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Effects of Sowing Date, Sowing Method and Coating Condition on Photosynthesis and Yield of Soybean (*Glycine max* L.)

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ABSTRACT

Background: Soybean is in great demand and contains a variety of nutrients. Higher yield and stable production is extremely important to soybean farming. Sowing dates, sowing methods and seed coating are factors affecting soybean cultivation.

Methods: This study used Kenfeng 16, a soybean variety widely cultivated in Heilongjiang province of China. Five sowing dates, two sowing methods (equidistant sowing and random sowing) and seed coating (coated and non-coated) were set as factors to determine the effects on flowering biomass, photosynthetic parameters and seed yield.

Result: The results of the study indicated that selecting a suitable sowing date (May 7th), equidistant sowing method and seed coating resulted to more stable high yields. Compared with other sowing dates, random sowing and non-coated seeds, the yields increased by an average of 33.66%, 12.74% and 16.24%, respectively. This research elaborated the dynamic changes of important indicators of soybean under different sowing dates, sowing methods and seed coating, which holds significant guiding value for choosing appropriate cultivation measures for inmproved seed yield in the field.

Key words: Seed coating, Sowing date, Sowing method, Soybean.

INTRODUCTION

The soybean is a yearly herbaceous plant, a significant legume for both grain and oil production. Soybean is a typical short-day thermophilic crop. Different sowing dates lead to changes in the agronomic traits, yield and quality of soybean (Serafin-Andrzejewska *et al.,* 2021). Timely sowing can better combine the growth stage of soybean with favorable seasonal conditions and give full play to the yield potential of high-quality varieties, which is the key technology of planting and management (Fischer *et al.,* 2019). Equidistant sowing and random sowing are indeed two commonly used planting methods. Equidistant sowing helps plants receive similar amounts of light, nutrients and water during growth (Lu *et al.,* 2017), but diseases and pests may spread more quickly among evenly spaced plants. Random sowing can better adapt to soil changes and changing natural conditions and reduce competition among plants. However, it also causes uneven distribution of yield in the whole field, thus affecting the overall productivity. The application of seed coating technology can accurately control pests and diseases in the crop seedling stage, reduce pesticide application and enhance the quality of agricultural products and agricultural sustainable developmen. Maishuping (22.1% thiamethoxam, 1.7% metalaxyl-M and 1.1% fludioxonil) were compound seed coating agent produced by Syngenta Group. They can effectively improve the insect resistance of crops, reduce the occurrence of pests and diseases and make soybean seeds and seedlings in a healthier environment, thus promoting early growth and development.

In this study, the local (Heilongjiang province, China) main cultivar Kenfeng 16 was used as the experimental variety and the ramifications of sowing dates, sowing methods and coating on flowering biomass, photosynthetic related indexes and yield were discussed. To determine the appropriate sowing date, sowing method and seed coating, is of great significance to the actual production of the field and the high and stable yield of crops.

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MATERIALS AND METHODS

Experimental design

The experiment was carried out at the Xiangyang Experimental base of Northeast Agricultural University (126.9°N, 45.8°E, altitude 150 m) from April 2021 to April 2022. The terrain is flat and belongs to the first accumulated temperature zone. The annual precipitation in the experimental area is 400~600 mm, the average temperature is 3.5~4.5°C and the accumulated temperature is between 2600~270°C. The basic conditions of temperature and precipitation from March to October 2021 are shown in Fig 1 (Data from the meteorological station of Northeast Agricultural University).

The local main soybean variety Kenfeng 16 was selected as the research material and carried out in the experimental field of Xiangyang base. Plant 30 plants per square meter, each plot 30 m^2 (10 m × 3 m), a total of 60 plots. Sowing was carried out on five sowing dates (from April 30, 2021, sown every 7 days until the end of May 28, S1-S5) and 12 plots were planted on each sowing date, which were equidistant sowing of coated seeds (Maishuping), random sowing of coated neutrons, equidistant sowing of uncoated seeds and random sowing of uncoated seeds. Each treatment was repeated three times. The biomass, photosynthetic parameters and yield of soybean at flowering stage were measured under the condition of consistent growth of soybean at different sowing dates.

