Analyzing Thermal Infrared Image Characteristics of Maize Seedling Stage

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Abstract. The temperature of crop leaf is closely related to leaf respiration, transpiration and its drought resistance. The rapid measurement of crop temperature is of great significance for breeding and agricultural cultivation management. The traditional infrared thermometer can only obtain the single point temperature. In this study, a high sensitive thermal infrared imager was used for recording the leaf temperature distribution of maize seedling stage. The temperature distribution of 5 different drought resistance varieties of maize in both normal water and drought stress treatment were analyzed. It turned out that there were obvious differences in temperature for different leaf position. The average temperature in the middle part of the leaf is 0.94℃ higher than the leaf apex and 0.81℃ higher than the leaf base. The results also showed that the leaf temperature is higher than that of the stem. And the average temperature of the whole blade is 24.07℃, which is higher than the background soil temperature (19.53℃). For the same maize variety, the leaf temperature of drought stress treatment is higher than that of normal water treatment. It was also found that the temperature of maize with good drought resistance is higher than that of the bad one, furthermore, the better the higher. The results above showed that the characteristics of temperature distribution in crops could be effectively obtained by using thermal infrared images, which also provided potential for the rapid identification of crop drought resistance.

Keywords: thermal infrared imaging, temperature, corn, drought resistance, image processing.

1 Introduction

Global warming has given rise to increasingly pressing drought. In China, the arid and semi-arid regions account for 52.5% of the land area, seriously affecting the development of agriculture [1]. From 1950 to 2007, the drought-led average annual losses of grains in China reached 15.8 billion kg, making up for over 60% of all natural disasters [2]. The growth of maize is threatened by the severe drought. For transpiration, leaf blades of plants control the inflow and effusion of moisture by controlling the size

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of stomata. Changes in transpiration intensity determine the heat loss degree on the blade surface, thus leading to the changes of blade temperature [3]. Under normal circumstances, the blade temperature of plants maintains a relatively stable state through dehydration from transpiration. Under external stress like drought, the variation of blade temperature can be used to detect the stress conditions of plants [4].

The traditional temperature measurements are mainly carried out by the infrared thermometer. But this approach can only realize spot measurement rather than the assay on temperature distribution of a specific area. The increasingly sensitive infrared imaging system provides feasibility for the studies on blade stomata changes through the observation of surface temperature variation of blades [5]. The principle of the thermal infrared imaging technology is as follows: different absorption and reflection of various substances exposed under rays with different wavelengths can be reflected on temperature variation. This property can be used in the detection of temperature variation of maize blade. Compared with conventional ways, it presented advantages of speedy, efficient and convenient operation. Stomatal conductance from the thermal imaging measurement update showed satisfying correlation with that from conventional porometer [6]. By changing the intensity of the irrigation, times of crop temperature variation can be counted. The infrared thermal imaging can be used to assay the stomatal conductance of crops [7].

In China, scholars like Liu found that when under the threats of drought, temperature variation of blades can effectively reflect the drought resistance of maize in the seedling stage. The blade temperature difference can be used as the preliminary indicator of the screening of drought resistance [8-9]; canopy temperature showed great correlation with leaf water potential of rice, setting percentage and biomass. Higher temperature leads to smaller indicator. Jones conducted remote sensing study on the infrared thermal imaging of crop canopy, so as to quantitatively analyze the reactions of crops on water stress [10]. Sirault applied infrared thermal imaging to quantitatively analyze the permeability of wheat and barley under the salt stress [11]. Qiu introduced a reference dry blade (without transpiration), and applied the plant transpiration conversion coefficient to assay the environmental stress around watermelon, tomato and lettuce and other plants, including conditions of hydropenia and high temperature [12]. Takai discovered that the canopy temperature difference between sunny days and cloudy days can be used to estimate the subtle changes in stomatal conductance of rice [13].

Studies at home and abroad achieved fruitful findings in the research of crop temperature. The contrastive analysis in the above studies was conducted based on leaf temperature and the conventional drought resistance parameters. In this study, blade temperature distribution characteristics of maize canopy were analyzed based on thermal infrared image to study on the temperature distribution characteristics at different leaf positions of different blades. In addition, different drought-resistant maize species were processed with water treatment to analyze the temperature variation of plants after the treatment of drought stress and to explore into the relationship between thermal infrared image characteristics of seedling stage and maize drought resistance.

