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EFFECT OF PLANT GROWTH REGULATORS ON MAIZE (*ZEA MAYS* L.) AGRONOMIC CHARACTERISTICS, STALK LODGING AND YIELD UNDER HIGH PLANTING DENSITY IN NORTHEAST CHINA

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ABSTRACT

Lodging is one of the major factors that constrain grain yield stability and quality worldwide. Stalk lodging often reduce maize (*Zea mays* L.) grain yield and also causes difficulties in harvest operations. Plant growth regulators (PGRs) are often used widely to control lodging in modern high input cereal management. Two years field experiments were conducted with commercial PGRs of Yuhuangjin (YHJ) to determine their effects on spring maize growth, agronomic characteristics, grain yield and stalk lodging under high planting density in Jilin province, Northeast China. The results showed that, in all experiments, maize lodging-related characters of plant height (PH), ear height (EH), gravity height (GH), dry matter accumulation (DMA), internode 2 to 7 length (IL) were consistently reduced, and stalk bending strength(BS) of node 2 to7 were consistently enhanced by application of YHJ in both years. It is much more significant about above-mentioned character to apply with two (Sprayed twice, before elongation stage and V8 stage, respectively) or three (Sprayed three times, before elongation stage, V8 stage and before tasseling stage, respectively) times YHJ treatment. Maize grain yield, lodging score and HI were significantly influence by PGRs (T), Hybrids (H), and Year (Y). Grain yield increased and lodging score deceased significantly under YHJ treatment in high lodging year, but had little influence on grain yield in low lodging years. Application of YHJ could increase maize harvest index (HI) in all experimental years by reducing maize DMA significantly. Based upon these results, we concluded that PGRs could enhance stem lodging resistance during growth period, provided that they are used in right quantity and time. This is the optimal agronomic management in maize crops cultivated under high planting density in Northeast China.

Key words: maize, Plant Growth Regulators (PGRs), stalk lodging, agronomic characteristics.

INTRODUCTION

Lodging, which is the state of permanent displacement of the stems from the vertical for a free-standing crop plant (Berry et al., 2004; Pinthus, 1974), is one of the major factors that constrain grain yield stability and quality worldwide (Berry et al., 1999). Lodging is a complicated phenomenon that is influenced by many external factors including: wind, rain, topography, soil type, previous crop, diseases, even more manage practice, such as planting density, etc (Berry, 2004; Ma et al., 2014). Lodging frequently bring about a series of negative effects on crops, like interfering with water and nutrient uptake, reducing light interception, providing a favourable environment for leaf diseases, limiting grain yield potential and also causing difficulties in harvest operations (Tripathi et al., 2003).

The Northeast China Plain is considered as having some of the most fertile soils in China. Consequently, the black soil region has become one of the most important regions for cereal grain production, which accounts for 35% of the total maize crop in China (Yang et al., 2007), and has been playing an important role in protecting national food security. Rising panting density is the most important

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reason for the increase of corn production in China and other countries (Ci et al., 2012; Esechie, 1985; Niu et al., 2013). Higher plant populations in corn significantly increased the yield of maize, but also simultaneous an increase in lodging risk has been noticed by previous studies (Pedersen and Lauer, 2002). Great strides have been made by commercial breeding to reduce lodging risk by the introduction of semi-dwarf varieties in the past few decades (Berry, 2004; Ma et al., 2014; Yang et al., 2007). At present, due to the limits of maize breeding technology in China, maize lodging is common in spring maize production zone of this area. Customarily, maize lodging is frequently associated with conditions that reduce the lodging resistance of plants by excessive maize planting density. Cao et al. (2013) reported that lodging caused by typhoon "Bravan" in grain filling stage of 2012 created maximum and average yield losses of 29.68% and 14.75%, respectively, in Jilin province, northeast China. Similarly, the fact that lodging remains a problem in cereals, and that maize lodging risk is increased by rising planting density has been noticed by previous studies in other countries recently (Zuber and Kang, 1978; Ci et al., 2012; Oladokun, 2006). Freeze and Bacon (1990) reported significant lodging when wheat row spacing was 4 inches in comparison to 6 or 8 inches; Berry et al. (2004) reported that with increasing planting density of wheat from 100 to 400 plants/sq.m., the lodging rate gradually increased linearly. Reducing the number of plants within a row or using wider row spaces both reduced lodging.