Assay method

Biomass

3 strains were randomly selected from each plots. After sampling, the plants were divided into aboveground and underground parts. These samples were killed at 105°C for 30 min, then dried at 80°C constant weight and finally weighed with a balance. Each treatment was repeated three times.

Photosynthetic indexes

The photosynthetic indexes of soybean leaves were measured by multifunctional plant measuring instrument (Beijing Huinuoruide Technology Co., Ltd., Model: Multispe QV2.0), repeat 3 times for each plots. The specific indicators and their meanings are shown in Table 1.

Soybean yield

Each treatment was randomly selected 2 m^2 for yield measurement and each plots was repeated three times.

Statistical analysis

All data were analyzed for correlations and using IBM SPSS (Version 21.0; IBM Corporation, Armonk, NY, USA). Use Microsoft Office Excel 2021 for graphical analysis and Microsoft Office Word 2021 for analysis tables.

RESULTS AND DISCUSSION

Effects of sowing method, coating condition and sowing date on biomass at flowering stag

Under the same sowing method, there were differences in flowering biomass at different sowing dates (Table 2). Under the condition of equidistant sowing, the biomass of S2 was the highest and the aboveground biomass was 22.58% and 67.15% higher than that of S4 and S5, respectively. The underground biomass was significantly higher than that of S3, S4 and S5, which was 68.38% higher than that of S5. At random sowing, the aboveground biomass of S1 and S2 was significantly higher than that of S3, S4 and S5. Among them, S1 and S2 were 54.57% and 68.84% higher than S5, respectively. The underground biomass S1 was significantly higher than that of the other four sowing dates, which was 105.17%, 481.00%, 453.45% and 705.02% higher than that of the other four sowing dates, respectively. In general, the biomass of single seedling was the highest and the growth rate was the best at S2.Under the same seed coating conditions, there were significant differences in flowering biomass at different sowing dates. When the seeds were coated, the biomass was the highest at S1 and the aboveground biomass was 34.46%, 68.19%, 104.81% and 161.61% higher than other sowing dates, respectively. The underground biomass was 110.51%, 107.50%, 139.09% and 226.40% higher than other sowing dates, respectively. When the seeds were not coated, the biomass was still the highest when S1 was still the highest. The above-ground biomass was 82.64%, 93.52%, 78.75% and 182.94 higher than other sowing dates and the underground biomass was 108.80%, 149.76%, 129.96% and 238.96% higher than other sowing dates, respectively. On the whole, the biomass of single seedling was the highest and the growth was the best at S1.

At the same sowing date, there were some differences in aboveground and underground biomass between soybean equidistant sowing and random sowing (Table 2). The aboveground biomass of soybean under equidistant

Table 1: Detailed indicators of Chlorophyll fluorescence parameters.

Abbreviation	Parameter name	Significance
SPAD	Soil and Plant Analyzer Development)	SPAD value is closely related to photosynthetic efficiency.
F0	Fluorescence origin	The initial fluorescence intensity of the fluorescence spectrum after the plant leaves are exposed to light.
Fs	Steady-state fluorescence	The fluorescence signal emitted by plant leaves under continuous light conditions.
Fm	Fluorescence maximum	The maximum fluorescence intensity of plant leaves under light irradiation.
Fv/Fm	Maximal quantum yield of PSa!	Light energy conversion efficiency of photosynthetic system II.
NPQ	Non-photochemical quenching	Reflects the heat dissipation capacity of plants.
Phi2	The effective quantum yield of Photosystem II	Photosynthetic system II intercepts the part of light energy and finally synthesize sugar.
phiNO	phi non-photochemical energy quenching	It is an important index of light damage.
phiNPQ	phi non-photochemical quenching	Like NPQ, is an important index of optical protection.

sowing was higher than that under random sowing. The increase of aboveground biomass S3 and S5 was the most obvious, which was 10.58% and 4.34%, respectively and the average increase of the five sowing dates was 4.49%.

