EFFECTS OF AGROMETEOROLOGICAL FACTORS ON SORGHUM YIELD AND QUALITY AT DIFFERENT SOWING DATES IN JIANGXI PROVINCE, CHINA

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Abstract. Sorghum varieties J67 and Jiniang 2nd (JN2) were used as test materials in this experiment. Regression analysis and multivariate comparison were used to explore the relationship between sorghum yield, quality and climate factors in different sowing dates, which provided a theoretical basis for the study of sorghum adaptability in Jiangxi region, China. The results showed that the inter annual, sowing date and sorghum yield reached significant ($P < 0.05$) and extremely significant level ($P < 0.01$), respectively. The yield of J67 and JN2 was the highest on the 25th April, and 5th May, respectively, and the average yield was 34.67% and 11.85% higher than that of other sowing dates. The content of protein, fat and starch increased first and then decreased with the delay of sowing date. The relationship between effective precipitation and yield is linear function, while the relationship between effective temperature, daily average temperature, sunshine hours and yield is quadratic function. In addition, the climate factor that has the greatest impact on the quality is the daily average temperature, while the hours of sunshine have the least impact. The results showed that suitable sowing date was the key to the formation of sorghum yield and grain quality.
Keywords: *sorghum, meteorological factors, variety, adaptability*

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth largest cereal crop in the world, and it is the third-largest cereal produced in the United States after corn and wheat (Awika, 2011; Mundia et al., 2019) with strong adaptability, drought resistance, water logging resistance and salinity resistance characteristics. Sorghum is the most important food security crops in the stress-prone regions of the world (Ajeigbe et al., 2018; Salim et al., 2017). It is a pioneer crop in barren farmland. Sorghum is widely used for food, feeding, energy and brewing (Taylor, 2019). It has great development potential and industrial advantages in agricultural production. Developing sorghum planting can effectively improve the land utilization rate, promote a virtuous ecological cycle and improve the dietary structure of residents. Sorghum production is beneficial to the adjustment of agricultural industrial structure and the development of regional characteristic agriculture (Xiao et al., 2014; Li et al., 2012).

However, in recent years, with the global warming, the yield and quality of sorghum is often restricted by seasonal high temperature, drought and other climatic factors (Dube et al.; 2018; Liu et al., 2010). Therefore, it is particularly important to understand the influence of meteorological factors on the yield and quality of sorghum, and to adjust the sowing date so that meteorological factors can effectively promote the formation of sorghum yield and quality. Li et al. (2014) found the meteorological factors during crop growth are closely related to crop growth and development. The

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suitable sowing date is one of the key factors affecting the high yield of sorghum (Tovignan et al., 2016). Because sowing date can affect the climate factors such as light, temperature and water during crop growth and development, it is important to improve the environmental conditions during population growth, and the photosynthetic performance, yield and quality formation during the growth period.

Scholars in China and abroad have also widely used staged sowing to study the impact of environmental factors on crop yield and quality (Umakanth et al., 2012; Rao et al., 2013; An et al., 2018; Zhang et al., 2018). Zhao (2014) and Liu (2013) believe that different sowing dates lead to changes in precipitation, accumulated temperature and hours of sunshine during the sorghum growth period. Sowing at the right time can improve sorghum yield, and effective accumulated temperature and precipitation are positively correlated with sorghum yield. Chen et al. (2012a) showed that the effects of effective accumulated temperature, hours of sunshine and effective precipitation on sorghum yield were all at significant levels, and effective precipitation and hours of sunshine were negatively correlated with tannin content, but not with protein content. Li and others (2009) investigated that late sowing at an appropriate time can effectively increase the starch content of sorghum. They also found that the average daily temperature during the growth period has an important impact on the accumulation of starch, and different sowing dates have different effects on the content of crude protein, crude fat and tannin in sorghum (Ji et al., 2013; Chen et al., 2012b). High yield and high quality are the core of efficient sorghum production (Zhang et al., 2019). The decline of yield and quality caused by meteorological disasters can be effectively avoided by adjusting the sowing date. At present, most scholars' research on sorghum grain yield and quality focuses on the synergistic effects of single or multiple factors such as sowing date, fertilizer, and planting mode (Koláková et al., 2020; Atiqueur et al., 2022). In fact, there are few studies on the yield and quality of northern varieties under the climatic conditions of southern China. Cultivated soil in Jiangxi province is mainly red soil and dry land, which is characterized by low pH, low nutrient content, relatively rich nitrogen, and soil clay weight. It is urgent to improve the utilization rate of red soil by changing the planting mode and other means. Sorghum has the advantages of strong resistance and wide adaptability, and is one of the dominant crops for improving the red soil dry land in the south, especially the northern sorghum varieties with developed roots, drought resistance, water logging resistance and barren tolerance. However, Jiangxi Province lacks excellent sorghum germplasm resources. The introduction of northern sorghum varieties in Jiangxi Province can not only enrich the types of crop varieties, but also overcome the lack of germplasm resources.