Many studies have demonstrated that agronomic characteristics, such as plant height, ear height, basic internode length and mechanics properties of bending strength, which related to stalk lodging resistance, are key indicators to evaluate the stalk lodging resistance of maize (Ma et al., 2014; Baker et al., 1998; Berry et al., 2000; Crook, 1994; Esechie, 1985). Stem-shortening PGRs are often used widely on a diversity of crops each year to control lodging in modern high input cereal management (Todorov et al., 1998; Gencsoylu, 2009; Rajala et al., 2002). Most of studies reported have demonstrated that PGRs had positive effects on reducing lodging, and enhancing yield in field corn (*Z. may*s L.) by reducing internode elongation and other lodging related characteristic, thereby shortening plant height and enhancing crop stalk bending strength (Tripathi et al., 2003; Gaska, 1988; Langan, 1987; Norberg, 1988). For example, application of ethephon was associated with a decrease in Leaf Area Index, Crop Growth Rate, and it was found to be more beneficial for grain yield with higher plant densities and under favourable water conditions (Shekoofa. and Emam, 2006).

YuHuangJin (30% Amine fresh grease, YHJ) is a Chinese agricultural product, which was widely used in spring maize of Northeast China, but at present, the information on lodging in maize under high planting densities in this area is rather scanty. The objective of the present study was to examine the effects of PGRs YHJ on spring maize (*Z. may*s L.) growth, agronomic characteristics, grain yield and stalk lodging under high planting density in Jilin province, Northeast China.

MATERIAL AND METHODS

Test materials, sources and experiment location

Two maize hybrids *Xianyu335* (XY335) and *Heyu33* (HY33), which were provided by Tieling Pioneer Seed Company, DuPont China Holding Co., Ltd and Jilin Heguan Seed Company respectively; while YHJ (amine fresh ethephon, fresh fat amine3% ethephon content of 27%) was made available by Fujian Haolun Biotechnology Engineering Ltd., Co.

The test was conducted at Agricultural Experimental Station of Jilin Academic of Agriculture Science, Lishu County, Jilin Province (123°55′42″E, 43°21′33″N), during 2013 and 2014 maize-growing seasons. The annual precipitation is 500 to 900 mm with 70% of the total rainfall during the summer (July- August). The total precipitation from May to September in 2013 and 2014 was showed in Figure 1, and the average temperature was 4.4ºC.

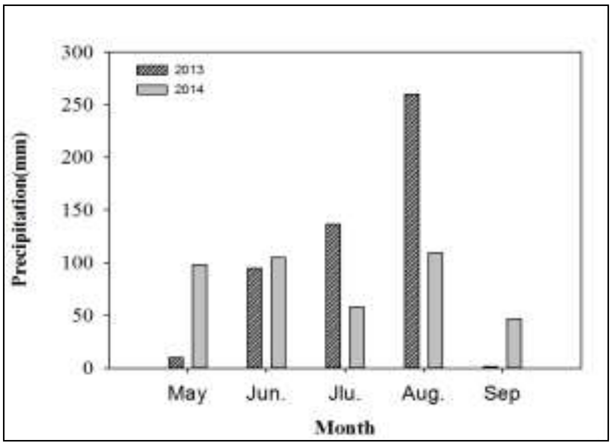

Figure 1. Precipitation of the experimental site from May to September during 2013 and 2014

The region is predominantly under rain-fed agriculture that has typical black and fertile soil, whose pH is 6.5 with rich Organic contents. Surface soil (0-20 cm) properties at the beginning of the experiment in 2013 are shown in Table 1.

Table 1. Surface soil (0-20cm) properties at the beginning of the experiment site in Jilin province, Northeast of China

Year	Organic matter (g kg^{-1})	Alkali-hydrolyzed N (g kg^{-1})	Olsen-P (g kg^{-1})	NH_4OAc-extracted K (g kg^{-1})
2013	26.9	118.9	18.02	111.1

Maize seeds were planted by hand on 7 May 2013 and 5 May 2014 with high density of 8.0 plants m^{-2}, subsequently harvested on 27 September 2013 and 25 September 2014.

The experimental design was a split-plot with 3 replications by using two maize hybrids as main plots and YHJ treatment as subplot. Corn was planted by wide-narrow row alternative planting pattern (wide and narrow row spacing was 80cm and 40 cm, respectively), with each plot consisting of 12 rows. One meter space was kept between blocks to reduce the edge effects.