For underground biomass, the biomass of S1-S5 increased by 5.64% on average. Equidistant sowing could obtain higher and more stable biomass than random sowing and the aboveground and underground biomass of S1-S5 increased by 5.07% on average. At the same sowing date, the biomass of coated soybean seeds was generally higher than that of uncoated soybean seeds.

Under the five sowing dates, the average above-ground biomass of coated seeds was 15.23% higher than that of uncoated seeds. The underground biomass of coated seeds was 15.64% higher than that of uncoated seeds.

Effects of sowing date on photosynthetic characteristics of leaves

As shown in Table 3, there were differences in chlorophyll content and photosynthetic characteristics of leaves during different sowing periods. The relative chlorophyll content of SPAD was affected by sowing date. The relative content of S2 was the highest, 17.82% higher than that of the lowest S5. The actual photosynthetic efficiency Phi2 of photosystem II also performed best under s2 condition, which was significantly higher than the observed values of other sowing dates. The initial fluorescence yield F0, the maximum fluorescence yield Fm and the steady-state fluorescence yield Fs fluctuated with the delay of the sowing date and the values were higher at the later sowing date. Fv / Fm, NPQ, phiNO and phiNPQ did not change significantly with sowing date.

Effect of sowing date on yield

As shown in Table 4, the yield of S2 sowing date (5.7) was significantly higher than that of other sowing dates under equidistant sowing and coated seeds, equidistant sowing and uncoated seeds, random sowing and coated seeds. For equidistant planting and coated seeds, the yield of S2 was 9.73%, 10.82%, 17.04% and 41.03% higher than that of S1, S3, S4 and S5, respectively, with an average increase of 19.66%. The yield of equidistant sowing and uncoated

Table 2: Aboveground and underground biomass of equidistant sowing and random sowing under different sowing dates.

Processing mode	Sowing date	Aboveground biomass ($g \cdot plant^{-1}$)	Belowground biomass ($g \cdot plant^{-1}$)
Equidistant sowing	S1	23.79±0.51ab	24.15±0.48ab
	S2	26.71±0.46a	26.57±0.38a
	S3	23.66±0.12ab	23.19±0.48b
	S4	21.79±0.12b	22.43±0.47b
Random sowing	S5	15.98±0.05c	15.78±0.30c
	S1	23.00±0.27a	23.54±0.41a
	S2	26.00±0.29a	25.80±0.55b
	S3	21.37±0.27b	20.81±0.06b
	S4	21.88±0.14b	21.71±0.36b
	S5	15.26±0.32b	15.50±0.45c
Coated seeds	S1	42.73±0.65a	5.81±0.22a
	S2	31.78±0.55b	2.76±0.23b
	S3	26.00±0.50c	2.80±0.53b
	S4	21.84±0.11d	2.43±0.35b
	S5	17.48±0.58d	1.78±0.26c
Uncoated seeds	S1	40.29±0.53a	5.22±0.42a
	S2	22.06±0.47b	2.50±0.60b
	S3	20.82±0.10c	2.09±0.48bc
	S4	22.54±0.23b	2.27±0.49bc
	S5	14.24±0.33d	1.54±0.41c
Sowing date		***	***
Sowing method			*
Sowing method and sowing date			
Coating condition		**	**
Sowing date		**	*
Coating condition and sowing date		**	

The different letters in the table indicate that the biomass of different sowing dates under the same treatment is significantly different at the $p<0.05$ level and the same letter indicates that the difference is not significant. * represents the effect of different factors on biomass and the significance level is $p<0.05$, * ($p<0.05$), ** ($p<0.01$). S1-S5 represent different sowing dates. The value is the mean ±standard deviation of the experiment.