In this study, the dwarf sorghum variety J67 and the medium-stalk variety JN2 were selected as the experimental materials, and the effects of local climatic and ecological conditions on sorghum yield and quality were explored by sowing in stages, which provided theoretical basis and technical reference for high-yield, high-quality and efficient cultivation of sorghum in Jiangxi Province of China.

Materials and methods

Study sites

The experiment was carried out in 2020 and 2021 at the teaching practice base of Yichun College (N27°77′, E114°29′), Yuanzhou District, Yichun City, Jiangxi

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Province, P. R. of China. The soil of this site is slightly acidic red loam, the soil pH of the tillage layer is 6.4, the organic matter content is 13.3 $g \cdot kg^{-1}$, the available nitrogen is 87.06 $mg \cdot kg^{-1}$, the available phosphorus is 25.04 $mg \cdot kg^{-1}$, and the available potassium is 84.71 $mg \cdot kg^{-1}$.

Plant materials

The tested cultivars were the dwarf sorghum variety J67 and the medium stalk cultivar Jiniang 2th (JN2), both of which were provided by the Institute of Crop Resources, Jilin Academy of Agricultural Sciences.

Experimental design

In the experimental set up there were 5 sowing periods, namely S1 (April 15th), S2 (April 25th), S3 (May 5th), S4 (May 15th), S5 (May 25th). A split-plot design was adopted, with the sowing period as the main plot and the variety as the subplot, repeated 3 times, with a total of 30 plots. The row length of the plot was 5 m, the row spacing was 0.5 m, the plot area is 15 m^2 (5 m×3 m), hole sowing and the planting density was 130,000 $plants \cdot ha^{-1}$. The previous stubble of the experimental site was a bean crop. The compound fertilizer (N:P:K = 12:10:15) was applied to the soil as a base fertilizer at a rate of 400 $kg \cdot ha^{-1}$, and top dressing urea at a rate of 225 $kg \cdot ha^{-1}$ during the joint stage of sorghum. After sowing, 2,4-D butyl ester and metolachlor were mixed and sprayed for closed weeding before seedling. The intertillage was conducted once at jointing stage.

According to the “Sorghum Germplasm Description Specifications and Data Standards” the seedling, flowering stage and maturity stage of different sowing stages were investigated. After the sorghum matures at different sowing dates, the plots were all harvested and the grain yield was calculated.

The starch content of sorghum grain was determined by anthrone colorimetry (Zhou et al., 2022). The protein content was determined by the Coomassie brilliant blue method (Xu et al., 2022). Fat content was determined by Soxhlet extraction (Hou et al., 2020). Tannin content was determined by potassium permanganate titration (Li et al., 2021).

Meteorological data

Meteorological data such as daily maximum temperature, daily minimum temperature, daily average temperature, effective rainfall, and hours of sunshine were obtained from the Yichun Meteorological Bureau. The effective accumulated temperature (growing-degree days, GDD) during the growth period is calculated by the following formula (*Eq. 1*) (Qu et al., 2019):

$$GDD = \sum_{t=1}^{N}[(T_{max} + T_{min})/2 - T_{base}] \quad \text{(Eq.1)}$$

In the formula: t is a certain time period in the growth period, N is the number of days from sowing to maturity. T_{max} and T_{min} are the daily maximum temperature and the daily minimum temperature on the i-th day. Physiological base temperature of sorghum T_{base} = 10℃ and physiological upper limit temperature of sorghum T_{ut} = 30℃. When $T_{min} < T_{base}$, $T_{min} = T_{base}$; when $T_{max} > T_{ut}$, $T_{max} = T_{ut}$.

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Growth period and meteorological conditions

The growth trend of two sorghum varieties at booting stage are shown in *Figure 1*. The growth duration of sorghum under different sowing dates (*Fig. 2*) and average daily temperature and daily effective precipitation during sorghum growth period (*Fig. 3*) in 2020 and 2021 were recorded.

