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Evaluation of Lodging Resistance and Yield of Maize Varieties in Response to Two Ethephon Compound Agents

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Abstract Using maize varieties including Zhengdan 958, Xianyu 335, Yudan 132, Xundan 20, Lianchuang 808, and Dingyou 163 as experimental materials, this study investigated the effects of two ethephon compound agents on the lodging resistance and yield of different maize varieties across various ecological regions. The results demonstrated that the lodging resistance of maize was significantly enhanced after the application of the two chemical control agents. Specifically, the lodging rate of Xundan 20 was reduced by 6.1 percentage points following treatment with benzylaminopurine (6-BA) · ethephon (ETH), while the lodging rate of Zhengdan 958 was decreased by 6.2 percentage points after treatment with diethyl aminoethyl hexanoate (DTA-6) · ETH. In the Shangqiu area, treatment of Lianchuang 808 with DTA-6 · ETH reduced its ear height coefficient by 9.8 percentage points, whereas in the Zhumadian area, treatment of Dingyou 163 with 6-BA · ETH lowered its ear height coefficient by 11.3 percentage points. Additionally, both ethephon compound agents improved the stalk puncture strength of maize. For the same maize variety, phenotypic traits such as ear length, ear diameter, and number of kernel rows showed no significant differences under different chemical control treatments. However, traits including kernel number per row, 1 000-kernel weight, and yield exhibited significant variations across treatments and years. Moreover, the yield performance of maize varieties after chemical control treatment varied by region. In Hebi, Zhoukou, and Zhumadian areas, the yield under the DTA-6 · ETH treatment surpassed that under the 6-BA · ETH treatment, with average yield increases of 4.22%, 8.41%, and 5.67% compared to the clear water control (CK), respectively. Conversely, in Shangqiu, Nanyang, and Changge areas, the 6-BA · ETH treatment outperformed DTA-6 · ETH, resulting in average yield increases of 6.96%, 7.54%, and 5.56% relative to CK.

Key words Maize, Chemical control agent, Lodging traits, Yield

0 Introduction

Chemical regulation technology has been widely applied in crop production[1]. It can modulate crop growth and development by altering the endogenous hormone balance through the external application of plant growth regulators, thereby achieving the objectives of stable yield and increased income, quality improvement, and enhanced stress resistance in plants[2-3]. Applying chemical regulation technology in maize production can effectively lower the plant's center of gravity and increase the number and thickness of aerial roots[4]. It can also enhance anchorage strength by shortening and thickening the basal internodes[5-6], consequently improving stalk lodging resistance. This technology can also effectively improve the canopy structure of the maize population, enhance photosynthetic performance, increase the grain filling rate, and achieve a coordinated improvement in light energy utilization and yield[7-8].

Commonly used chemical control agents in maize include ethephon, diethyl aminoethyl hexanoate (DTA-6), benzylaminopurine (6-BA), chlormequat, paclobutrazol, and uniconazole, *etc.*[9] Currently, ethephon and its compound formulations are extensively studied and applied in maize chemical control[4,6,10-15]. Ethephon (ETH) can reduce apical dominance, moderately dwarf plants, promote root growth and internode thickening, thereby preventing lodging. Improper application may cause premature abscission of leaves and fruits, leading to early maturation[16-17]. Benzylaminopurine (6-BA) is an effective regulator that promotes cell division, breaks apical dominance, encourages lateral bud germination, modulates plant architecture, improves photosynthetic function, delays leaf senescence, and enhances crop stress resistance and yield[18-20]. Diethyl aminoethyl hexanoate (DTA-6) is characterized by its broad spectrum and high efficiency. It can enhance enzyme activity, increase chlorophyll content, accelerate photosynthetic rate, promote cell division and elongation, stimulate root development, and alleviate plant stress, thereby improving yield and optimizing quality[16,21-22]. Using a single plant growth regulator often induces a series of growth effects[23]. These effects can include both positive and negative impacts. In practical production, growth regulators are often added to inhibitors or retardants. A primary substance is supplemented with one or more auxiliary substances to exert synergistic effects or reduce side effects, achieving more effective results in maize chemical control.

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This study utilized the main summer maize varieties from the Huang – Huai – Hai region—Zhengdan 958, Xianyu 335, Yudan 132, Xundan 20, Lianchuang 808, and Dingyou 163—as experimental materials. Two ethephon compound agents, DTA-6 · ETH and 6-BA · ETH, were sprayed at the 8 fully expanded leaves stage. The experiment was conducted over two years in six different ecological areas: Zhoukou, Nanyang, Zhumadian, Hebi, Shangqiu, and Changge, aiming to provide a theoretical basis for lodging prevention cultivation in Henan summer maize and to assist farmers in selecting appropriate chemical control agents.

1 Materials and methods

1.1 Selection of experimental sites The experiment was conducted from 2022 to 2023 within the experimental parks of six demonstration stations of the Henan Corn Industry Technology System: Zhumadian, Nanyang, Changge, Hebi, Zhoukou, and Shangqiu.