Table 3: Differences in relative Chlorophyll content and fluorescence parameters at the flowering period of soybean under different sowing periods.

Sowing time	SPAD	F0	Fs	Fm	Fv/Fm	NPQ	Phi2	phiNO	phiNPQ
S1	47.97±8.47^{a}	269.00±17.13^{b}	453.66±66.13^{b}	796.10±127.75^{bc}	0.65±0.04^{b}	1.58±0.54^{a}	0.42±0.0^{ab}	0.22±0.03^{b}	0.34±0.05^{a}
S2	50.65±2.83^{a}	267.80±19.47^{b}	463.26±52.44^{b}	836.22±103.77^{ab}	0.67±0.01^{ab}	1.31±0.18^{ab}	0.45±0.07^{a}	0.24±0.16^{ab}	0.31±0.02^{a}
S3	49.37±8.33^{a}	287.6±12.07^{b}	534.13±81.34^{ab}	811.81±179.28^{bc}	0.68±0.02^{ab}	1.22±0.31^{ab}	0.42±0.02^{ab}	0.26±0.04^{ab}	0.31±0.03^{a}
S4	49.53±6.44^{a}	283.60±17.60^{b}	572.07±105.01^{a}	579.76±265.01^{c}	0.70±0.03^{a}	1.06±0.30^{b}	0.41±0.01^{b}	0.29±0.04^{a}	0.29±0.03^{a}
S5	42.99±8.65^{a}	321.80±17.52^{a}	598.20±74.78^{a}	1049.47±122.89^{a}	0.69±0.02^{ab}	1.19±0.27^{ab}	0.43±0.02^{ab}	0.26±0.03^{ab}	0.31±0.04^{a}

In the comparison of different sowing dates within the same index, different letters indicated significant differences (p<0.05). S1-S5 indicates different sowing dates. The value is the mean±standard deviation of experiments.

seeds S2 was 14.59%, 47.8%, 30.2% and 66.73% higher than that of other sowing dates, respectively, with an average of 39.83% higher than that of other sowing dates. The yield of random planting and coated seeds S2 was 8.49%, 32.32%, 73.43% and 51.69% higher than that of other sowing dates, respectively, with an average increase of 41.48%. Regardless of whether the sowing time, sowing method and seed coating are considered individually, or in combinations of two, there are significant differences in soybean yield when all three factors are considered together.

Effect of coating on yield

As shown in Fig 2, coated seeds can obtain more stable and higher yield than uncoated seeds under random sowing conditions. Under the condition of random sowing, the yield of coated seeds was higher than that of uncoated seeds in five sowing periods. The yield of S1-S5 increased by 7.76%, 3.19%, 37.63%, 14.8% and 22%, respectively, with an average increase of 17.08%. Under the condition of random sowing, the yield of coated sowing was not always higher than that of uncoated sowing. The yield of coated sowing under S1, S2 and S4 was 39.7%, 43.85% and 17.31% higher than that of uncoated sowing, respectively. The yield of uncoated sowing under S3 and S5 was 10.16% and 13.66% higher than that of coated sowing, respectively. The yield of coated sowing under S1-S5 was 15.4% higher than that of uncoated sowing. In general, under random sowing conditions, the number of uncontrollable factors increases, making the yield unstable. Coated sowing can obtain higher and more stable yield.

Effect of the sowing method on yield

Under the condition of seed coating, the yield of different sowing dates was different (Fig 2). The random sowing yield of S1 and S2 was 1.86% and 0.8% higher than that of equidistant sowing, respectively. The yield of S3-S5 was 18.46%, 47% and 6.7% higher than that of random sowing. The average yield of equidistant sowing was higher than that of random sowing, which increased by 13.9%. This shows that under the condition of seed wrapping, the difference between equidistant sowing and random sowing in early sowing date is not significant, but due to the delay of sowing date, equidistant sowing can obtain higher and more stable yield. Under the condition that all seeds are not coated, the yield of different sowing methods will also be different. The yield of equidistant sowing of S1, S2 and S4 was higher than that of random sowing, which increased by 27.28%, 38.29% and 50.22% respectively. The yield of random sowing of S3 and S5 was higher than that of equidistant sowing, which increased by 28% and 29.95%, respectively. On average, the yield of equidistant sowing was higher than that of random sowing.