2 Experiments and Methods

2.1 Experimental Material

Five maize species suitable for cultivation in the north were selected, namely, Kuancheng 60(KC 60), Jingdan 68(JD 68), Jingke 528(JK 528), Dantiannuo No.3(DTN 3) and Yinnuo No.1(YN 1). With the query of species description from breeding units and breeding experts, the features of species were shown in Table 1.

Table 1. Information of different maize species

Species	Drought resistance	Breeding Places
KC 60	Good	Kuancheng Seed Co., Ltd, Hebei Province
JD 68	Good	Maize Research Center, Beijing Academy of Agriculture and Forestry Sciences
JK 528	Good	Maize Research Center, Beijing Academy of Agriculture and Forestry Sciences
DTN 3	Poor	Horticulture Institute, Dandong Academy of Agricultural Sciences
YN 1	Poor	Key Laboratory of Beijing Municipal Agricultural Application Technologies

2.2 Experimental Design and Plantation Management

The experiment was conducted in the solar greenhouse of Beijing Academy of Agriculture and Forestry. Flower pots with the aperture diameter of 25cm and depth of 15cm were selected, which were filled with 5kg of soils from fields. Quality corn seeds were selected and sowed in one cavity per pot with two seeds in one cavity. Each species was sowed for 10 pots so it was 50 pots. 2.0g of compound fertilizer carbonate diamine was applied. To the seedling stage, the final singling of seedlings with consistent growth length was made as 1 plant per pot. After sowing, timely ventilation, illumination, watering and fertilization were conducted according to the greenhouse maize management.

A control group was set in the experiment. In the early seedling stage (15 days after sowing, with the twin leaves), drought stress was conducted. 5 pots of each species of maize seedlings stopped watering, taken as the experiment group. The other 5 pots were watered regularly as the control group.

2.3 Infrared Image Acquisition

The experimental image acquisition device uses a high-resolution portable infrared thermal imaging instrument (VarioCam). The detector type: UFPA; Spectral range: 7.5 to 14μm; thermal sensitivity: at 30℃, the thermal sensitivity < 0.065℃; Frame frequency: 50/60Hz; infrared image: 384x288 pixels.

20d after sowing, we started the image acquisition. Acquisition time: 8:00am and 14:30pm in sunny days were selected until maize plants died under drought stress. When photographing, the thermal infrared imager was placed on the top of maize plants, keeping the lens perpendicular to the ground (about 0.5 to 0.8m from the top). The focal length and camera lens position was adjusted so that the canopy image can be clear and recognized. Thermal infrared images of all plants were taken, coded and preserved.

In the experiment, 5 infrared images were collected on October 17, 19, 23, 25 and 31, 2012. The weather during the experiment was sunny with the temperature varying from 28 to 33℃.

2.4 Infrared Image Processing

The original image acquired by the infrared camera was. IRB file, and different colors in the image represented different pixel values. Pixels of different colors show different temperature values. At 8: 00 a.m., as the plant leaves went through no illumination at low temperatures overnight, the plant temperature was almost consistent, no showing distinct differences. Hence, the infrared image taken in the afternoon was selected for analysis.

The IRBIS image processing software was used. First, the target image was opened on IRBIS 3. Color distribution of the image was adjusted through the scale calibration plate, so that the maize in the image was obviously separated from objects in the background to facilitate the processing. According to different shapes of blades, oval, round, or self-crossed circle was selected under the measurement label to circle the specific area of the leaves or stems. The maximum, minimum and average temperature in the circled region was read so as to obtain the temperature information of different blades at different leaf positions. The extracted temperature information was then recorded in the table.