The experiments consisted of three PGRs treatments and control, each treatment was replicated three times, in total 12 plots were laid out in the field. The plots were fertilized with 50 kg N ha^{-1}, 69 kg P ha^{-1} and 120 kg K ha^{-1} before sowing. Additional N fertilizer (urea) was applied with a quantity of 150 kg N ha^{-1} for each treatment on 15 June 2013 and 21 July 2014, to ensure that all the individual plants received sufficient amount of N applied. The plants were not irrigated during the whole experimental period, because there was enough rainfall during the growing season.

The treatments consisted of control and the commercial PGRs *YHJ*, they were sprayed with an air-pressurized backpack sprayer in water as carrier at 150 L ha^{-1} using Tee-jet nozzle tips. Each treatment was applied at recommended rates, at the stages as shown in Table 2.

Table 2 Experiment treatment and PGRs of *YHJ* applied time and rate

Application stage	Treatment				Recommended rates
	Control†	A	A+B	A+B+C	
Before Elongation stage (A)	-	√	√	√	250 ml ha^{-1}
Bell stage (V8) (B)	-		√	√	300 ml ha^{-1}
Tassel elongation (C)	-			√	300 ml ha^{-1}

† Sprayed with the same amount of water using an air -pressurized backpack sprayer in Before Elongation stage, Bell stage (V8) and Before VT.

Sampling of Agronomic Characteristics

At the silking stage, firstly, three successive plants were chosen to measure plant gravity height (GH), internode length (IL) and internode diameters with rulers and vernier calliper from the second internode to the sixth. Afterward, the chosen plants were cut at ground level and the centre of gravity was determined by placing separate plants across an outstretched index finger and moving the plant along the finger until the balance point was reached. The height of the centre of gravity was the distance from the base of the stem to the balance point (Crook and Ennos, 1994). Plant fresh weight was determined using a top loading balance, while the stem diameter was measured in the middle of each node from the base in two (right-angled) directions i.e. the long axis and short axis of an approximate ellipse.

The cross-sectional area (CSA) of the stem base was then calculated from the base using the formula (Oladokun, 2006):

$$CSA = (bc)\ \pi/4 \quad (1)$$

where A is the cross-sectional area, and b and c are the diameters of the stem along the long and short axis, respectively.

The stalk bending strength (BS) of each internode from the second to the sixth (below ear position) was measured using a Stalk Strength Tester (YYD-1; The Zhejiang Top Instrument Co. Ltd) (Ennos et al., 1993). The stalk bending strength (BS) was calculated according to Crook, 1994; and Ennos et al., 1993):

$$BS = F_{max}\, L/4 \quad (2)$$

where F_{max} is the maximum force the stem will withstand before it fails, and L is the distance between the supports.

Simultaneously, plant height (PH) and ear height (EH) were measured from the ground surface to the plant terminal and ear position was recorded by checking 10 plants per replication by meter rulers.

At physiological maturity, all plants were hand-harvested from 4 m of the 2 middle rows in each 12-row plot. The yield was converted to total yield in kg ha^{-1}. Five plants were randomly selected from the harvested spring maize, separated into cob, stalk, and grain. The weight of each component was measured before and after oven-drying at 80℃, and harvest index (HI) was calculated based upon the dry grain yield and aboveground biomass or dry matter accumulation (DMA). Harvest index (HI) was calculated as follows:

$$HI = Grain\ yield/DMA \quad (3)$$

Lodging at maturity was estimated visually. All plants in the central four rows of each plot, excluding the most exterior plants of each row, were used to calculate stalk lodging score, based upon 1 (erect) to 5 (prostrate), (Weber, 1966).

Statistical analysis

All statistical analyses of the data were done with the (IBM SPSS Inc., USA) after verifying the homogeneity of error variances. Multiple comparisons among the treatments were analysed with least-significant difference (LSD) test at the 0.05 level of probability.