Statistical analysis

Microsoft Excel 2010 was used to organize data, SPSS 19.0 software was used for statistical analysis, and Duncan's method was used for multiple comparisons.

Results

Variation of sorghum yield under different sowing dates

The effects of interannual and sowing periods on the grain yield of the two sorghum varieties reached significant ($P < 0.05$) and extremely significant levels ($P < 0.01$), respectively. The grain yield of the two sorghum varieties was generally higher in 2021 than in 2020 under different sowing dates. The main reason may be that the sorghum suffered from drought and less rain during the critical growth period of flowering and grain filling in 2020 (*Fig. 3*). In addition, with the delay of the sowing date, the yield of sorghum increased first and then decreased. The highest yield of JN2 appeared in the S3 stage, while the highest yield of J67 appeared in the S2 stage. The average annual grain yield of JN2 and J67 ranged from 5772.37 to 7078.52 kg hm^{-2} and 5289.18 to 6390.60 kg hm^{-2}, respectively. The grain yield of sorghum varied significantly between years. The average annual yield of JN2 in 2020 and 2021 was 6171.67 and 6538.24 kg·hm^{-2} respectively, with an average annual increase of 5.95%; while the inter-annual average yield of J67 was 5722.72 6 (2020) and 5926.53 kg·hm^{-2} (2021), with an average annual increase of 3.56%. The effect of the interaction of year and sowing date on the yield of JN2 and J67 reached extremely significant level ($P < 0.01$) and significant level ($P < 0.05$) respectively (*Table 1*).

Figure 1. *The growth trend of two sorghum varieties at booting stage*

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Figure 2. *Growth duration of sorghum under different sowing dates in 2020 and 2021*