3 Results and Discussion

3.1 Temperature Distribution Characteristics of Maize at the Seedling Stage

Seedling stage of maize refers to the stage from germinating to elongation. The seedling stage of maize is a crucial stage for the differentiation and growth of roots, stems, leaves and other vegetative organs and the differentiation of tassels. In this stage, less moisture was needed. Yet, water stress would lead to poor seedling development, influencing the later nutrition absorption and reproductive growth, and eventually reducing the production [14]. Thus, it can be seen that some characters of the maize at the seedling stage were closely related with the drought resistance of maize. In this study, the temperature distribution characteristics of maize canopy were studied and the relationship between thermal infrared image characteristics at the seedling stage and drought resistance of maize was discussed.

Infrared images acquired at 2:30 p.m. on October 31, 2012 were selected. Fig. 1 shows the thermal infrared image of a maize plant at the seedling stage. Three blades of the leaf canopy were analyzed with the measurement function of the software. In this study, we measured the temperature of leaf opex, leaf center and leaf base, with the data unit of ℃ and the precision of 0.01℃. The right side of the figure shows the scale plate. Different colors show the corresponding temperature range. Before each measurement, the scale plate was adjusted so that the blade color can be easily distinguished compared with the color of background objects so that the measurement region can be found precisely.

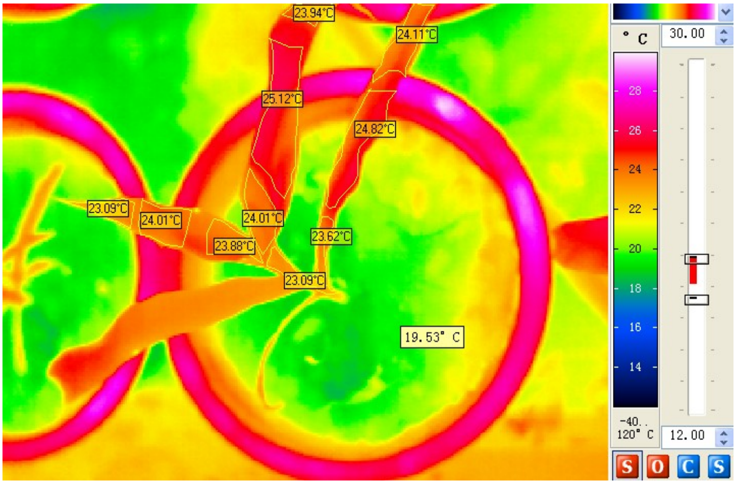


Fig. 1. Infrared Image Processing of Maize at the Seedling Stage

As shown in Fig.1, the average temperature of three blades at different leaf positions was recorded in Table 1. It should be noted while circling that the circled area should be smaller than leaves so as to ensure that the circled areas were a part of the leaves. The average blade temperature was measured. Each small area was formed by several pixels. The size of circled area will influence the second digit of the temperature while the accuracy has met the requirements.

Table 2. Average Temperature of Different Blades at Different Blade Positions

Average Temp. (℃)	leaf opex	leaf center	leaf base
Blade 1	23.09	24.01	23.88
Blade 2	23.94	25.12	24.01
Blade 3	24.11	24.82	23.62
Average Temp.	23.71	24.65	23.84
Soil Temp.		19.53	
Stalk Temp.		23.09	

As can be seen from Table 2, for the temperature of each maize leaf, leaf center > leaf base > leaf opex. The average temperature of leaf center was higher than that of leaf opex by 0.94℃, while that of leaf center was higher than that of leaf base by 0.81℃. The plant temperature was much higher than soils in the pot (19.53℃). The stem temperature (23.09℃) was lower than leaves.

Transpiration and respiration affect the airflow and water flow in the leaves of plants. For moisture, with temperature variation, plants will carry out according self-regulation to offset the impact from water stress, and to adapt to the environment change so as to maintain the development and growth. The changes were reflected on the temperature variation of plant leaves. In this experiment, it was found that the temperature at different leaf positions in the maize canopy at the seedling stage showed the following regularities: leaf opex < leaf base < leaf center (as shown in Table 2). In the normal growth, the leaf shape of maize was arched, and the middle of the leaf was facing the sun, receiving most of the sun irradiation and high temperature; two ends of leaves received less sun irradiation and temperature. With the control over the open and closure of stomata, plants can control the moisture diffusion, thus enlarging the biomass of plants. The mechanism stems from the plant adaptation to drought, which is conducive to maintaining the normal growth and metabolism of plants.

