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The germination and seedlings growth response of wheat and corn to drought and low temperature in spring of Northeast China

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1 SUMMARY

Wheat and corn were chosen to study the single and combined stress effects of low temperature and drought on their germination characteristic and early seedlings growth. Results showed that both single and their interaction of low temperature and drought could affect the germination and early seedlings growth of wheat and corn significantly. With the increasing Polyethylene Glycol (PEG) levels and decreasing temperature, wheat seeds could keep higher germination percentage when temperature was between 15 °C and 25 °C or PEG level was between 0 to 20%. The germination percentage reduced markedly when temperature was 10 °C, or PEG level was at 30%. Corn seeds decreased sharply with the increasing PEG levels and decreasing temperature, and could not germinated when temperature was 10 °C, or PEG level was at 30%. The length and biomass of wheat early seedlings had similar change tendency, which increased first then decreased. The length and biomass change of corn seedlings was consistent with their germination, which decreased significantly. The peaking values of wheat and corn seedlings were showed at 10% and 0 PEG levels, 20 °C and 25 °C, respectively. Wheat had higher root/shoot than corn. More root biomass and higher root/shoot were the adaptation characteristic of wheat seedlings to low temperature and drought stress. From these results, it can be concluded that maize growth would be better, if the temperature and water condition was good in Northeast China (temperature was between 20 °C to 25 °C; water condition was lower than PEG 5%), if not, wheat could germinate and grow better than corn. In the maize planting zones of Northeast China, the adaptive management method is to delay the planting time until the temperature and water condition improves to avoid loses of maize production.

2 INTRODUCTION

In recently 10 years, extreme weather problems happens frenquently due to global climate change. The high temperatures (Egli *et al*., 2005), freezing (Woltz *et al*., 2006) and other environmental factors have affected crops germination and filling immensely. There is an increasing trend in the low temperature both extremely and minimally, especially in winter of northern China in the past 40-50 years (Zhai *et al*., 1999). Northeast of China is one of the important districts for growing crops and for maintaining food security. However, it also belongs to the zone which is affected by global climate change significantly (Zhao *et al*., 2008). Water and temperature are two main effective factors for crops growing and development. The cold stress caused by low temperature in northern China causes loss of corn production by 20% (Ma *et al*., 2003). Therefore it is becoming one of the biggest areas with fluctuated crop production per unit area, being one of the main crops production districts (Cheng and Zhang, 2005). Many researches focused on single stress of low temperature and drought on plants physiological-biochemical characteristic, such as areca-nut (Wu *et al*., 2007), coix seed (Dong, 2011), and coffee (DaMatta and Ramalho 2006). These plants increased the plasma membrane permeability, malondialdehyde and proline content, SOD enzymatic activity inordinately. There were also two different results about plant responses to the cross stress of drought and low temperature. One point is that one stress would improve the resistance of plant to another stress. Wheat seedlings had a cross-adaptation to combined stresses of drought and low temperature (Ungar, 1996) by enhancing the protective enzyme activity and antioxidant contents, membrane permeability, based on reactive oxygen scavenge system function of wheat seedlings. Hay *et al*. also indicated that the most important factor of promoting *Potamogeton* species germination was cold stratification prior to placing at the germination temperature (Hay *et al*., 2008). The damage of low temperature on photosynthetic apparatus, cell membrane and cell structural of cucumber seedlings could be alleviate by PEG drought stress, and drought stress improved cucumber adaptation to low temperature (Prasad 1997; Sun *et al*., 2012). Another adverse point is that the cross effects of two different stresses on plants are more serious. The single stress of moderate low temperature or light drought would promote root growth of tomato seedlings. However the interactive stress led to a decrease of root growth index (Khan and Ungar, 1997). The growth adaptation of crops to the outside environments varied with the development period. Germination was the initial stage in the life cycle of plants, which was also the most crucial and sensitive stage responding to environments. Successful establishment of plants depended on their germination quality (Ma *et al*., 2008; Egli *et al*., 2005). Seedlings growth after germination was another important stage for life cycle of plants, which would affect the size, development and genetic variation ability of plant population (Woltz *et al*., 2003). Wheat and corn, as the two main crops in dry farmland in northeast of China, were chosen to study the single and combined stresses effects of low temperature and drought (which maybe happening in the spring of Northeast of China) on their germination characteristic and seedlings growth, and to explore their response and adaptation ability. This study hypothesized that (1) the cross stresses of drought and low temperature would sharpen the damage effects on crops germination and early seedlings growth; (2) the germination and early seedlings growth of corn under single or combined stresses of low temperature and drought, would be better than that of wheat, because the corn seeds are bigger than wheat seeds. The results could be used as scientific basis for coping with global climate change, maintaining food production and managing agricultural production.