RESULTS

Agronomic characteristics

Maize agronomic characteristics treated with commercial PGRs of YHJ are presented in Table 3. Plant height (PH), ear height (EH) and gravity height (GH) were significantly affected by YHJ treatment (T), and T×H×Y interaction in both years for two hybrids; PH and EH were also significantly affected by T×Y interaction (Tables 3 and Table 8). Compared to control, combined PH under A, AB, ABC treatments were reduced and ranged from 2.14-13.81% and 3.58-14.56% for XY335 and HY33, respectively. Combined EH were reduced and ranged from 0.63 to 16.86% and 10.83-19.78% for XY335 and HY33, respectively. Similarly, combined GH was reduced and ranged from 2.25 to 16.33% and 4.09 to 15.79 % for XY335 and HY33, respectively. For different YHJ treatments, the effect of reduction on PH, EH, and GH, was much more significant under AB and ABC treatment, as compared to control. The rainfall was relatively lower in 2014 than 2013 and plants growth was restricted, leading to significant variances of PH among years. Regarding maize varieties, PH of XY335 was higher than HY33, but EH and GH showed opposite trend; this may be due to the differences in specific varieties.

Table 3. Agronomic characteristics under PGRs treatment with hybrid maize XY335 and HY33 during 2013 and 2014

Varieties	Treat-ments	Plant height (cm)			Ear height (cm)			Gravity height (cm)		
		2013	2014	Combined	2013	2014	Combined	2013	2014	Combined
XY335	CK	320.24a	318.67a	319.45	130.17a	109.82a	120.00	120.72a	116.83a	118.78
	A	314.88b	310.33b	312.60	133.67a	104.82b	119.25	117.05a	115.17a	116.11
	AB	304.76c	277.64c	291.20	101.33b	99.88c	100.61	105.22b	96.50b	100.86
	ABC	284.69d	266.00d	275.34	99.67b	99.85c	99.77	103.11b	95.67b	99.39
HY33	CK	306.80a	293.33a	300.07	132.33a	128.89a	130.61	124.80a	116.17a	120.49
	A	292.31b	286.33b	289.32	121.50b	111.40b	116.45	119.82a	111.33a	115.58
	AB	272.00c	267.17c	269.58	106.67c	101.20c	103.93	107.61b	100.00b	103.83
	ABC	265.78d	247.00d	256.39	106.83c	100.70c	104.77	104.78b	98.17b	101.47

Stem characteristics

There were significant differences between the lengths of stalk internodes (IL) under YHJ treatment for the two hybrids ($p<0.05$) as compared to control. Under treatment A, IL of internodes 2-4 were reduced significantly compared with control and, in the same fashion, under AB and ABC treatment IL of internodes 2-7 were reduced significantly compared to control and A. Lastly, the IL of internodes 6-7 under ABC treatment was reduced significantly in comparison with AB.

For both hybrids, internode cross sectional area (CSA) was reduced gradually from Node 2 to Node 6 (Table 4). The CSA of internodes at the same position showed differences under YHJ for both hybrids. Correspondingly, under A treatment, CSA of internodes 2 increased significantly over control. Compared to control and A, CSA of internodes 2-4 increased significantly under AB and ABC treatment; CSA of internodes 5-6 had an increase trend, but not significant; CSA of Internodes 5-6 under ABC was enhanced significantly over AB.

Table 4. Plants stem characteristics under PGRs treatment with hybrid maize XY335 and HY33 during 2013 and 2014

Parameters	Internode no.	**XY335**				**HY33**			
		CK	A	AB	ABC	CK	A	AB	ABC
Internode length, IL (cm)	Int.2	12.43†a‡	10.41b	10.20b	10.17b	13.75a	10.20b	9.48b	10.64b
	Int.3	17.5a	16.28b	16.17b	15.57b	17.60a	15.10b	15.08b	15.83b
	Int.4	22.5a	19.42b	19.18b	19.13c	19.62a	17.81b	17.88b	18.67b
	Int.5	24.71a	23.75a	20.50b	19.58b	22.10a	21.40a	18.75b	20.00b
	Int.6	23.21a	21.48a	16.18b	13.01c	21.92a	21.22a	13.83b	12.25c
	Int.7	20.77a	19.75a	13.57b	11.98c	18.92a	18.45a	11.58b	9.95c
Cross sectional area, CSA (mm^2)	Int.2	498.30c	520.12b	529.69b	559.46a	483.83d	514.62c	525.20b	534.81a
	Int.3	451.43c	448.27c	472.67b	495.75a	447.70c	468.48b	477.85b	491.74a
	Int.4	393.97c	404.17c	413.47b	432.76a	404.31c	424.27b	431.37a	435.46a
	Int.5	360.00b	358.77b	365.78b	389.83a	380.58b	386.36b	395.53a	399.66a
	Int.6	338.22b	342.94b	345.45b	358.08a	347.94a	350.84a	358.50a	358.09a
Dry weight per unit, DWPU ($g\ cm^{-1}$)	Int.2	0.65b	0.70b	0.79a	0.79a	0.62b	0.81a	0.85a	0.83a
	Int.3	0.57b	0.65 a	0.71a	0.69a	0.58b	0.70a	0.74a	0.79a
	Int.4	0.51 b	0.59 a	0.61a	0.60a	0.50b	0.62a	0.68a	0.69a
	Int.5	0.45c	0.49b	0.55a	0.53a	0.48c	0.51b	0.55b	0.60a
	Int.6	0.42b	0.45b	0.52a	0.52a	0.48a	0.49a	0.51a	0.52a