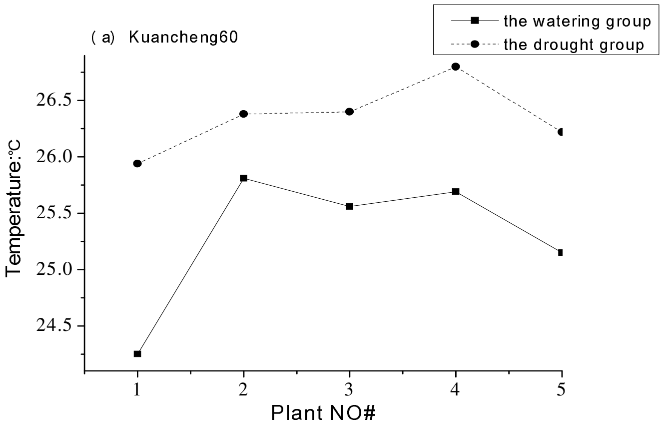
3.2 The Maize Temperature Difference between the Watering Group and the Drought Stress Group

Infrared images acquired at 2:30 p.m. on October 31, 2012 were selected, when the leaves under the drought stress showed wilting. In image processing, the self-crossed way was used to circle the canopy leaves of various species in two groups. The average temperature of leaves was recorded in the following table.

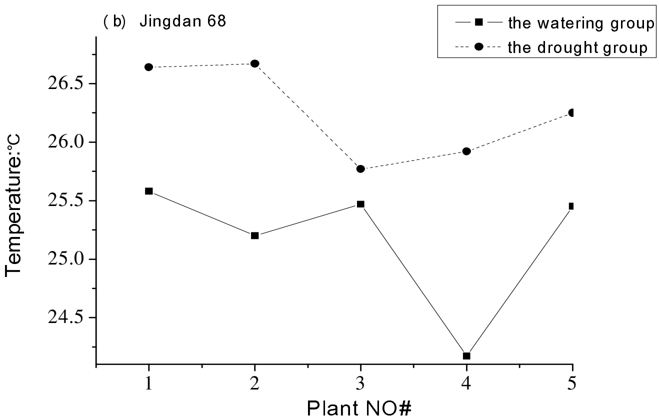
Table 3. Average temperature in the watering group and the drought group

Species	Group	1	2	3	4	5	Avera
KC 60	the watering	24.25	25.81	25.56	25.69	25.15	25.292
	the drought	25.94	26.38	26.40	26.80	26.22	26.348
JD 68	the watering	25.58	25.20	25.47	24.17	25.45	25.174
	the drought	26.64	26.67	25.77	25.92	26.25	26.25
JK 528	the watering	25.19	25.34	24.96	24.82	24.68	24.998
	the drought	26.51	25.47	25.41	25.34	25.08	25.562
DTN 3	the watering	25.52	25.28	24.82	25.28	24.72	25.124
	the drought	25.80	25.34	25.35	25.03	25.13	25.33
YN 1	the watering	24.84	24.89	24.73	24.96	24.10	24.704
	the drought	24.58	25.62	24.32	24.65	24.17	24.668

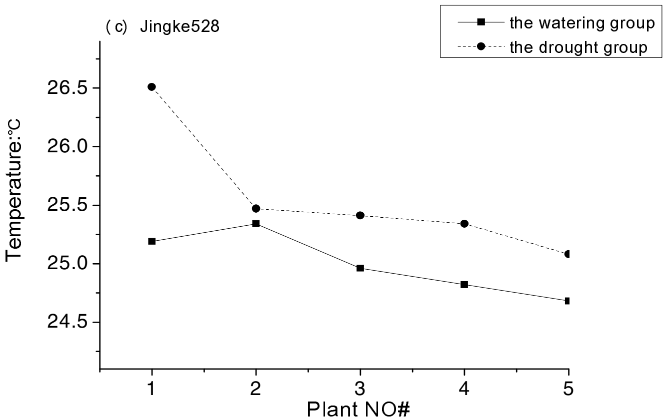
To better demonstrate the temperature differences, the table was showed in the following curve graph:



(a) Kuancheng60 Temperature

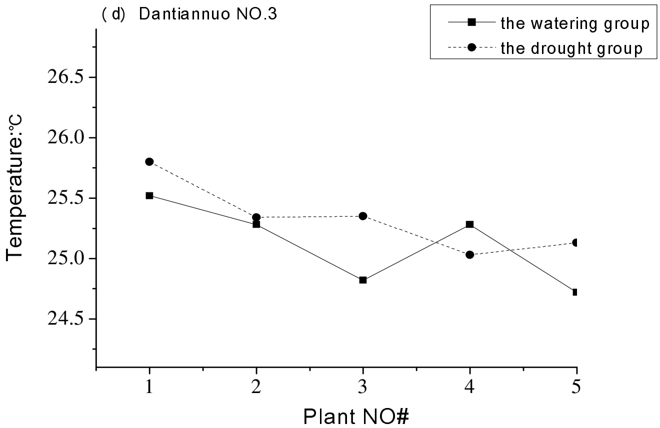


(b) Jingdan68 Temperature

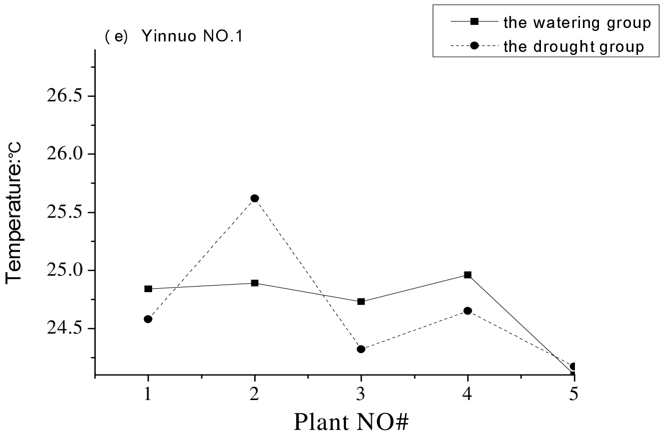


(c) Jingke528 Temperature

Fig. 2. Temperature Comparison between the Watering Group and the Drought Group



(d) Diantiannuo NO.3 Temperature



(e) Yinnuo NO.1 Temperature

Fig. 2. (*Continued.*)

It can be seen from the above figures that at the seedling stage of the five maize varieties, the average temperature of canopy leaf under drought stress (25.63℃) was higher than that in the watering group (25.06℃).

Under drought stress, the composition and structure of the plant plasma membrane has undergone significant changes. The cell membrane permeability was damaged so that cells cannot be divided and grow. In addition, stomata on the surface were closed, which influenced photosynthesis, the normal growth and development of plants and eventually lower yields [15].

In the experiment, two groups of water treatment were set for the simulation of the arid geographical environment in the north of China. 10 pots of each species were planted. Five pots were not watered under drought stress and the rest were watered. After that, infrared images were acquired, coded and preserved. The images were processed and the average temperature of canopy leaf was extracted. As shown in Fig. 2 that for different maize species at the seedling stage, the blade temperature in the drought group was higher than that of the watering group. Under drought stress, plans will resist drought stress within a certain range through a series of measures, mainly including stomatal regulation, osmotic adjustment, reactive oxygen removal, the protective effect of specific molecules and plant hormones regulation etc. 15. The direct reaction of plants to drought signal is to adjust the size of the stomatal aperture so as to prevent water loss. Under regular watering, maize stomata will be at the on-state and the water loss maintains the status quo. Under the drought stress, the water loss was much less compared with that with regular watering. Meanwhile, water loss will reduce the heat of leaves and lower the temperature. That is, the thermal loss under the drought stress was less than that under the watering. Hence, the blade temperature under the drought stress was lower than that in the watering group.

3.3 Temperature Difference between Drought-Resistant Plants and Non-drought Resisting Plants under the Normal Condition of Watering

Infrared images acquired at 2:30 p.m. on October 31, 2012 were selected, and temperature of plants in the watering group was extracted as the following table 4.