1.2 Experimental materials The tested maize varieties were the main cultivars in the Huang – Huai – Hai region: Zhengdan 958, Xianyu 335, Yudan 132, Xundan 20, Lianchuang 808, and Dingyou 163. The chemical control agents used were 30.0% DTA-6 · Ethephon aqueous solution (containing 3.0% DTA-6 and 27.0% ethephon, produced by Sichuan Run'er Technology Co., Ltd.) and 30.0% 6-BA · Ethephon aqueous solution (containing 0.5% 6-BA and 29.5% ethephon, produced by Sinochem Crop Protection Co., Ltd.). The application timing and dosage were uniformly based on the recommendations on the pesticide packaging, ensuring no over-spraying or missed areas.

1.3 Experimental design At each experimental site, trials were conducted to evaluate the lodging resistance and yield of the six test varieties in response to the two chemical agents, with a planting density of 75 000 plants per hectare. Three treatments were established: Treatment 1: DTA-6 · ETH; Treatment 2: 6-BA · ETH; Treatment 3 (Control, CK): clear water. The plot area was 20 m^2, arranged in five rows with a row length of 6.67 m, using a randomized complete block design with three replications per treatment. Field management practices were consistent with local field standards, and chemical control was uniformly applied at the 8 fully expanded leaves stage of maize.

1.4 Measurement items and methods

1.4.1 Measurement of morphological indicators. At the early grain filling stage, 10 representative plants from the middle three rows were continuously measured for plant height and ear height to calculate the ear height coefficient. The ear height coefficient was calculated as (ear height/plant height) ×100.

1.4.2 Measurement of lodging and breaking. The actual lodging rate and breaking rate in the field were investigated at the full maturity stage.

1.4.3 Measurement of stalk mechanical indicators. At the milk stage, 10 representative plants were randomly selected from each plot, and the puncture strength of the third internode above ground was measured using a YYD-1A plant stalk strength tester, recording the maximum value.

1.4.4 Measurement of economic trait indicators. After harvest, the middle three rows of each plot were actually harvested for yield measurement. Additionally, 10 consecutive ears were selected for indoor assessment, measuring economic yield indicators such as ear length, ear diameter, number of kernel rows, kernel number per row, and 1 000-kernel weight.

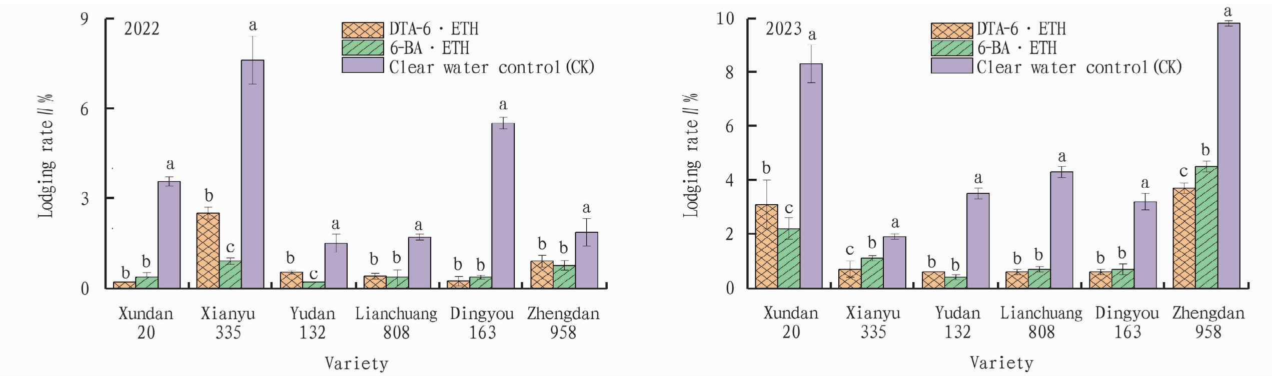
1.4.5 Measurement of yield indicators. After threshing and sun-drying, the average moisture content was measured three times using a grain moisture meter, and the yield per 667 m^2 was calculated (with moisture content standardized to 14%).

1.5 Data processing Experimental data were processed and analyzed using Microsoft Excel 2010. Data were subjected to analysis of variance and multiple comparisons using DPS 7.05 statistical software, and charts were generated with Origin2023 software.