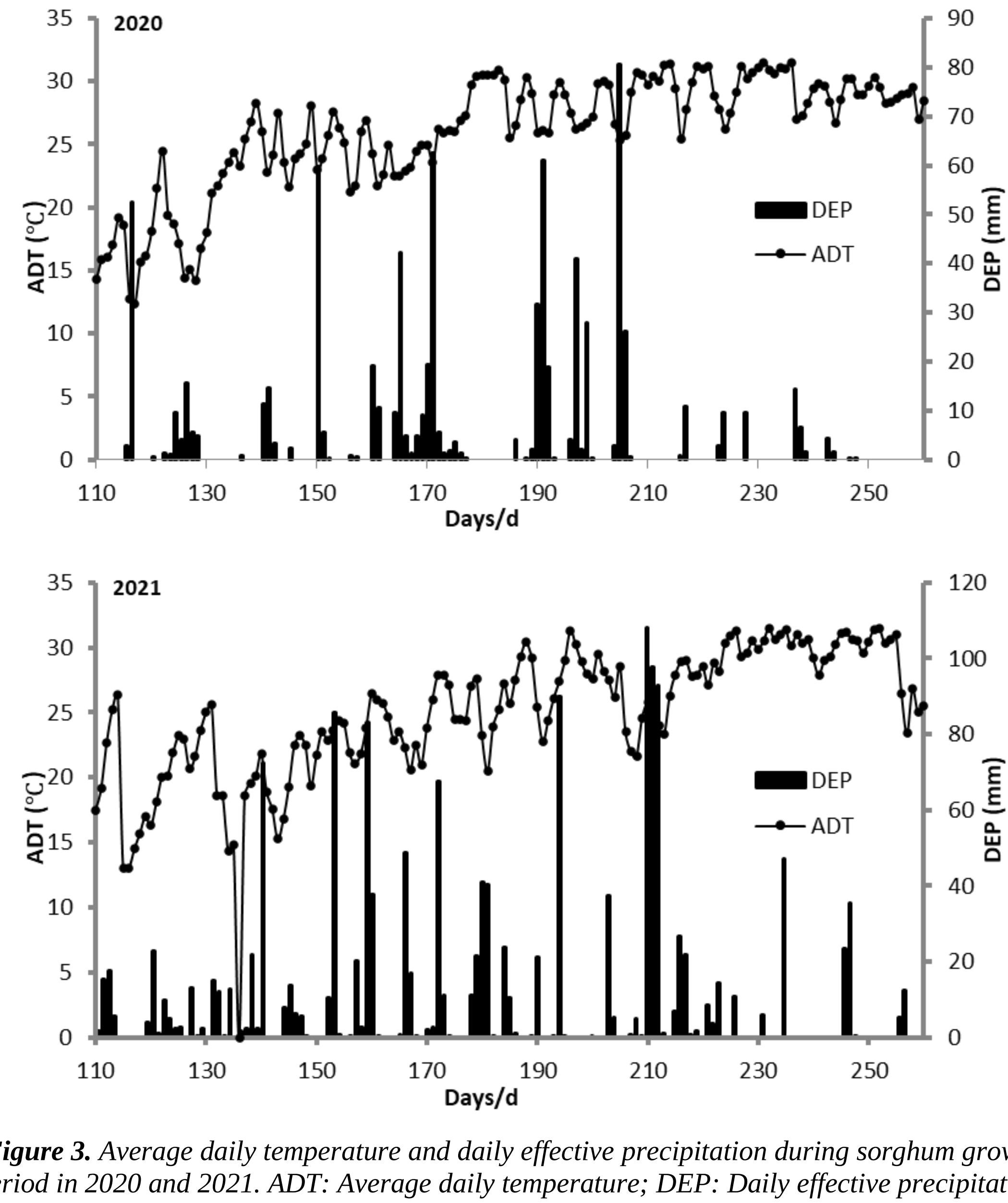

Figure 3. *Average daily temperature and daily effective precipitation during sorghum growth period in 2020 and 2021. ADT: Average daily temperature; DEP: Daily effective precipitation. The same as below*

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Table 1. *Grain yield of two sorghum varieties among different sowing dates in 2020 and 2021*

Sowing	J67(kg·hm^{-2})		JN2(kg·hm^{-2})	
	2020	2021	2020	2021
S1	5683.33C	5876.35C	5588.21E	6310.92D
S2	6243.33A	6537.86A	6258.74B	6673.83B
S3	5985.65B	6091.31B	6954.53A	7202.51A
S4	5487.65D	5762.41D	6175.15C	6547.42C
S5	5213.64E	5364.72E	5881.65D	5956.53E
Variance analysis	F-value	*P*-value	F-value	*P*-value
Year (Y)	519.46	0.0582*	423.86	0.0331*
Sowing date (S)	6.82	0.0005**	7.27	0.0003**
Y*S	3.65	0.0143*	5.23	0.0005**

Values followed by different letters are significantly different among sowing dates at the 0.05 probability level. ** means significant difference at the 0.01 probability level, and * means significant difference at the 0.05 probability level. The same as below. S1, S2, S3, S4 and S5 indicate that the sowing date is April 15th, April 25th, May 5th, May 15th and May 25th respectively

Effects of climatic factors on sorghum yield during growth period

The influence of main meteorological factors on yield during the growth period of sorghum were shown in *Figure 4*.