†Value is mean of ten replications.
‡Means followed by the same letter within a row for the same variety do not differ at $p<0.05$.

Dry weight per unit (DWPU) of the internode showed a similar trend with CSA, being reduced gradually from node 2 to 6 (Table 4). The CSA of internodes at the same position was different under YHJ for both hybrids. Correspondingly, under A treatment, CSA of internodes 2 increased significantly over control. Compared to control and A, CSA of internodes 2-4 increased significantly under AB and ABC treatment, CSA of internodes5-6 had an increase trend, but not significant; CSA of Internodes 5-6 under ABC was enhanced significantly over AB.

Stalk bending strength

Significant differences were observed in the stalk bending strength (BS) from the second to sixth internodes in 2013 and 2014 (Figure 2); application of PGRs YHJ could strengthen internode BS gradually, especially for internode 2 to 4 for the two hybrids in both years.

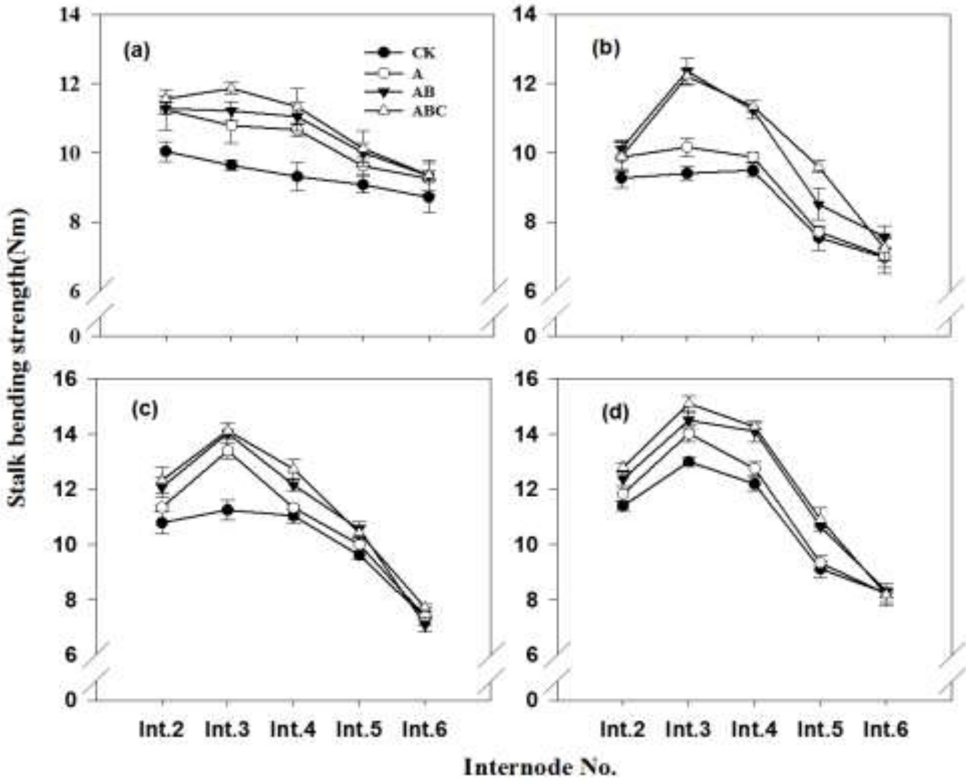

Figure 2. Effect of PGRs on Stalk bending strength of internode 2 to 6: (a) and (c) for hybrid XY335 during 2013 and 2014, respectively; (b) and (d) for HY33 correspondingly. Results are means ±standard deviation, where n=3.