3 MATERIALS AND METHODS

3.1 Materials: The plants seeds, wheat (*Triticum aestivum*) cv. Jimai 3 and maize cv. Liangyu, were used as the experimental materials in 2012. They were obtained from seed distribution station of Jilin Agriculture University. One hundred (100) wheat seeds or maize seeds were collected separately and weighed with a balance, then recorded the weight. The thousand weights were calculated with ten of hundred weights.

3.2 Germination experiments: Seeds were surface sterilized in 0.58% sodium hypochlorite solution for 1 min, subsequently washed with distilled water and air-dried before being used in the germination experiments to avoid fungus attack. Petri dishes (90 mm) containing two disks of Whatman No.1 filter papers with 5 mL (50 seeds of wheat) or 10 mL (20 seeds of maize) of different PEG solution were prepared. The PEG volume was depended on the weight of seeds. Germination experiments were conducted in incubators set at 10°C, 15°C, 20°C, and 25°C. Seeds were germinated in distilled water (0), and 5%, 10%, 15%, 20%, and 30% PEG solutions under these temperatures. A completely randomized design and 4 replicates of each treatment were used in plant growth chambers under 16:8 h light and dark conditions with 12000 LUX. The germinated seeds were counted by emerging radicle elongating to 2 mm during 7 days of germination. Distilled water was added to each Petri dish every day to maintain PEG concentration near the garget levels throughout the germination period.

3.3 Germination percentage and seedlings growth determination: The germination percentage was estimated by germinated seeds/total germinated seeds at the end of germination. All seeds that did not germinate under the lowest temperature (10°C) after 7 days at different PEG treatments, were placed in new Petri dishes with filter paper moistened with the corresponding PEG solution, and incubated under 25°C for additional 7 days to study the recovery of germination.

The recovery percentage was $a/b \times 100$,

Where

a is the total number of seeds germinated both under 10°C and 25°C, b is the total number of seeds. At 7th day of germination, the root and shoot were sampled to determine the length and dry biomass. Then root/shoot was calculated.

3.4 Statistical analysis: SPSS statistics for Windows (version 13.0) were used to analyses data. A two-way analysis of variance (ANOVA) was carried out to test effects of main factors (temperature and drought) and their interaction on the germination percentage and seedlings growth. LSD test was used to estimate least significant range between means.

4 RESULTS

4.1 Thousand Weight: Both wheat and corn were gramineous plants; their thousand seed weight was about 180 g and 30 g, respectively.

4.2 Germination percentage: The germination was affected by crop types, temperature and drought significantly, including single and combined stresses (Table 1, $P<0.05$). When temperature were between 15°C and 25°C, germination percentage of wheat seedlings had no significant change (63.33-87.33%) with the increasing PEG concentration from 0-20%, but they nearly could not germinate at 30% PEG level (0-18%). When temperature was 10°C, germination percentage of wheat seedlings reduced significantly with increasing PEG level (0%-64.67%). The highest germination of wheat was 87% at 0 PEG level when temperature was 25°C, the lowest was 0 at 30% PEG level when temperature was 10°C or 15°C. The germination of maize seedlings decreased significantly (2.22-100%) with the increasing PEG level when growth temperature was between 15 °C and 25 °C, but they could not germinate at 10 °C even at 0 PEG level. The highest germination of corn was 100% at 0 PEG level when temperature was 25°C , and the lowest was 0 at 30% PEG level when temperature was between 15°C and 25°C, or 0-30% PEG levels at 10 °C. The un-germinated seeds at 10 °C could re-germinate at 25 °C, which was 22.67-70.67% of wheat and 0-97.78% of corn, respectively (Figure 1).