2 Results and analysis

2.1 Effects of two ethephon compound agents on lodging resistance of six maize varieties across different regions The actual lodging incidence of maize varieties in the field is a direct indicator of their lodging resistance[24]. The results showed that the field lodging and breaking rates of the six maize varieties were generally consistent across regions during 2022 – 2023. Application of both DTA-6 · ETH and 6-BA · ETH chemical control treatments reduced the incidence of lodging and breaking in all six varieties (Fig. 1 and 2). In 2022, the lodging resistance of the six maize varieties treated with 6-BA · ETH was superior to that with DTA-6 · ETH, with the most significant anti-lodging effects observed for Xianyu 335 and Dingyou 163 (Fig. 1). In 2023, the incidence of lodging and breaking was higher for many varieties compared to 2022, primarily due to southern rust and bacterial wilt, with Xundan 20 and Zhengdan 958 being the most severely affected. However, application of both chemical agents significantly improved lodging resistance. The lodging rate of Xundan 20 was reduced by 6.1 percentage points with 6-BA · ETH treatment compared to the clear water control (CK), while the lodging rate of Zhengdan 958 was reduced by 6.2 percentage points with DTA-6 · ETH treatment compared to CK. The occurrence of lodging and breaking varied due to differences in environmental conditions across the regions.

2.2 Effects of two ethephon compound agents on ear height coefficient of maize varieties in six regions The ear height coefficient serves as an indicator of lodging resistance in maize; a smaller coefficient denotes stronger lodging resistance, and vice versa[25]. As shown in Fig. 3, after application of DTA-6 · ETH and 6-BA · ETH during 2022 – 2023, both plant height and ear height were reduced for the six maize varieties grown in different regions, leading to a clear decreasing trend in the ear height coefficient compared to the clear water CK. Following treatment with 6-BA · ETH, the ear height coefficient of Xundan 20 was significantly lower than with DTA-6 · ETH treatment. In Nanyang, Zhumadian, and Changge, the coefficient was reduced by 5.2, 6.5,



NOTE Bars labeled with different lowercase letters indicate statistically significant differences between treatments ($P<0.05$). The same below.

Fig. 1 Effects of two ethephon compound agents on the average lodging rate of six maize varieties in various regions

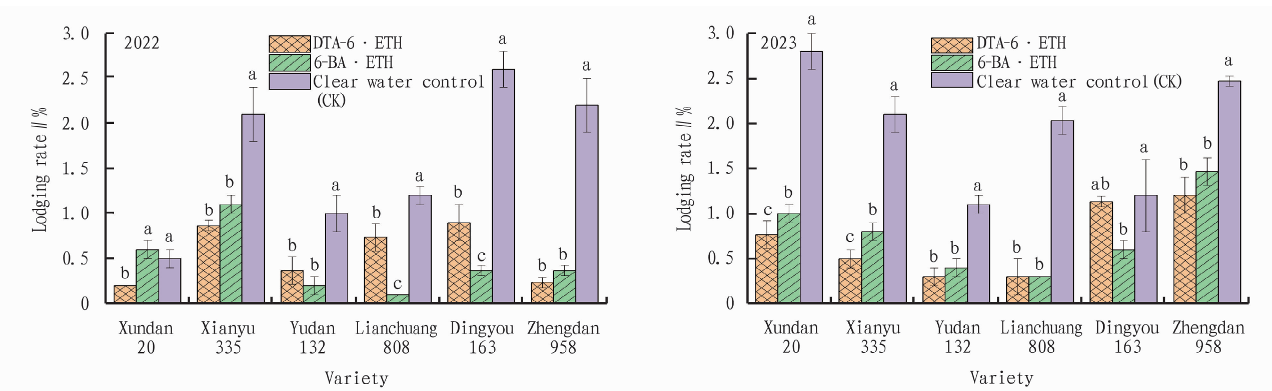
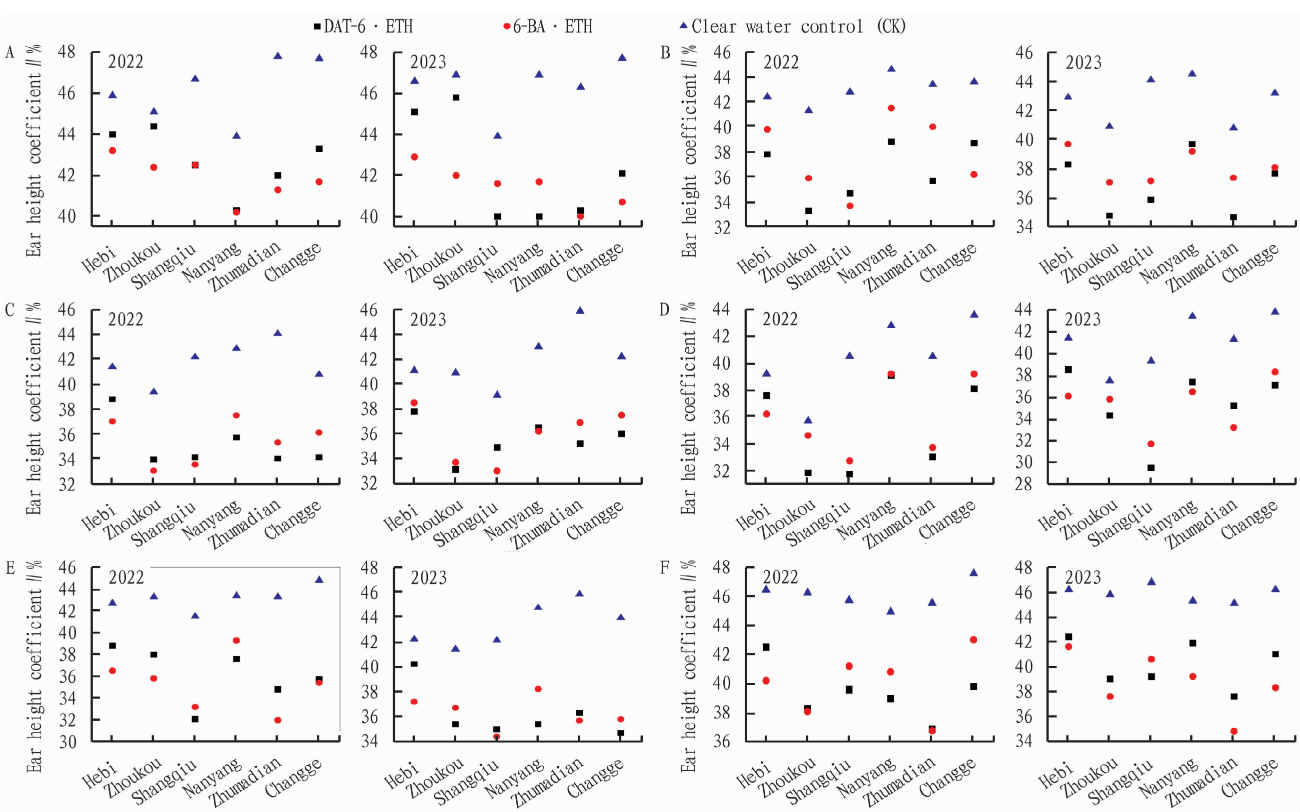