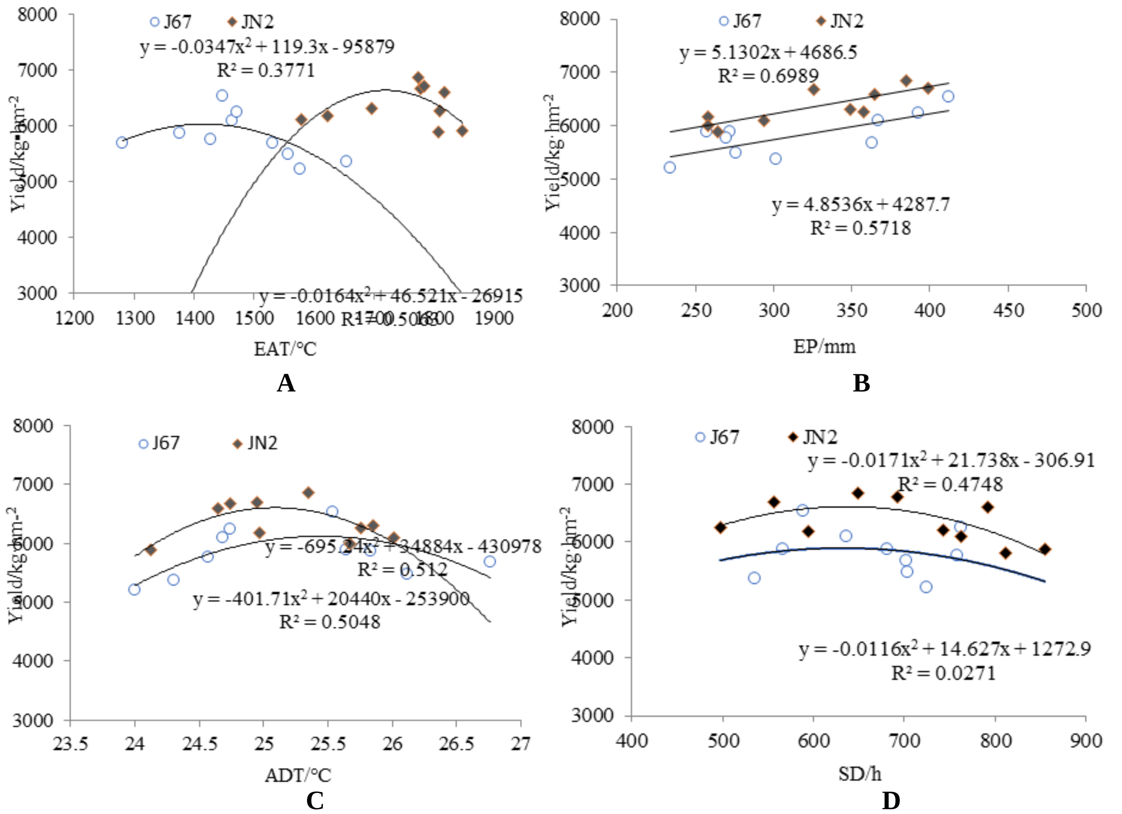

Figure 4. *Relationship between sorghum grain yield and climatic factors. A: effective accumulated temperature (EAT), B: effective precipitation (EP), C: average daily temperature (ADT) and D: sunshine duration (SD)*

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Figure 4A shows the effect of effective accumulated temperature on the yield of the two types of sorghum, both of which showed trend of increasing first and then decreasing, but J67 (1 423.6°C) was more sensitive to effective accumulated temperature than JN2 (1 712. 8°C). *Figure 4B* shows the effect of effective rainfall on grain yield of J67 and JN2 during growth period. There was a linear relationship between rainfall and grain yield, with the increase of effective rainfall, sorghum yield showed an upward trend ($P < 0.05$). The effect of daily average temperature on the yield of the two sorghum varieties showed a quadratic function relationship with the trend of increasing first and then decreasing ($P < 0.05$), but there was no significant difference in the response to daily average temperature between varieties (*Fig. 4C*). The sensitivity of the two varieties to hours of sunshine was very similar (J67: 589.95 h; JN2: 649.12 h) (*Fig. 4D*). Through statistical analysis, the regression equations of grain yield and main meteorological factors of J67 and JN2 were $Y = 12362.41 - 57.23X_1 + 16.18X_2 + 21.35X_3 + 6.35X_4$ ($R_2 = 0.89$, $F = 11.50$, $P = 0.0043$*; Where X_1 is the effective accumulated temperature, X_2 is the daily average temperature, X_3 is the effective rainfall, X_4 is the sunshine hours, the same below) and $Y = -63684.6 + 68.43X_1 + 21.07X_2 + 37.54X_3 - 2.37X_4$ ($R_2 = 0.96$, $F = 21.53$, $P = 0.0005$**) ($P < 0.01$). Comprehensive analysis shows that sorghum yield is mostly affected by effective accumulated temperature, followed by rainfall and average daily temperature, and is least affected by sunshine hours in Jiangxi province.

Effects of sowing date and meteorological factors on sorghum quality

Quality changes of sorghum under different sowing dates

The content of starch, protein, fat and tannin in sorghum grains is the main physiological indicator of sorghum quality, which directly affects the quality of winemaking and the level of wine yield.

Table 2. *Quality of two sorghum varieties among different sowing dates in 2020 and 2021*