For example, under A treatment, BS of Node 2 and Node 3 increased significantly compared to control. Correspondingly, besides the effect on BS of Node 2 and Node 3, BS of Node 4 and Node 5 both increased significantly under AB and ABC treatment, but the effect of YHJ on Node 6 was not significant under AB and ABC treatments. There is the little difference from IL and CSA.

Maize yield and lodging score

Maize grain yield, DMA, HI and lodging score were significantly affected by PGRs (T), Hybrids (H), and Year (Y). Grain yield and lodging score were also affected by T×Y, H×Y interaction. Highly significant increase was observed in grain yield in 2013 for both hybrids under YHJ application. However, a slow decline, but not significant, was observed in 2014, due to large area of maize lodging brought about by wind and rainfall. This could also be observed by comparison of lodging score in 2013 and 2014. In a high lodging year (2013), application of PGRs could reduce lodging score by 29.81-47.96% and increase maize grain yield by 6.30-10.16% respectively. In a low lodging year (2014), application of PGRs decreased maize grain yield by 4.58-6.74%, but the effect on maize lodging score was not significant as compared to treatment of AB and ABC for maize HY33. Due to higher rainfall in August during maize growing season and lodging in 2013, maize grain yield were lower than in 2014.

DMA was significantly decreased by PGRs (T) in 2013 and 2014 for both hybrids under YHJ application (Tables 5 and 6), especially for the treatment AB and ABC. On the contrary, HI was highly increased by PGRs (T) in 2013 and 2014 for both hybrids. This suggested that application of PGRs YHJ would be favourable to the transfer of dry matter accumulated in vegetative and reproductive growth stage to kernels.

Table 5. Grain yield, biomass, harvest index and lodging rate under PGRs treatment with hybrid maize XY335 and HY33 during 2013 and 2014

Varieties	Treatment	Grain yield (Mg ha^{-1})		Dry matter accumulation (Mg ha^{-1})		Harvest index (Mg ha^{-1})		Lodging Index (Mg ha^{-1})	
		2013	2014	2013	2014	2013	2014	2013	2014
XY335	CK	10.15†b‡	12.46a	23.67a	25.72a	0.43c	0.48c	3.66a	1.92a
	A	10.74a	12.14a	22.63b	24.13a	0.52b	0.50c	2.63b	1.25b
	AB	11.07a	12.23a	21.16b	20.32b	0.54b	0.60b	2.18c	0.63c
	ABC	11.13a	12.02a	18.90c	18.57c	0.63a	0.65a	1.92c	0.62c
HY33	CK	9.70c	11.78a	22.15a	24.42a	0.49d	0.48b	3.10a	1.42a
	A	10.38b	11.22a	21.25b	23.59a	0.53c	0.48b	2.12b	1.05b
	AB	10.56a	10.60b	20.00c	19.95b	0.59b	0.53a	1.86b	0.67c
	ABC	10.75a	10.58b	17.57d	19.67b	0.65a	0.54a	1.60c	0.53c

†Value is mean of three replications.
‡Means followed by the same letter within a column in each year do not differ at $p<0.05$.

Table 6. Summary of ANOVA for grain yield, aboveground biomass and harvest index

Source of variation	Grain yield	Aboveground biomass	harvest index	Lodging score	PH	EH	GH
Treatment (T)	p<0.01	p<0.01	p<0.05	p<0.01	p<0.01	p<0.01	p<0.01
Hybrid (H)	p<0.01	p<0.05	p<0.01	p<0.01	p<0.01	p<0.01	p<0.05
Year (Y)	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01
T×H	ns	ns	ns	ns	ns	p<0.01	ns
T×Y	p<0.01	ns	ns	p<0.01	p<0.01	p<0.05	ns
H×Y	p<0.01	ns	ns	p<0.05	ns	p<0.05	ns
T×H×Y	ns	ns	ns	ns	p<0.01	p<0.05	ns

ns: not significant ($p>0.05$).

DISCUSSION

Plant growth and development are affected by several endogenous and exogenous factors. Exogenous application of plant hormones (PGRs) play a vital role in regulating growth and development of plants at different stages of plant development (Zhang et al., 2012; Alam et al., 2012), especially in reducing the risk of lodging.

Previous studies have demonstrated that plant height, ear height, and ear ratio (the ratio of ear height to plant height) are key indicators that can be used to evaluate the stalk lodging resistance of maize and to find a positive correlation between lodging and plant height (Esechie, 1985b). Application of PGRs could significantly reduce lodging-related stalk characteristics such as plant height, ear height (Esechie et al., 1977; Li, 2004; Shekoofa, 2008).