Fig. 2 Effects of two ethephon compound agents on the average breaking rate of six maize varieties in various regions



NOTE A. Xundan 20; B. Xianyu 335; C. Yudan 132; D. Lianchuang 808; E. Dingyou 163; F. Zhengdan 958.

Fig. 3 Effects of two ethephon compound agents on the ear height coefficient of maize varieties in six regions

and 7.0 percentage points, respectively, compared to CK. The ear height coefficient also decreased for varieties like Xianyu 335 and Yudan 132 under both chemical treatments, with notable effects in Zhoukou, Shangqiu, and Zhumadian. In Shangqiu, the ear height coefficient of Lianchuang 808 was reduced by 9.8 percentage points with DTA-6 · ETH treatment compared to CK, while in Zhumadian, the coefficient of Dingyou 163 was reduced by 11.3 percentage points with 6-BA · ETH treatment compared to CK.

2.3 Effects of two ethephon compound agents on the puncture strength of the third internode in six maize varieties Puncture strength is an important indicator of maize stalk quality. As shown in Fig. 4, the average puncture strength of the third internode for the six maize varieties treated with the two ethephon compound agents was greater than that of the CK in all regions, though the magnitude of improvement varied by variety. The average puncture strength of the third internode for Xundan 20 and Yudan 132 increased by 11.39% and 15.59%, respectively, with 6-BA · ETH treatment compared to CK, and by 8.59% and 12.71%, respectively, with DTA-6 · ETH treatment compared to CK.

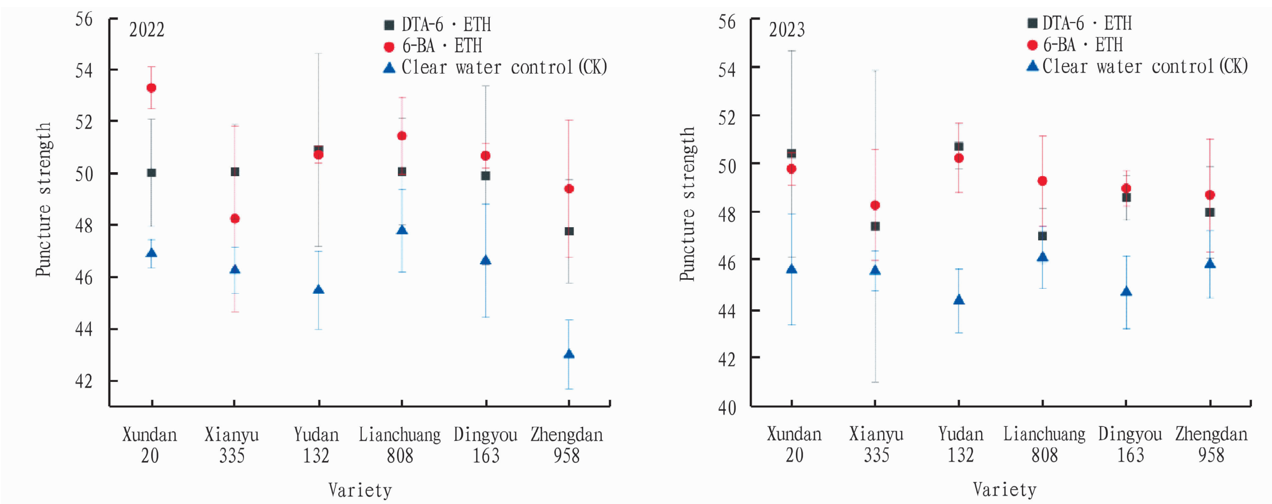


Fig. 4 Effects of two ethephon compound agents on the puncture strength of the third stem of six maize varieties

