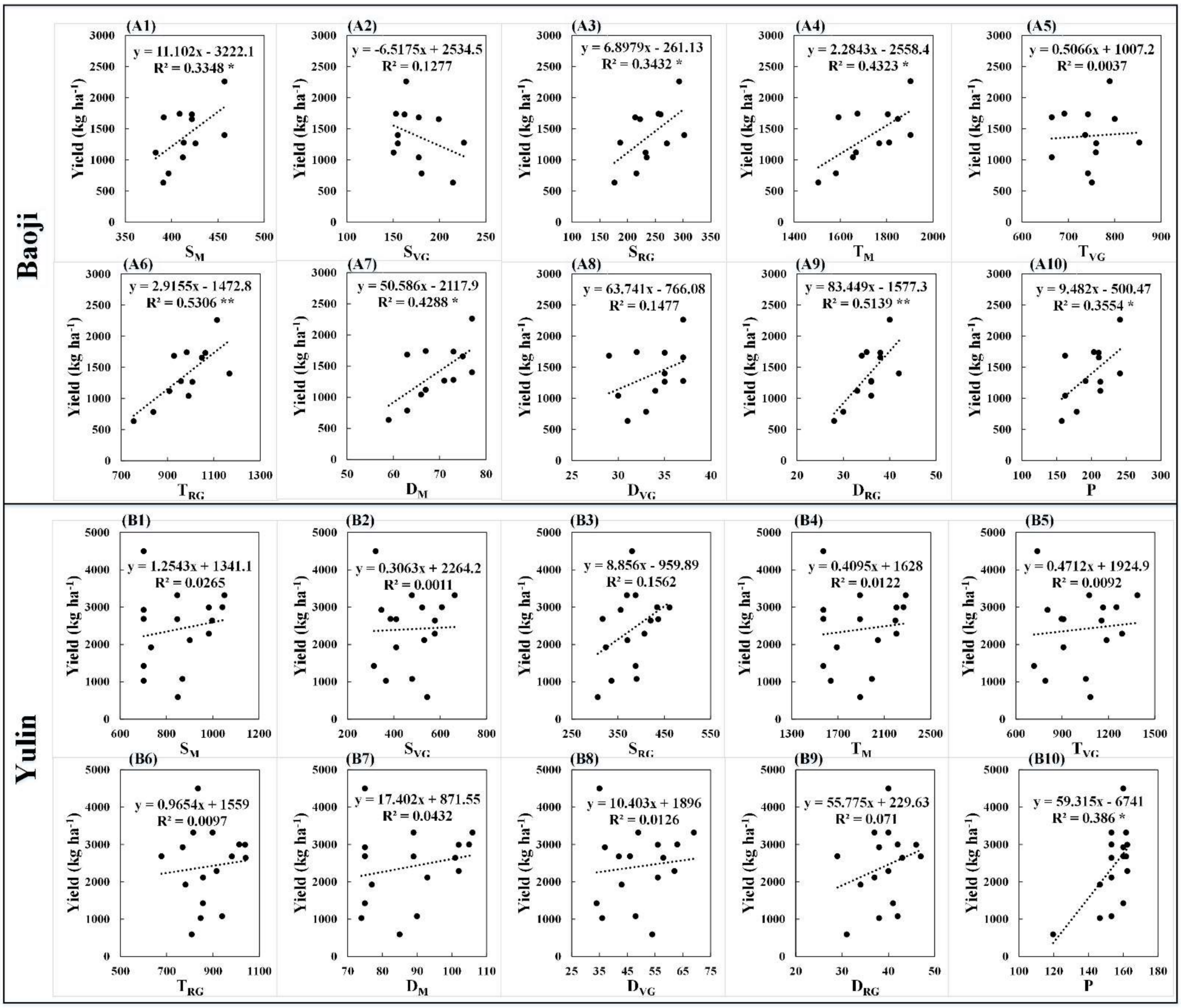

Figure 6. The linear fitting relationship between yield and sunshine duration (**A1**–**A3** and **B1**–**B3**), accumulated temperature (**A4**–**A6** and **B4**–**B6**), the number of growth days (**A7**–**A9** and **B7**–**B9**) and precipitation (**A10** and **B10**) during the growing period in Baoji (**A**) and Yulin (**B**).