Table 4. Average temperature of canopy leaf of different varieties at seedling stage in the watering group

Species\Temp.	1	2	3	4	5	Aver Temp.
KC 60	26.33	27.49	27.60	27.62	27.76	27.36
JD 68	26.73	27.25	27.12	27.40	27.30	27.16
JK 528	27.02	26.88	26.57	26.98	27.06	26.902
DTN 3	26.86	26.24	26.37	26.63	26.30	26.48
YN 1	26.50	26.35	26.32	26.42	25.64	26.246

To better demonstrate the temperature differences, the table was showed in Fig.3.

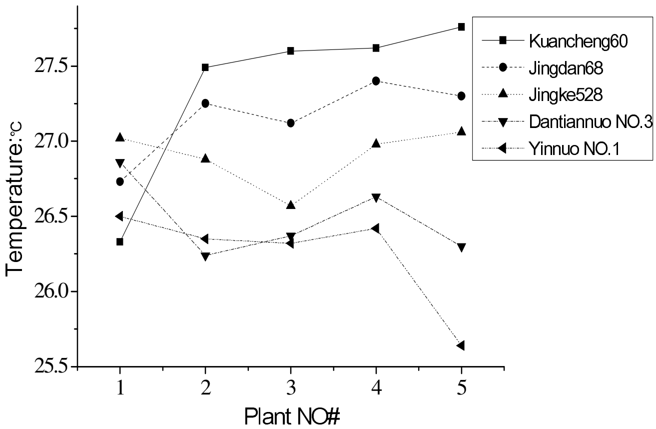


Fig. 3. The graph of the temperature in the watering group

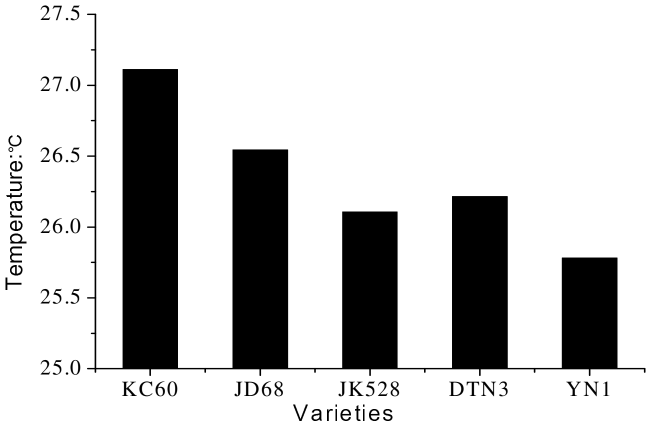


Fig. 4. Bar graph of average temperature in the watering group

From the above chart, in the watering group, plants with good drought resistance had higher blade temperature than those with poor drought resistance. The better the drought resistance, the higher the temperature of blades will be given the normal conditions.

3.4 Temperature Difference between Drought-Resistant Plants and Non-drought Resisting Plants under the Drought Stress

Infrared images acquired at 2:30 p.m. on October 31, 2012 were selected, and temperature of plants in the drought group was extracted as the following table 5.

Table 5. Average temperature of canopy leaf of different species at seedling stage in the drought group

Species \ Temp.	1	2	3	4	5	Aver Temp.
KC 60	27.51	27.69	27.01	27.04	26.31	27.112
JD 68	27.68	26.60	26.19	26.29	25.97	26.546
JK 528	27.09	26.24	25.91	25.90	25.39	26.106
DTN 3	26.70	26.36	26.21	26.22	25.59	26.216
YN 1	25.91	25.88	25.95	25.47	25.70	25.782

To better demonstrate the temperature differences, the table was showed in Fig.6.