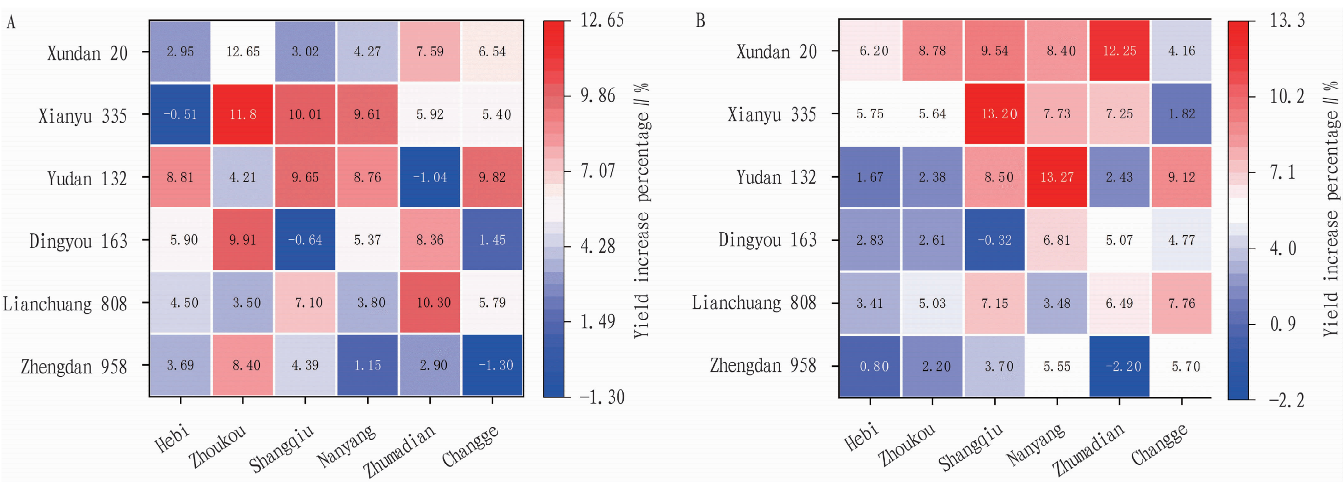
2.4 Effects of two ethephon compound agents on yield traits of six maize varieties grown in different regions As shown in Table 1, the two ethephon compound agents had certain effects on the yield traits of the six maize varieties. Differences in ear length, ear diameter, and number of kernel rows were not significant across years, whereas kernel number per row, 1 000-kernel weight, and yield showed highly significant differences. All yield trait indicators showed highly significant differences among the different varieties. Among the chemical control treatments, kernel number per row showed significant differences, while 1 000-kernel weight and yield showed highly significant differences. For a given variety, phenotypic traits such as ear length, ear diameter, and number of kernel rows showed no significant differences under different chemical treatments. However, for most varieties, kernel number per row, 1 000-kernel weight, and yield showed significant differences across treatments and years. In 2022, the two chemical treatments resulted in significant differences in kernel number per row for Xundan 20, Xianyu 335, Yudan 132, and Dingyou 163. Compared to CK, DTA-6 · ETH treatment changed kernel number per row by +3.49%, −2.45%, +7.72%, and −5.38% for these varieties, respectively, while 6-BA · ETH treatment increased by +9.37%, +3.92%, +5.38%, and +1.58%, respectively. Yield differences compared to CK were significant for Xundan 20, Xianyu 335, Yudan 132, and Dingyou 163 after application of the two chemical agents during 2022 – 2023. The yield of Lianchuang 808 in 2023 was significantly different from CK after chemical treatment, with DTA-6 · ETH and 6-BA · ETH increasing yield by 5.83% and 3.59%, respectively, compared to CK.

2.5 Effects of two ethephon compound agents on yield variation of maize varieties across regions The results (Fig. 5) showed that the yield increase percentages of the two ethephon compound agents varied among the six maize varieties across the six regions. The yield increase range for DTA-6 · ETH was from −1.30% to 12.65%, while for 6-BA · ETH it was from −2.20% to 13.30%. The effect of DTA-6 · ETH was superior to that of 6-BA · ETH in Hebi, Zhoukou, and Zhumadian regions. Compared to CK, the average yield increase for the six maize varieties with DTA-6 · ETH treatment was 4.22%, 8.41%, and 5.67% in these three regions, respectively. The effect of 6-BA · ETH was superior to that of DTA-6 · ETH in Shangqiu, Nanyang, and Changge regions. Compared to CK, the average yield increase for the six maize varieties with 6-BA · ETH treatment was 6.96%, 7.54%, and 5.56% in these three regions, respectively.