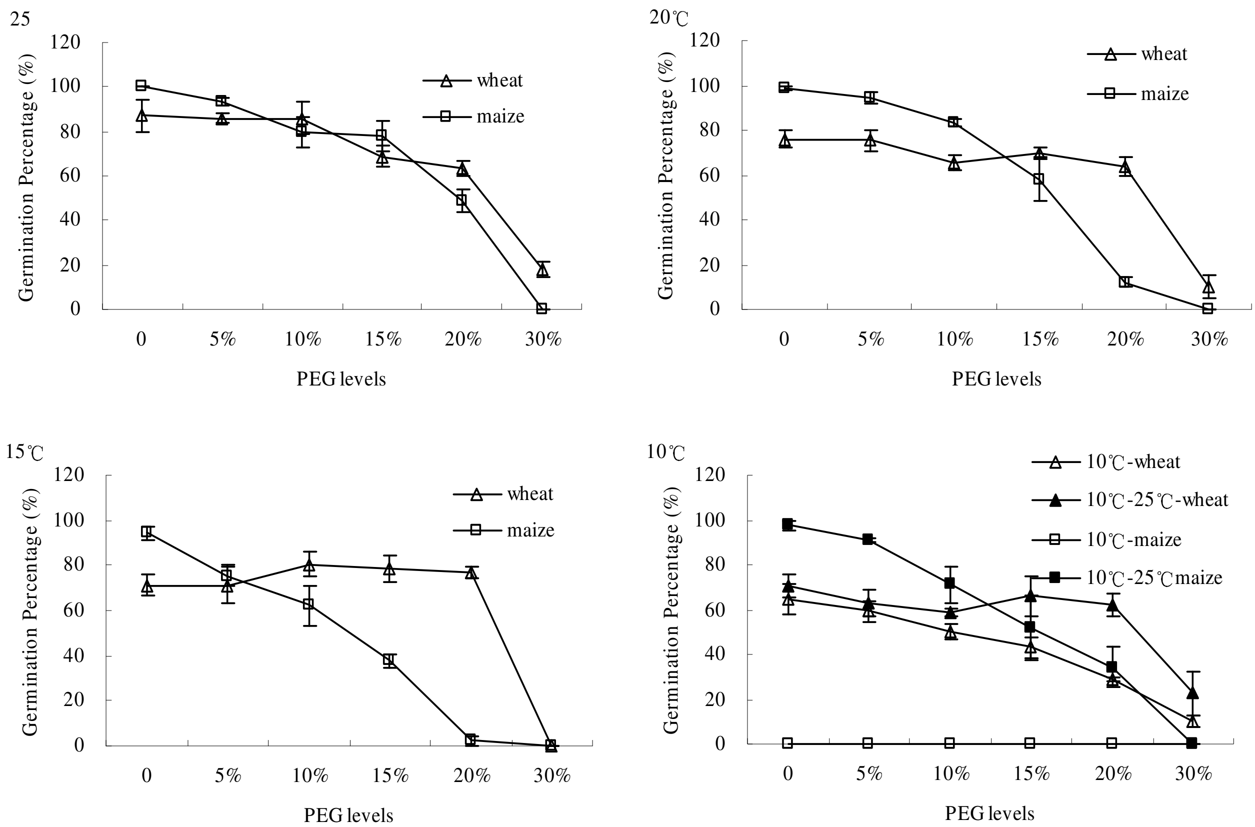

Fig. 1: Low temperature and drought condition effects on germination percentage of wheat and maize.

Comparing the germination characteristic of wheat and maize seeds, germination percentage of wheat was lower than that of maize when temperature was 25 and 20 °C under 10% PEG level. When the PEG level was higher than 20% or 15%, germination of wheat was higher than that of maize. When the temperature was as low as 15 and 10 °C and drought was over 5%, wheat seeds was also higher than maize at germination.

4.3 Seedlings Growth: Early seedlings growth was also affected by single and combined effects of crop types, temperature and drought significantly, including length and weight of shoot and root (Table 2, $P<0.05$).