4. Discussion

4.1. Responses of Photosynthetic Characteristics and Chlorophyll Fluorescence Parameters to Sowing Dates

The leaf net photosynthesis (Pn) showed non-uniform patterns in space and time. It was complicated by the microclimates of different environmental control regimes and external microclimate conditions, and air temperature and leaf temperature were the strongest factors that influenced leaf Pn [21]. The cumulative photosynthetically active radiation during the growing stage has a positive correlation with crop growth [22]. Crop leaves are sensitive to the light environment and temperature, sufficient sunshine duration and suitable temperature play important roles in promoting photosynthesis and the photosynthetic capacity is affected by sowing dates to a certain extent. In the current study, with the delay of the sowing dates, the Pn values under BJ3 significantly increased compared to BJ1 in Baoji; the opposite trend occurred in Yulin. These results could be explained by the meteorological factor differences in two sites, as Pn was negatively related to meteorological factors in Baoji, but positively related to those in Yulin. In particular, the average air temperature in Baoji was higher during the growth period, and the high air temperature did not coincide with large precipitation; thus, the whole growth period was shortened by many days, indicating that the accumulated temperature was lower. In contrast, with the delay of the sowing date in Yulin, the temperature and sunshine duration significantly decreased, resulting in decreased Pn values.

Moreover, our study found that sunshine duration during the growth period and its variation are important factors in determining crop growth, and this is consistent with studies in North China [16]. However, the maximum values were in S2 or S3 at both sites, which was related to the metabolic activity of crops at this stage. From flowering to grain filling, crops need to accomplish strong photosynthesis to produce assimilates and metabolites to meet the demands of grain growth [23]. Furthermore, this phenomenon resulted in the maximum chlorophyll fluorescence parameters of leaves at this stage, i.e., Fv/Fm and Φ_{PSII}, whether in Baoji or Yulin. We also found that the NPQ value gradually decreased as the plant matured, especially with BJ3 and YL3 treatments. These variations indicated that a low NPQ value was conducive to reducing the dissipation of excess energy as heat and further increasing the use of excess light energy [24]. The effect of sowing dates on the chlorophyll fluorescence parameters of broomcorn millet leaves was inconsistent, as indicated by the BJ3 treatment which achieved the maximum Fv/Fm and Φ_{PSII} values in Baoji, whereas the Fv/Fm value under the YL2 treatment was higher compared to other treatments in Yulin. Additionally, the relations between meteorological factors and the chlorophyll fluorescence parameters were inconsistent in the two sites. The reason for this phenomenon might be that the higher PSII/PSI ratio caused by later sowing in Baoji or early sowing in Yulin compensated for the reduction in the amount of red light [25]. Such results may suggest that light absorption might be linked to the changes in the temperature and humidity of the leaf [26]. In conclusion, the sowing date is critical to the photosynthetic metabolism of crops, which depends on the local environment. Selecting a reasonable sowing time helps delay plant senescence.

4.2. Responses of the Grain Characteristics and Yield to Sowing Dates

Global climate change will inevitably challenge the future production and resource utilization of crops [27]. Delayed sowing can greatly reduce the growth period and regulate the ratio of reproductive growth to vegetative growth ($R_{R/V}$), which was reflected in this current study. The growth period of broomcorn millet was significantly reduced by late sowing and the effect was greater in Yulin than Baoji, as shown by the increased $R_{R/V}$ compared to BJ1 and YL1. Reduced vegetative growth days have an adverse effect on crop development, as a shortened broomcorn millet lifecycle dramatically reduced the available time for broomcorn millet to acquire radiation, CO_2 and nutrients for biomass accumulation [17]. Accordingly, this operation resulted in a decreased plant height, stem diameter and number of stem nodes. However, the influencing range varied at the two sites, which may be related to the local water and fertilizer conditions. Along with the shortened growth duration, broomcorn millet yields were reduced by up to 27.2% under BJ3 treatment in Baoji and 12.7% under YL4 treatment in Yulin, respectively. Generally, this is a typical form of crop yield loss: most climate-change-related yield loss around the world can be explained by this kind of shortened growth duration. However, it should be noticed that the decline in yield in Baoji (658.8 kg ha^{-1}) was greater than in Yulin (608.3 kg ha^{-1}) and the changes in different varieties were inconsistent for the two sites, which indicated that the varieties with different growth periods should be sown differently. Moreover, the linear fitting analysis showed that yield was strongly associated with sunshine duration, temperature and precipitation during the growth period of broomcorn millet. In fact, crop development rate would not accelerate continuously with temperature increase [15], which is especially true for broomcorn millet on the Loess Plateau of China, as the growing season temperature is close to or even exceeds the optimal development temperature during the baseline period [28]. Thus, yield loss in semi-arid regions could be largely attributed to the increased heat events and precipitation that occurred during the key broomcorn millet growth stages.

In addition to yield, grain size was affected by the sowing date, especially grain width and length/width. As illustrated in the correlation analysis results, higher average sunshine duration hours in the critical stage around flowering was associated with higher grain forming. Similar to a previous study, high relative humidity appeared to destroy the pollens and hinder pollination, thus lowering the kernel number, which was consistent with the findings from Gao et al. [29]. Additionally, inappropriate sowing dates result in insufficient temperature during the filling stage, inadequate grain filling and poor grain fullness [9]. However, the effect of the sowing date on grain size parameters was inconsistent in the two sites. In general, the grain size parameters were negatively related to meteorological factors in Baoji (except for length/width) and were not related to meteorological factors in Yulin (except for precipitation). The results showed that suitable sowing was beneficial to grain filling and increased grain volume in semi-arid areas.