Table 1 Effects of two ethephon compound agents on the yield traits of six maize varieties in different regions

Year	Varieties	Treatment	Ear length//cm	Ear diameter//cm	Number of kernel rows	Kernel number per row	1 000-kernel weight//kg	667 m^2 yield//kg
2022	Xundan 20	DTA-6 · ETH	16.39 ±1.19 a	4.88 ±0.37 a	15.40 ±0.72 a	32.04 ±1.29 b	323.92 ±33.46 a	640.52 ±88.44 a
		6-BA · ETH	16.47 ±1.56 a	4.86 ±0.30 a	15.40 ±0.41 a	33.86 ±1.54 a	319.88 ±18.35 b	667.77 ±78.11 a
		CK	16.37 ±1.16 a	4.80 ±0.38 a	15.60 ±0.37 a	30.96 ±2.12 b	315.52 ±31.71 c	607.52 ±92.40 b
	Xianyu 335	DTA-6 · ETH	18.56 ±1.29 a	4.57 ±0.37 a	15.20 ±0.83 a	29.08 ±0.90 b	341.18 ±31.83 a	670.57 ±43.21 a
		6-BA · ETH	18.69 ±0.73 a	4.61 ±0.40 a	15.40 ±0.54 a	30.98 ±1.71 a	339.37 ±31.77 a	662.95 ±61.86 a
		CK	18.15 ±1.87 a	4.51 ±0.44 a	15.40 ±0.82 a	29.81 ±1.74 b	337.80 ±31.32 a	635.70 ±64.89 b
	Yudan 132	DTA-6 · ETH	18.32 ±1.33 a	4.60 ±0.29 a	15.00 ±0.60 a	33.22 ±1.90 a	330.60 ±33.73 ab	664.97 ±82.12 a
		6-BA · ETH	17.87 ±1.16 a	4.47 ±0.20 a	15.20 ±0.41 a	32.50 ±1.54 ab	332.47 ±35.20 a	672.35 ±65.97 a
		CK	17.31 ±1.75 a	4.61 ±0.25 a	15.00 ±0.62 a	30.84 ±1.95 b	319.50 ±34.01 b	624.85 ±69.70 b
	Lianchuang 808	DTA-6 · ETH	18.68 ±0.97 a	4.64 ±0.23 a	15.20 ±0.41 a	33.24 ±2.51 a	341.93 ±33.06 a	628.83 ±74.74 a
		6-BA · ETH	19.10 ±1.41 a	4.46 ±0.26 a	15.00 ±0.53 a	33.52 ±2.29 a	338.22 ±36.63 ab	628.08 ±92.63 a
		CK	17.99 ±1.65 a	4.66 ±0.20 a	14.80 ±0.78 a	33.11 ±2.15 a	322.27 ±36.14 b	607.08 ±86.02 a
	Dingyou 163	DTA-6 · ETH	15.32 ±1.27 a	4.37 ±0.36 a	15.60 ±0.65 a	28.13 ±1.82 b	316.45 ±25.10 a	615.57 ±30.54 a
		6-BA · ETH	16.14 ±0.94 a	4.43 ±0.30 a	16.00 ±0.76 a	30.20 ±1.41 a	315.40 ±20.75 a	621.07 ±39.02 a
		CK	16.14 ±1.85 a	4.33 ±0.24 a	15.60 ±0.83 a	29.73 ±1.13 ab	312.02 ±24.55 a	579.28 ±34.19 b
	Zhengdan 958	DTA-6 · ETH	17.11 ±1.32 a	4.76 ±0.21 a	14.80 ±0.74 a	31.25 ±1.74 a	330.88 ±35.62 a	628.83 ±74.74 a
		6-BA · ETH	16.74 ±1.35 a	4.76 ±0.25 a	14.80 ±0.66 a	32.53 ±2.31 a	325.85 ±32.78 a	631.42 ±86.62 a
		CK	17.04 ±1.29 a	4.78 ±0.17 a	14.80 ±0.63 a	31.83 ±1.65 a	325.62 ±35.43 a	607.08 ±86.02 a