Previous studies have shown that even when the same variety is planted in the same location, differences in sowing periods can lead to changes in growth stages and biomass (ZHOU Enqiang 2023). This is because changes in sowing period alter the length and intensity of light, accumulated

temperature and radiation during various developmental stages of crops (Allen *et al.,* 2018), affecting the process by which plants transition from vegetative to reproductive growth. It consistent with our experimental results, which found differences in biomass for different sowing periods after measuring aboveground and belowground biomass. The delay of sowing date shortened the growth period of soybean and the effective accumulated temperature may be insufficient, which leads to the low dry matter accumulation rate of grain and then leads to the sharp reduction of grain weight and yield (Qinghua *et al.,* 2021). In early spring, the temperature is low and the rainfall is abundant, which is easy to make the plants affected by low temperature or frost (Gupta *et al.,* 2019). At the same time, early sowing will slow down the growth of seedlings and reduce their resistance, making them vulnerable to damage (Ravensbergen *et al.,* 2024). The SPAD value directly reflects the concentration of chlorophyll in leaves (Janila *et al.,* 2015) the Phi2 value reflects the effectiveness of photosystem II (Slattery *et al.,* 2017). In this experiment, the maximum SPAD value and Phi2 value were observed at the optimal sowing period S2, indicating the strongest photosynthetic capacity at this time. The corresponding yield at S2 is also the highest.

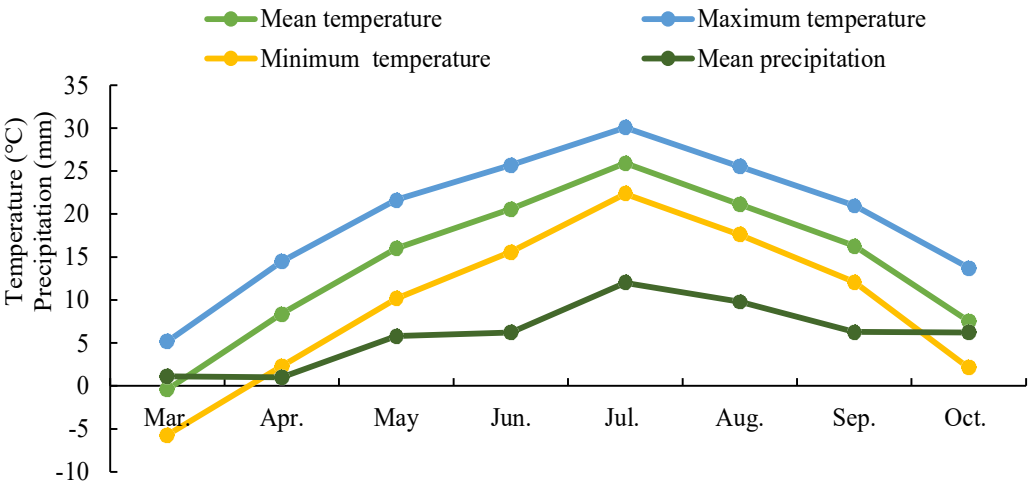
Many scholars have proven through practical research that the biomass and yield of crops sown in a grid pattern are higher than those sown randomly for example wheat, corn and rice (Olsen *et al*., 2005; Ying *et al.,* 2023; Lu *et al*., 2020). The sowing method regulates the absorption and utilization of nutrients by affecting the growth morphology of plants (Mabudi *et al.,* 2016). In this experiment, the advantage of equidistant sowing was not obvious when the seeds were coated and sown earlier. This may be because the appropriate choice of seed coating and sowing date has better protection for plant growth and the sowing method has little effect on yield. However, in the case of uncoated and coated late sowing, the yield of equidistant sowing was higher than that of random sowing. On the whole, equidistant sowing can obtain a higher and more stable yield than random sowing.