In this study, PH, EH, GH were significantly affected by YHJ treatment (T), and by T×H×Y interaction in both years for two hybrids. Plant height and EH were also significantly affected by T×Y interaction. Compared to control, combined PH showed reduced range from 2.14 to 13.81% and 3.58 to 14.56%; EH was also reduced ranging from 0.63 to 16.86% and 10.83 to 19.78%, GH was reduced from 2.25 to 16.33% and from 4.09 to 15.79 % for XY335 and HY33, respectively. The results are consistent with the previous studies.

The basal part of the stem plays an important role in lodging resistance, as it provides a lever to hold the plant upright (Tripathi et al., 2003); short lower internodes are positively correlated with lodging (Esechie, 1985b). The current studies showed that there were significant differences between the IL, CSA and DWPU under YHJ treatment for two hybrids, compared to control. Previous studies mostly concentrated on the basal part of the stem (Node 1 to Node 3), but our studies measured all the internodes below maize ear position. IL was significantly reduced compared to control from Node 2 to Node 7 under PGRs YHJ treatment, especially under the application of YHJ with two (treatment of AB, sprayed Before Elongation stage and V8 stage) or three (treatment of ABC, sprayed Before Elongation stage, V8 stage and Before Tasseling stage) times (Table 5). Correspondingly, the cross-sectional area of stem (CSA), dry weight per unit (DWPU) and the stalk bending strength (BS) were all enhanced significantly to a lager extent, compared with control. This is different from other results and represents very useful findings in PGRs application for improving crop lodging-resistance.

Gaska and Oplinger (1988) reported that, if lodging is not a problem, ethephon applied to certain hybrids at high rates and late application times may reduce yields. In this study, maize grain yield, DMA, HI and lodging score were significantly influenced by PGRs (T), Hybrids (H), Year (Y), and grains yield, lodging score were also effect by T×Y interaction. The difference of rainfall was the main cause of yield variance between years. In a high lodging year (2013), maize grain yield not only increased by 6.30-10.16%, but stalk lodging was significantly reduced by 29.81-47.96% with PGRs YJH treatment. In contrast, in a low lodging year (2014), maize grain yield had a low decline trend, but it was not significant in our studies. These observations further validate the findings of many workers who have reported that application PGRs in different times and rates had different effect on crop lodging score and maize grain yield (Langan, 1987; Gaska and Oplinger, 1988).

PGRs regulate growth and development, such as growth and metabolism through the mediation of genes that may determine their orientation, physiology, and productivity in a plant’s life cycle (Wu and Hu, 2009; Moore, 1979). In the present study, DMA was significantly decreased by PGRs (T) in 2013 and 2014 for both hybrids under YHJ application (Tables 5 and 6). Moreover, maize biomass was very significantly reduced by application of YHJ with two (treatment AB, sprayed Before Elongation stage and V8 stage) and three (treatment AB, sprayed Before Elongation stage, V8 stage and Before Tasseling stage) times (Table 5).

The HI significantly increased with the increase in YHJ application times in 2013 and 2014 for both hybrids. The increase of HI was associated with the increase or non-significant decrease for grain yield and extremely significant reduction of maize biomass under YHJ treatment. The maximum value of HI was achieved under ABC treatment of XY335, and the value of HI was minim under control treatment of XY335. The incresed HI indicated that application of PGRs YHJ is favourable for the transfer of dry matter accumulated in vegetative and reproductive growth stage to kernels.

CONCLUSION

In all experiments conducted in both years, maize lodging –related characters of PH, EH, GH, DMA and length of 2 to7 internodes were consistently reduced, and stalk bending strength (BS) of internodes 2 to 7 were consistently enhanced by application of YHJ, especially applied with two (treatment of AB, sprayed Before Elongation stage and V8 stage) or three (treatment of ABC, sprayed Before Elongation stage, V8 stage and Before Tasseling stage) times. These findings are important to reduce maize lodging risk and to improve crop lodging-resistance by repetitive spraying of PGRs.

Maize grain yield, lodging score and HI were significantly influenced by PGRs (T), Hybrids (H), and Year (Y). Grain yield increased HI and lodging score decreased significantly in lodging years. Hence, there is a need to strengthen the agricultural meteorological forecast, and to use lodging resistant varieties for maize lodging prevention in Northeast China.

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