2023	Xundan 20	DTA-6 · ETH	16.34 ±1.43 a	4.82 ±0.11 a	15.40 ±0.48 a	32.58 ±2.35 a	310.15 ±21.52 a	611.32 ±44.31 a
		6-BA · ETH	16.04 ±1.28 a	4.85 ±0.16 a	15.60 ±0.44 a	32.89 ±1.67 a	308.13 ±17.07 a	607.92 ±43.07 a
		CK	16.34 ±1.32 a	4.83 ±0.15 a	15.60 ±0.84 a	32.60 ±1.99 a	307.30 ±26.85 a	573.33 ±39.59 b
	Xianyu 335	DTA-6 · ETH	18.01 ±1.64 a	4.45 ±0.25 a	15.40 ±0.60 a	31.15 ±2.25 b	329.07 ±23.64 a	622.53 ±53.83 ab
		6-BA · ETH	19.06 ±1.26 a	4.62 ±0.29 a	15.60 ±0.60 a	33.20 ±1.43 a	320.83 ±23.61 a	632.45 ±86.81 a
		CK	18.84 ±1.70 a	4.50 ±0.39 a	15.60 ±0.51 a	31.28 ±2.04 b	321.18 ±26.83 a	578.93 ±82.18 b
	Yudan 132	DTA-6 · ETH	18.10 ±1.12 a	4.43 ±0.15 a	14.60 ±0.51 a	32.02 ±2.00 b	316.73 ±25.72 a	600.68 ±58.03 a
		6-BA · ETH	18.14 ±1.37 a	4.52 ±0.15 a	14.80 ±0.78 a	33.02 ±2.16 a	318.88 ±19.33 a	586.98 ±47.91 a
		CK	17.96 ±1.32 a	4.62 ±0.13 a	14.80 ±0.86 a	32.54 ±2.19 a	316.35 ±32.76 a	562.40 ±56.12 b
	Lianchuang 808	DTA-6 · ETH	19.03 ±0.97 a	4.54 ±0.12 a	15.20 ±0.27 a	33.60 ±1.61 a	324.48 ±34.46 a	646.92 ±77.05 a
		6-BA · ETH	19.47 ±1.31 a	4.48 ±0.13 a	14.60 ±0.29 a	33.97 ±2.17 a	316.67 ±29.20 ab	633.22 ±74.78 ab
		CK	19.28 ±1.08 a	4.67 ±0.12 a	14.80 ±0.44 a	33.38 ±2.19 a	317.37 ±34.13 ab	611.30 ±80.32 b
	Dingyou 163	DTA-6 · ETH	16.74 ±1.26 a	4.47 ±0.24 a	15.80 ±0.77 a	30.91 ±2.11 a	307.82 ±31.09 a	597.25 ±71.61 a
		6-BA · ETH	16.23 ±1.14 a	4.45 ±0.16 a	16.00 ±0.61 a	31.10 ±1.52 a	301.50 ±34.43 a	588.53 ±66.64 a
		CK	16.15 ±1.67 a	4.50 ±0.17 a	15.80 ±0.77 a	30.83 ±2.28 a	298.47 ±34.94 a	556.93 ±62.34 b
	Zhengdan 958	DTA-6 · ETH	17.14 ±1.05 a	4.83 ±0.14 a	15.20 ±0.52 a	32.89 ±2.09 a	324.02 ±20.40 a	557.32 ±61.50 a
		6-BA · ETH	17.22 ±1.05 a	4.85 ±0.16 a	15.20 ±0.82 a	33.63 ±1.99 a	316.47 ±23.40 b	550.22 ±54.10 a
		CK	17.20 ±0.78 a	4.78 ±0.16 a	15.00 ±0.41 a	32.60 ±1.60 a	312.15 ±22.32 b	544.35 ±59.17 a
Source of variation								
Year (Y)			NS	NS	NS	**	**	**
Hybrid (H)			**	**	**	**	**	**
Treatment (T)			NS	NS	NS	*	**	**
Y×H			NS	NS	NS	NS	NS	NS
Y×T			NS	NS	NS	NS	NS	NS
H×T			NS	NS	NS	NS	NS	NS
Y×H×T			NS	NS	NS	NS	NS	NS