Coating agents are used for the coating of seeds or seedlings of crops or other plants. The application of seed coating technology can accurately prevent and control diseases and pests in the early stage of crop growth,

Table 4: Yield of soybean under different sowing periods, planting methods and coating conditions.

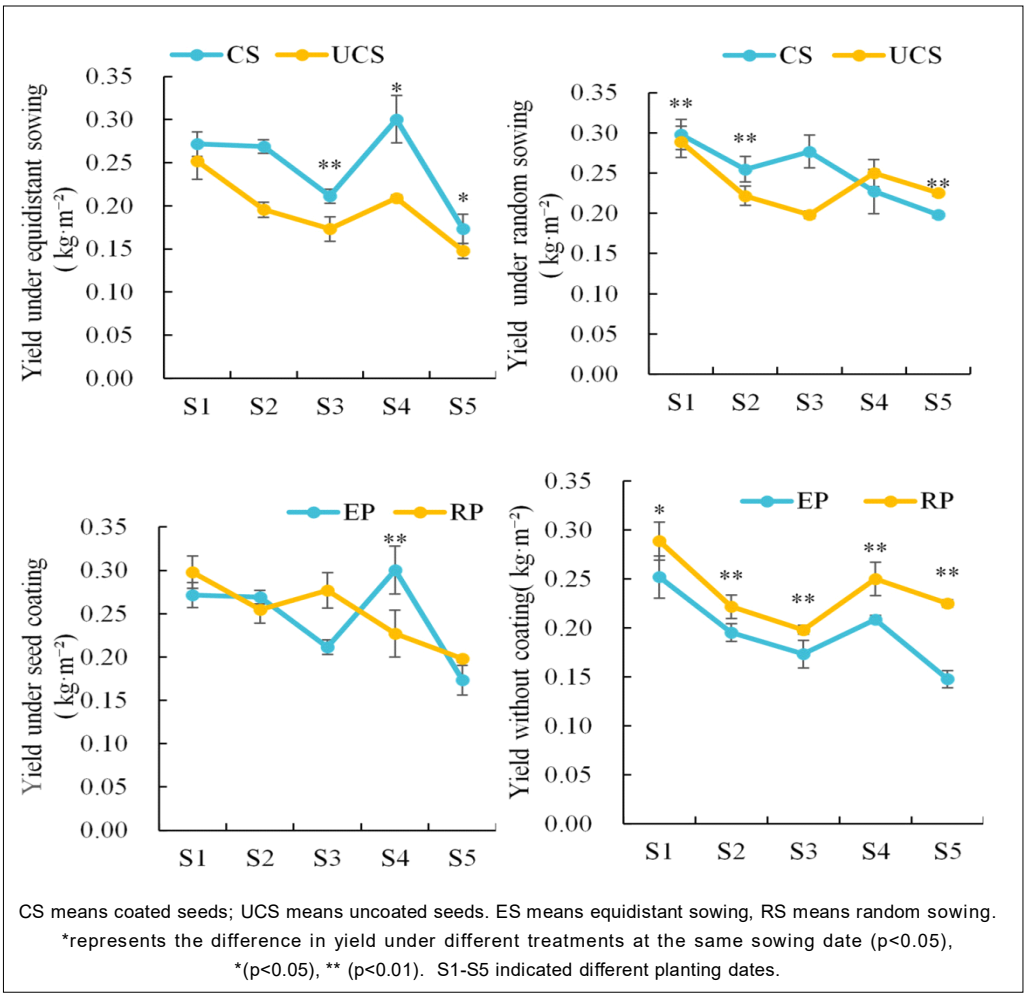
Sowing date	Sowing method	Coating condition	Yield ($kg \cdot m^{-2}$)
S1	Equidistant sowing	Coated seeds	0.272±0.014b
		Uncoated seeds	0.252±0.022b
	Random sowing	Coated seeds	0.298±0.019a
		Uncoated seeds	0.289±0.020c
S2	Equidistant sowing	Coated seeds	0.269±0.008a
		Uncoated seeds	0.195±0.009a
	Random sowing	Coated seeds	0.255±0.016a
		Uncoated seeds	0.222±0.012bc
S3	Equidistant sowing	Coated seeds	0.211±0.008b
		Uncoated seeds	0.173±0.014cd
	Random sowing	Coated seeds	0.277±0.020b
		Uncoated seeds	0.198±0.004a
S4	Equidistant sowing	Coated seeds	0.300±0.028b
		Uncoated seeds	0.209±0.004c
	Random sowing	Coated seeds	0.227±0.027c
		Uncoated seeds	0.250±0.017d
S5	Equidistant sowing	Coated seeds	0.173±0.017c
		Uncoated seeds	0.148±0.009d
	Random sowing	Coated seeds	0.198±0.004bc
		Uncoated seeds	0.225±0.004c
Sowing date			**
Sowing method			**
Coating condition			**
Sowing date and sowing method			**
Sowing date and coating condition			
Sowing method and coating condition			**
Sowing date and sowing method and coating condition			**