4.3. Variety Adaptability and Ecological Environment

Low amounts of and high variation in annual and growing season precipitation rates are key limiting factors for agricultural production on the Loess plateau of China [30,31]. Temperature is regarded as the main factor that affects plant growth, development and productivity in sunflowers [32], and high temperature stress during the flowering and grain filling stage decreased wheat yield by 29% and 44% [33]. Moreover, selecting a suitable planting date and cultivar maturity is the most effective way to increase yield and reduce yield variability [34,35]. Several studies found that late planting would shorten the crop growth period and aggravate terminal drought [16]. Additionally, in our experiment, the results showed that the limiting factors of plant growth, yield and grain size in broomcorn millet were different for the two sites. In the semi-arid area (Yulin), the limiting factor was the precipitation, while in the semi-humid area (Baoji), the limiting factors were sunshine duration, accumulated temperature and the number of growth days.

Given the special grain production situation in China, shifting the sowing date is anticipated to help mitigate the effects of climate change on crop production [36]. However, considering the different planting systems of the two sites, in Baoji, late planting (i.e., BJ3) within the potential planting window could result in the full use of the growing season's precipitation and make the winter wheat and broomcorn millet rotation system more efficient, for instance, as shown by the higher grain size, yield components and yield of V3 and V4. In contrast, sowing early was important for high yields in Yulin. This is because precipitation, sunshine duration and accumulated temperature during the whole growth period are the limiting factors of plant growth and grain filling in Baoji and precipitation is the limiting factor in Yulin. Therefore, regarding the selection of broomcorn millet varieties, areas with a warm temperate and semi-humid climate can postpone sowing, especially for varieties which have a shorter growth period, to ensure that the land has a longer fallow period or more time for the last season's crops. Our study found good growth performance and productivity of V1 and V2, indicating that early sowing can receive more radiation and accumulated temperature for broomcorn millet growth than later sowing [37], especially in the semi-arid area. Hence, varieties with longer growth periods are not suitable for late sowing and varieties with shorter growth periods are not suitable for early sowing.

5. Conclusions

In conclusion, the varieties with a longer growth season (V1 and V2) were more suitable for early sowing, obtaining more precipitation and ultimately achieving a larger yield of broomcorn millet in Yulin. On the other hand, the variety with the shorter growth period (V3) was suitable for early sowing in Baoji, obtaining longer sunshine duration and an increased number of growth days. With the postponement of the sowing date, the days from seeding to emergency decreased by 1–2 d in Baoji (except V3) and 4–6 d in Yulin, seedling to maturity was decreased by 4–11 d in Baoji and 10–31 d in Yulin and the ratio of reproductive growth to vegetative growth increased in V2 and V4 and decreased in V1 and V3 in Baoji and increased for all varieties in Yulin. Additionally, the yield was reduced by 12.4% and 27.2% compared to BJ1 in Baoji and 15.5%, 3.6% and 12.7% compared to YL1 in Yulin. Multivariate analysis showed that the variety and sowing dates had a significant effect on the leaf net photosynthesis, chlorophyll fluorescence, plant morphological traits, yield and yield components in both sites. Additionally, correlation analysis for each site showed that leaf characters, plant morphology traits and grain size and yield with meteorological factors and the number of growth days were different for the two sites. Moreover, precipitation was positively related to yield in both sites. Additionally, accumulated temperature, sunshine duration and the number of growth days of the whole growth period were positively related to plant height and stem diameter in both sites. Linear fitting analysis showed that the sunshine duration during the reproductive growth stage, the number of growth days during the full growth period and sunshine duration during the full growth period were the top three meteorological factors that affect the yield in Baoji and it was precipitation in Yulin.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy12071727/s1, Figure S1: The annual average of meteorological factors in two sites; Figure S2: The leaf photosynthesis (Pn) of broomcorn millet under different treatment in Baoji (A, C and E) and Yulin (B, D and F); Figure S3: The overall difference in leaf fluorescence characteristics of broomcorn millet at Baoji (Fv/Fm, NPQ and Φ_{PSII}, A, B and C, respectively) and Yulin (Fv/Fm, NPQ and Φ_{PSII}, D, E and F, respectively); Figure S4: The overall difference in grain size parameters of broomcorn millet at Baoji (A and B) and Yulin (C and D); Table S1: Multivariate analysis results for different treatments of broomcorn millet in Baoji and Yulin.

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