Table 2: The significance analysis of main factors and their interaction on seedlings length and biomass of wheat and maize

Index	Crop types	Temperatures	Drought	C×T	C×D	T×D	C×T×D
Df	1	3	5	3	5	15	15
Root length	166.56***	307.44***	159.58***	49.15***	13.02***	22.51***	6.26***
Shoot length	758.90***	217.92***	126.90***	109.42***	49.92***	18.51***	9.84***
Shoot biomass	16.08***	1272.67***	632.78***	324.37***	84.33***	134.59***	74.76***
Root biomass	840.81***	561.43***	361.02***	6363.23***	177.67***	64.75***	51.48***
Root/shoot	73.88***	50.11***	25.36***	21.26***	13.56***	9.66***	7.13***

*** means significant difference at $p<0.001$.

Wheat seeds could germinate under 10 °C or 30% PEG level, but they could not grow as a healthy seedling. So, the length and biomass value of these treatments, were 0. Wheat seedlings length increased first and then decreased with the biggest value at 10% PEG level with the increasing PEG levels, when they grew at 25 °C and 20 °C. However, the shoots length of wheat reduced significantly. With the decreasing temperature, the shoot and root length of wheat seedlings all increased first then decreased with the biggest value at 20 °C, when drought stress intensity was lower than or equal to 15% PEG level, and they decreased straightly at 20% PEG level significantly. Different from that of wheat seeds, both shoot and root of maize seeds decreased markedly with the increasing PEG levels and decreasing temperature. Shoot and root biomass of wheat seedlings did not change significantly under 15 °C, 20 °C and 25 °C when the PEG level was lower than 15%, but decreased when at 20%. Wheat root biomass had a similar tendency of root length, which was increased first then decreased. Biomass of maize seedlings decreased with the increasing drought stress and decreasing temperature.

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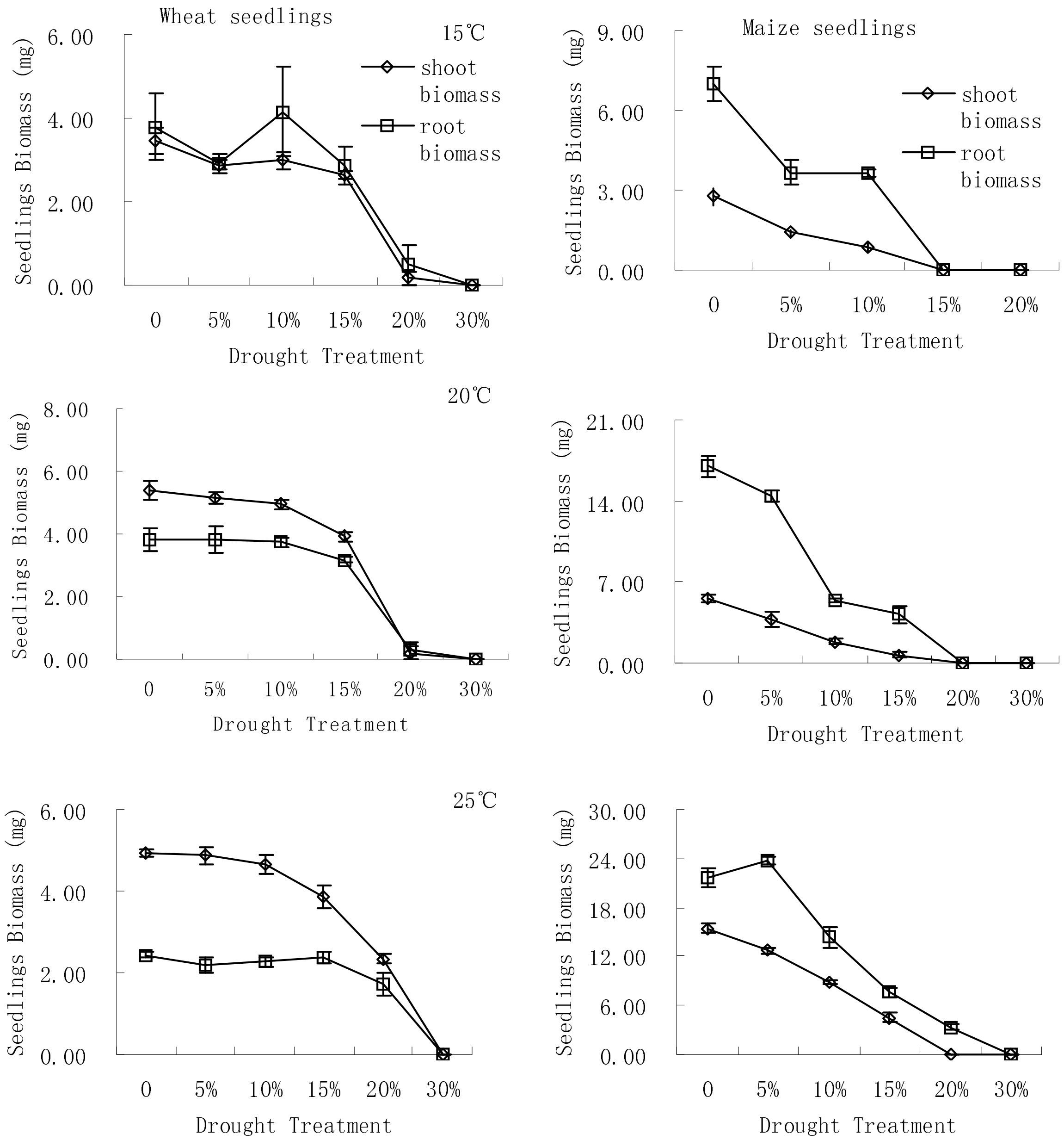