In the comparison of different sowing dates under the same conditions, different letters showed significant differences ($p<0.05$). The significance level was set to $p<0.05$, * ($p<0.05$), ** ($p<0.01$). S1-S5 represent different sowing dates. The value is the mean± standard de*via*tion of the experiment.



The horizontal coordinate corresponds to the month and the vertical coordinate corresponds to the temperature (degrees celsius) and precipitation (millimeters). (Data source: Meteorological Observation Station of Northeast Agricultural University).

Fig 1: Average monthly temperature and precipitation in Harbin City.



CS means coated seeds; UCS means uncoated seeds. ES means equidistant sowing, RS means random sowing. *represents the difference in yield under different treatments at the same sowing date ($p<0.05$), *($p<0.05$), ** ($p<0.01$). S1-S5 indicated different planting dates.

Fig 2: Yield under different treatments.

regulate seed germination and seedling growth, reduce the use of pesticides (Kumar *et al.,* 2021) and is conducive to ensure the quality of agricultural products and promote the development of green agriculture (Halmer, 2008).

Numerous studieshave pointed out that the improvement of biomass and yield by seed coating agents is that seed coating can promote the active defense response of plants while protecting crops from seeds and soil-borne pathogens (Mnasri *et al.,* 2017) and at the same time, it can make seeds germinate early, improve seedling robustness, enhance photosynthesis at seedling stage, promote the formation and accumulation of substances and enhance the activity of some enzymes in the body (Tian *et al.,* 2024). As a compound seed coating agent, Maishuping has dual control effects, which can prevention and control of plant diseases and insect pests and increase yield and drought tolerance. It has been widely used in rape and cotton and soybean (Zhang *et al.* 2024; Jacob *et al.,* 2023). In this study, the comparison of coated and uncoated was consistent with the previous research conclusions, showing obvious yield advantages. The biomass at the flowering stage increased by 15.64% on average, the yield increased by 17.08% on average when sowing equidistantly and the yield increased by 15.4% on average when sowing randomly.

CONCLUSION

Sowing date, sowing method and coating condition have effects on crop growth and development. With the change of sowing date, the biomass at the flowering stage, most of the light and indexes and yield fluctuated and the comprehensive performance was the best at the suitable sowing date (S2). The yield at S2 was higher than other sowing dates (33.66% higher on average). Compared with random sowing, equidistant sowing was more suitable for field cultivation. The biomass and yield of the flowering period were higher than those of random sowing, which increased by 5.07%, 4.05% and 12.74% respectively. Compared with no coating, the coating could obtain better yield benefits and the biomass and yield of the flowering period increased by 15.44% and 16.24%, respectively.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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