Varieties	Sowing date	Protein		Starch		Fat		Tannin	
		2020	2021	2020	2021	2020	2021	2020	2021
J67	S1	8.91cd	9.65cd	71.02c	72.14c	3.22b	3.37b	1.23c	1.16c
	S2	10.37a	10.51a	73.16a	73.91a	3.57a	3.53a	1.31ab	1.25b
	S3	9.23b	9.83b	71.98b	72.65bc	3.19b	3.12c	1.35a	1.28ab
	S4	9.01c	9.71c	71.01c	72.94b	2.85c	3.01d	1.22c	1.31a
	S5	8.76d	9.52d	69.88d	71.64d	2.51d	2.96d	1.28b	1.17c
	Variance	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
	Y×S	2.73	0.0031*	2.81	0.0036*	0.68	0.0421*	1.32	0.0003**
JN2	S1	9.89c	10.03c	71.92b	72.75c	3.17cd	3.75b	1.22c	1.28b
	S2	10.01ab	10.08bc	72.17b	73.53b	3.54b	3.81b	1.31ab	1.30ab
	S3	10.06a	10.25a	73.29a	73.98a	3.89a	3.93a	1.37a	1.33a
	S4	9.98b	10.14b	70.02c	72.86c	3.26c	3.85ab	1.17c	1.30ab
	S5	9.82d	10.05c	69.29c	72.15d	3.01d	3.72b	1.25b	1.24b
	Variance	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
	Y×S	2,81	0.0422*	0.96	0.0362*	1.21	0.0385*	0.83	0.0015**

Table 2 shows the grain quality of different varieties of sorghum at different sowing dates from 2020 to 2021. It can be seen from *Table 2* that the differences in protein, starch, fat and tannin content between J67 and JN2 reached significant levels ($P < 0.05$) under the conditions of different sowing dates. In addition to tannin, other measurement indicators increased first

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and then decreased with the delay of sowing date, which was consistent with the change trend of grain yield. The highest contents of indexes of J67 and JN2 were at S2 and S3 stages, respectively. Sowing date has little effect on the change of tannin content. The content of physiological indices of the two varieties was significantly different between years. In 2021, the average protein content of J67 and JN2 at different sowing dates was 9.84% and 9.97%; the average starch content was 72.66% and 73.05%; the average fat content was 3.16% and 3.81%, respectively; Compared with 2020, the average protein content of grains increased by 5.90% and 1.56%, the average starch content increased by 1.71% and 2.35%, and the average fat content increased by 2.85% and 1.15%, respectively. The average tannin content of J67 decreased by 3.42% while JN2 increased by 2.31% compared with the previous year, respectively. At the interaction level of the year × sowing date, the measurement physiological indicators of J67 and JN2 were at significant level ($P < 0.05$), among which the tannin content of JN2 was extremely significantly different at the interaction level ($P < 0.01$).

The relationship between meteorological factors and sorghum quality under different sowing dates

The main nutritional quality of sorghum was affected differently by the climatic conditions during different sowing dates. Regression analysis was performed on the quality content of each variety and meteorological factors, namely hours of sunshine (X_1), effective accumulated temperature (X_2), daily average temperature (X_3) and rainfall (X_4), and the linear regression equation obtained are presented in *Table 3*. It can be seen from the table that the average daily temperature has the most significant effect on sorghum grain quality content than other meteorological factors, and the effect on starch content is higher than that of protein, fat and tannin. Precipitation has a greater effect on protein and starch content than effective accumulation and hours of sunshine. The effect of effective accumulated temperature on fat content was stronger than that of rainfall and hours of sunshine. The influence of various meteorological factors on tannin content varied with different varieties, the effective accumulated temperature has the greatest influence on the tannin content of J67, while the rainfall has the greatest influence on the tannin content of JN2.

Table 3. *Relationship between main nutritional quality of sorghum and meteorological factors*

Varieties	Nutritional quality	Regression equation	F	R^2
J67	Protein	$Y = -10.57 + 0.028X_1 - 0.0029X_2 + 0.57X_3 + 0.03X_4$	8.77^{*}	0.8543
	Fat	$Y = -5.38 + 0.002X_1 - 0.0071X_2 + 0.641X_3 + 0.0061X_4$	14.95	0.9045
	Starch	$Y = 23.52 + 0.0151X_1 - 0.052X_2 + 3.35X_3 + 0.1127X_4$	4.42^{**}	0.6643
	Tannin	$Y = 0.1975 - 0.0003X_1 - 0.0007X_2 + 0.0716X_3 - 0.0002X_4$	10.61^{*}	0.8765
JN2	Protein	$Y = -65.81 - 0.0022X_1 + 0.0052X_2 + 3.5361X_3 + 0.0061X_4$	13.25^{**}	0.9245
	Fat	$Y = -38.46 - 0.0005X_1 + 0.0031X_2 + 1.3826X_3 + 0.0029X_4$	25.43^{**}	0.9865
	Starch	$Y = -10.04 - 0.0042X_1 - 0.0051X_2 + 3.6328X_3 + 0.0536X_4$	4.87	0.7754
	Tannin	$Y = -1.8538 - 0.0004X_1 - 0.0007X_2 + 0.468X_3 - 0.0008X_4$	7.81	0.8564