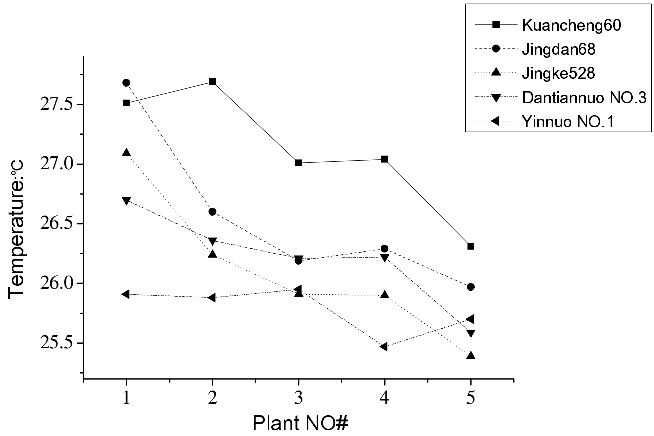


Fig. 5. The graph of the temperature in the drought group

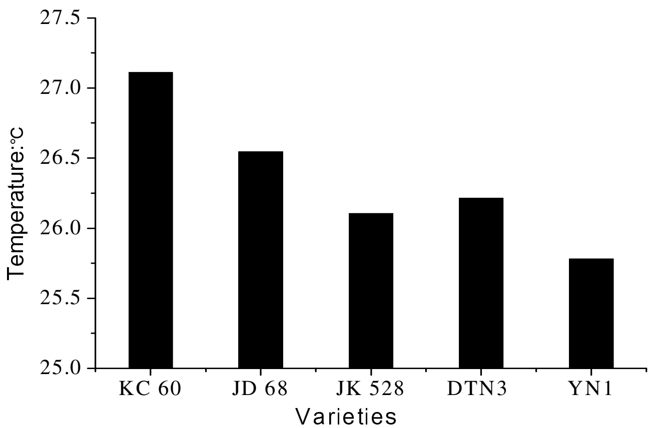


Fig. 6. Bar graph of average temperature in the drought group

From the above chart, in the drought group, plants with good drought resistance had higher blade temperature than those with poor drought resistance. The better the drought resistance, the higher the temperature of blades will be given the normal conditions.

Drought is the main limiting factor in maize growth. Different maize species present different reactions under water stress [16-20]. In this experiment, five maize species suitable for cultivation in the north were selected, and infrared images of plants of different species at the seedling stagewere acquired. As can be seen from Figure 4, in the watering group, plants with good drought resistance had higher blade temperature than those with poor drought resistance, that is, Kuancheng 60＞Jingdan 68＞Jingke 528＞Dantiannuo No.3＞Yinnuo No.1, which formed a positive correlation with the drought resistance; as seen from Figure 6, the positive correlation with the drought resistance was also formed under drought stress. Thus, given different water treatment, temperature of canopy blade of plants with good drought resistance was higher than that with poor drought resistance. The above analysis presented that temperature of canopy blade of plants at the seedling stage can reflect the drought resistance of plants, which was demonstrated in the different controlling capacities of plants with different drought resistance over the stomatal conductance. Plants with good drought resistance have stronger control over transpiration through stomata opening and closing. As less moisture was taken away by transpiration, the temperature was eventually elevated.

4 Conclusions

Thermal infrared images of temperature distribution of maize at the seedling stage shows distinct features. Temperature distribution characteristics of different leaf positions reflect the growth of plants, and can provide significant guidance for secondary prevention and control of diseases and pests and timely spraying fertilizer. Temperature characteristics of species with different drought resistance can be used as the preliminary identification of the drought resistance of maize at the seedling stage. Average temperature of canopy leaves can be used as a reference indictor to identify the drought resistance of maize. It is a new approach to apply thermal infrared imaging technology in the research of maize and to use digital image processing technology with the temperature as the parameter to show the maize features at the seedling stage in the breeding, screening and growth detection of plants with drought resistance.

To sum up, it is feasible to use thermal infrared imager to acquire maize image at the seedling stage and analyze distribution characteristics of blade temperature to predict the drought resistance of plants. Compared with conventional ways of detecting the plant drought resistance, this approach is fast, efficient and convenient.

This approach can analyze and evaluate the drought resistance of different maize species, thus providing a fast judgment and filtering maize species with properties of water-saving, high yield and high drought resistance. This is of great importance and meanings to alleviate the drought in the current Northern China and improve the current food and water shortage in China.

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