Fig. 2: Low temperature and drought condition effects on seedlings biomass of wheat and maize.

4.4 Root/shoot: There was no significant difference of root/shoot when PEG levels were lower than 15%, but they increased with the decreasing temperature in wheat seedlings. This result also support that wheat had activity to resistant low temperature and drought stress by extend root. There was no regular change of maize seedlings root/shoot under different temperature and drought stress. There was no change happening under 25 °C when the PEG level was lower than 15%. Although root/shoot of maize seedlings increased with the drought stress, they were not significant under 15 °C and 20 °C.

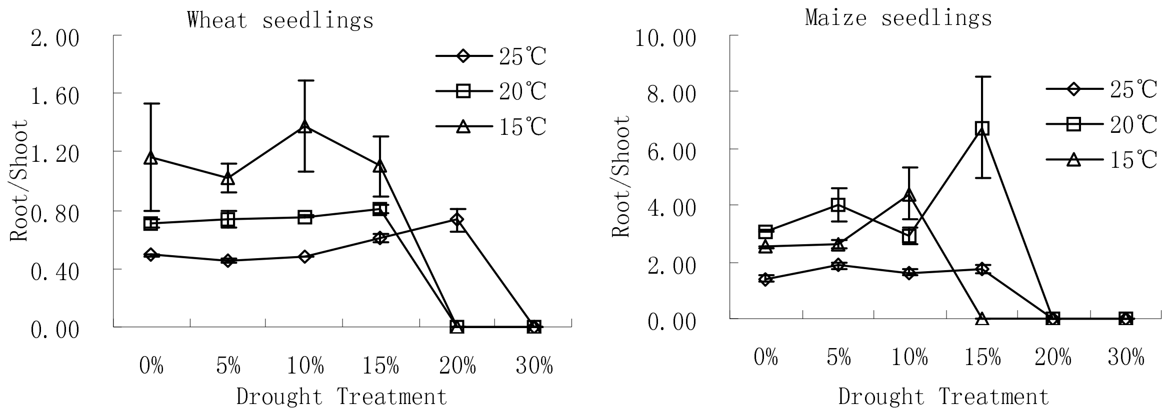

Fig.3: Low temperature and drought condition effects on root/shoots of wheat and maize

5 DISCUSSION

5.1 The cross stresses effects on crops' germination and seedlings growth: Both low temperature and drought and their interaction decreased the germination of wheat and corns. Low temperature or drought could enhance the damage on the crops. And both wheat and maize seeds could germinate effectively after removing the stress conditions. Low temperature did not destroy their seeds germination ability. Low temperature inhibited the germination process of two kinds of seeds significantly. The un-germinated wheat seeds at 10 °C could re-germinate at 25 °C (Figure 1), after the removal of low temperature stress, which final germination was improved from 0-64.67% to 22.67-70.67%. The germination of corn was increased from 0 to 0-97.78%. Just like *Lasia spinosa*, which final germination increased from 0 to 78% when they were transferred to 25 °C from 10 °C (where none of the seeds germinated) (Tang and Long, 2008). It showed that the two crops seeds still keep activity under low temperature, which only prolonged the germination time. If there was a cold temperature in spring, the crops seeds would go on to germinate after the cold temperature was over.