NOTE The yield traits are averaged values summarized from six locations. In the same column, different lowercase letters indicate significant differences ($P<0.05$) between treatments within the same year; * and ** denote significant and highly significant treatment effects at $P<0.05$ and $P<0.01$ levels, respectively.



NOTE A. Two-year average yield increase percentage of DTA-6 · ETH chemical regulation compared to water control (CK); B. Two-year average yield increase percentage of 6-BA · ETH chemical regulation compared to water control (CK).

Fig.5 The differential heat map of the yield increase ratio of two ethephon compound agents in various maize varieties in six regions

3 Conclusions and discussion

The Huang – Huai – Hai summer maize region is the second largest maize production area in China and also a winter wheat-summer maize double-cropping system area[26]. During July and August each year, strong convective weather frequently causes storms. At this time, maize is in the jointing to grain filling stages, and due to rapid plant growth and fragile stalks, lodging is highly likely to occur. Therefore, the unique ecological environment and farming system impose strict requirements for improving maize adaptability[27–28]. Using chemical regulation technology to prevent lodging is currently the most common and cost-effective measure in production.

The strategy of mixing two or more chemical control agents is commonly employed[29]. Fan Haichao *et al.*[30] found that spraying a DCPTA and ETH compound agent can significantly improve stalk breaking resistance and the lodging resistance index, and enhance fiber quality. Ma Dong *et al.*[31] suggested that using compound chemical control agents can prevent lodging, fully regulate the endogenous hormone levels in maize, improve field ventilation and light penetration, increase the photosynthetic rate, and promote maize plant growth and development. Wang Lifeng *et al.*[32] found that spraying two compound chemical agents on three different types of maize varieties could optimize plant architecture, improve lodging resistance, enhance seed setting rate, and increase kernel percentage, thereby strengthening the comprehensive resistance of the maize varieties. This study found that applying the two chemical control treatments significantly improved lodging resistance. The lodging rate of Xundan 20 was reduced by 6.1 percentage points with 6-BA · ETH treatment compared to CK, and the lodging rate of Zhengdan 958 was reduced by 6.2 percentage points with DTA-6 · ETH treatment compared to CK. Simultaneously, both DTA-6 · ETH and 6-BA · ETH significantly reduced the ear height coefficient, increased stalk puncture strength, and enhanced plant lodging resistance. After treatment with 6-BA · ETH, the ear height coefficient of Xundan 20 was reduced by 5.2, 6.5, and 7.0 percentage points compared to CK in Nanyang, Zhumadian, and Changge, respectively. In Shangqiu, the ear height coefficient of Lianchuang 808 was reduced by 9.8 percentage points with DTA-6 · ETH treatment compared to CK, while in Zhumadian, the coefficient of Dingyou 163 was reduced by 11.3 percentage points with 6-BA · ETH treatment compared to CK. The two-year average stalk puncture strength of Xundan 20 and Yudan 132 increased by 11.39% and 15.59%, respectively, with 6-BA · ETH treatment compared to CK, and by 8.59% and 12.71%, respectively, with DTA-6 · ETH treatment compared to CK.

Most studies on the effects of chemical control agents on maize yield remain focused on single varieties[33], yet substantial evidence indicates that the effects of chemical control vary among different maize varieties. Zhang Neng *et al.*[34] applied four chemical control agents to three dense-tolerant genotype maize varieties (Liangyu 99, Xindan 336, and Hongshuo 899). The results showed that the yield-increasing effects of different chemical agents varied among the different varieties. Hongshuo 899 showed a 14.81% yield increase with chlormequat spray, Xindan 336 showed a 55% yield increase with "Yuhuangjin" spray, and Liangyu 99 showed an 8.90% yield increase with "Tiegan Dabang" application. Wang Gengxin *et al.*[35] sprayed "Yuhuangjin" on six maize varieties (Baiyu 1, Baiyu 2, Xianyu 335, Xundan 20, Zhengdan 958, and Nongle 988). Among them, Nongle 988 had the highest yield with a 5.30% increase, while some other varieties showed yield reduction. Cheng Yonggang *et al.*[36] treated six maize varieties with five chemical control agents. The research indicated that different maize varieties require different chemical agents, and no single agent can satisfy all varieties simultaneously. This study found that for a given variety, phenotypic traits such as ear length, ear diameter, and number of kernel rows showed no significant differences under different chemical control treatments. However, traits including kernel number per row, 1 000-kernel weight, and yield exhibited significant variations across treatment years. In 2022, the kernel number per row of Xundan 20 and Yudan 132 increased by 3.49% and 7.71%, respectively, with DTA-6 · ETH treatment compared to CK, while with 6-BA · ETH treatment, it increased by 9.37% and 5.38%, respectively, compared to CK. The average yield across six regions for Xundan 20, Xianyu 335, Yudan 132, and Dingyou 163 showed significant differences compared to CK over two years after application of the two chemical agents. The yield of Zhengdan 958 showed no significant difference over the two years. The yield of Lianchuang 808 showed a significant difference in 2023 after chemical treatment, with DTA-6 · ETH and 6-BA · ETH increasing yield by 5.83% and 3.59%, respectively, compared to CK.

The effectiveness of chemical regulation technology is closely related to the maize variety, ecological environment, planting density, application timing, and concentration[37-38]. The interactive effects of different chemical regulation measures on yield vary among different regions and maize plant populations. This study found that the effect of DTA-6 · ETH was superior to that of 6-BA · ETH in Hebi, Zhoukou, and Zhumadian regions. The average yield increase for the six maize varieties after DTA-6 · ETH treatment was 4.22%, 8.41%, and 5.67% in Hebi, Zhoukou, and Zhumadian, respectively. Conversely, in Shangqiu, Nanyang, and Changge areas, the 6-BA · ETH treatment outperformed DTA-6 · ETH, resulting in average yield increases of 6.96%, 7.54%, and 5.56% for the six varieties.

The application of maize chemical control technology provides important assurance for lodging prevention[39]. The two ethephon compound agents involved in this study, applied to six maize varieties across six ecological regions, effectively reduced the ear height coefficient and significantly lowered the risk of lodging. They had minor effects on various yield indicators such as ear length, ear diameter, number of kernel rows, kernel number per row, and 1 000-kernel weight. Kernel number per row and 1 000-kernel weight were slightly increased in some varieties after chemical application. The yield performance of the six maize varieties grown in different ecological regions showed that yield increases outweighed decreases. Therefore, the optimal chemical control agent should be selected based on the specific variety and ecological region to guide agricultural production.

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