Discussion

Effects of sowing date on growth period, yield and quality of sorghum

The suitable sowing date is the basis of high yield and efficient cultivation of crops. The sowing date can regulate the temperature, light, moisture and other meteorological

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factors during the growing period of crops, thus affecting the growth process of crops (Tovignan et al., 2016; Saimahe et al., 2020). In this study, the two sorghum varieties from S1 to S5 were able to mature normally and obtain good yield, indicating that these two varieties are suitable for the climatic conditions of Jiangxi Province. The results of the two-year experiments showed that with the delay of the sowing date, the growth period of sorghum gradually shortened, and the yield increased first and then decreased, which was consistent with the research results of Yin (2022) and Zhou (2019). Previous research results have shown that the sowing date will directly affect the changes of protein, fat and starch content in crop grains (Pan et al., 2018; Guo et al., 2007). In this study, the effects of different sowing dates on the content of protein, fat and tannin in sorghum grains were similar to the results of Zhang (2020), while the changes in starch content were different from their results. It shows that the effects of light and heat resources on crop quality and content is different in different growth periods. Its mechanism remains to be further studied.

Response of climatic factors to sorghum yield

When crop varieties, cultivation measures and management levels are determined, meteorological conditions are the main factors affecting crop yield. Previous studies have shown that the effective accumulated temperature (Cao et al., 2013), daily average temperature (Li et al., 2005; Hou et al., 2010), effective precipitation (Orefi, 2015; Hadebe et al., 2017) and sunshine hours (Jia et al., 2011) during the growth period can directly or indirectly affect the formation of crop yield. Zheng et al. (2018) showed that under suitable sowing date conditions, climatic conditions such as light, temperature, and water are beneficial to increase productive tiller percentage, promote individual development and increase yield. According to the analysis of the relationship between the main climatic factors and the yield in this study, the effective rainfall, daily average temperature, effective accumulated temperature and hours of sunshine during the growth period has different effects on the yield formation of sorghum. The effects of effective accumulated temperature, effective rainfall and hours of sunshine on the yield of the two sorghum varieties are similar, while the influence of daily average temperature on the yield of different sorghum varieties is obviously different. The results showed a little difference from previous studies (Qu et al., 2019). The possible reasons are mainly in two aspects: first, different types of varieties in the experiment have different genetic bases and different response modes to meteorological factors; Secondly, different crop growth regions lead to large differences in the climate environment, so the test results are not completely consistent.

Response of sorghum quality to climatic factors

Sorghum grain quality mainly contains starch, fat, protein and tannin, which plays an important role in food, feed and brewing (Kou et al., 2015). However, climatic conditions have a certain impact on the formation of sorghum quality (Luo et al., 2011), and sorghum quality will show certain differences under different climatic conditions. This study shows that different meteorological factors have different effects on sorghum quality. The average daily temperature has a higher impact on sorghum grain quality than other meteorological factors. Effective rainfall has the greatest impact on protein and starch content. Effective accumulated temperature has great influence on fat content. The influence of climate factors on tannin varies with varieties. It shows that

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the formation of sorghum quality is the result of the interaction between environmental factors and variety characteristics. The annual variation of sorghum quality is significant, indicating that the influence of environmental factors on sorghum quality may be greater than that of varieties themselves.

Conclusion

Sowing date is an important factor affecting sorghum plant characters and yield formation, which has great influence on seedling emergence, organ formation and yield. In this study, it was found that it was easier to get high yield by sowing the sorghum varieties J67 and JN2 on 25th April and 5th May, respectively. In two years, the average yield per hectare of the plot reached 6390.60 $kg \cdot ha^{-1}$ and 7098.52$kg \cdot ha^{-1}$ respectively. Through the correlation analysis between climatic conditions and sorghum yield and quality, it is known that effective accumulated temperature is the key factor affecting sorghum yield, and the daily average temperature has the greatest influence on sorghum quality. JN2 with longer growth period is more suitable for planting and production in Jiangxi, and the suitable sowing date is about 5th May. However, the test results are only the test data for two consecutive years, and the popularization and application of varieties need to be verified by multi-point tests for many years. This conclusion only provides technical reference for local sorghum introduction and production research.

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