Low temperature and drought inhibited the growth of plants seedlings, and they changed the physiological characteristic in plants. Such as, they inhibited the growth of oil palm seedlings, and oil palm possibly showed different response mechanisms under low temperature and drought stress (Cao *et al*., 2011). Wheat seedlings length increased first and then decreased with the highest value at 10% PEG level and 20 °C, especially the root. The result indicated that moderate temperature and drought stress could promote wheat growth effectively. Increased shoot and root length and stable root biomass under low temperature and drought stress was the growth adaptation of wheat to both stresses (Table 3; Figure 2). Wheat root played an important role in resistant to drought stress and low temperature, they will get much more water by extend root and get more photosynthetic energy by extend shoot length. Maize seedlings had weaker resistance to low temperature and drought relative to wheat.

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Table 3: Seedlings length of wheat and maize under different temperature and drought conditions

Index	Temperature (°C)	Drought Treatment 0	5%	10%	15%	20%	30%
Wheat							
Root length (cm)	25	5.23±2.03	6.08±0.80	7.19±0.66	5.93±0.56	3.51±0.42	0
	20	9.72±0.84	9.56±1.1	9.84±2.92	6.60±0.31	2.89±0.24	0
	15	6.01±0.84	5.51±0.11	5.28±0.95	4.56±0.70	1.89±0.17	0
	10	0	0	0	0	0	0
Shoot length (cm)	25	6.89±0.63	6.46±0.21	6.04±0.24	4.67±0.12	2.62±0.19	0
	20	8.14±0.23	7.98±0.39	8.12±3.55	5.01±0.38	1.26±0.19	0
	15	5.05±0.35	4.19±0.30	3.22±0.60	2.76±0.32	0.71±0.07	0
	10	0	0	0	0	0	0
Maize							
Root length (cm)	25	8.12±2.11	7.15±1.19	5.96±0.45	3.56±0.31	1.47±0.31	0
	20	6.66±0.61	4.73±0.97	3.03±0.39	2.02±0.22	0.82±0.47	0
	15	3.00±0.33	2.18±0.23	1.68±0.09	1.01±0.17	0	0
	10	0	0	0	0	0	0
Shoot length (cm)	25	3.14±0.46	2.66±0.27	1.6±0.19	0.77±0.08	0	0
	20	1.35±0.11	0.88±0.25	0.43±0.13	0	0	0
	15	0.62±0.06	0.45±0.09	0.17±0.04	0	0	0
	10	0	0	0	0	0	0

5.2 The difference of wheat and corn adapted to drought and low temperature: Although there was no corresponding research conclusion about the germination and seedlings growth comparison among different seeds sizes of crops varieties, articles about seed size or seed mass effects on the seedlings performance and establishment in the same varieties had been reported (Du and Huang, 2008; Blade and Vallejo, 2008; Willenborg *et al.*, 2005). Seed germination and total, shoot and root biomasses of seedlings were significantly and positively affected by seed size in *Euterpe edulis* (Pizo *et al.*, 2006). Small seed such as wheat had more resistance to low temperature and drought than big seed like maize. Wheat seeds ensured higher germination percentage from 10 °C to 25 °C (60-90%) (Figure 1). However maize could not germinate until it was over 10 °C. The results indicated that the resistance of wheat to low temperature and drought was higher than maize. If the temperature and water condition was good (temperature was between 20 to 25 °C; water condition was lower than PEG 5%), it would be suitable for maize growth. The climate in northeast of China was always good, it was the reason why maize was planted in large areas and with high productivity. This high yield has reduced significantly once the temperature and water condition changed, due to simultaneous drought and low temperature. Therefore, the manager in maize planting zones of Northeast China needs to delay the planting time of maize until the temperature improves and water condition changes. However, the resistance of wheat seeds to cold and drought was better than maize. The ability of plants to resist drought and cold was related to the seed size. The big size seeds could absorb enough water to help germinate and grow at moderate temperature and water condition. When they were under low temperature and drought condition, the big seed need more water and temperature to help germination, but this is not available under the severe growth condition. In contrast, wheat seeds were smaller size and low weights, need less temperature and water for proper germination.

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