

Effects of High Temperature on Pakchoi Quality and Simulation Study (Postprint)

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Date: 2017-11-09T00:00:00+00:00

Abstract

To investigate the effects of high temperature stress on quality indicators of pakchoi (*Brassica rapa chinensis*), the cultivar 'Huawang' was used as experimental material. Batch sowing experiments were conducted from October 2015 to May 2016, with three gradients of day/night temperatures set at 32°C/22°C, 35°C/25°C, and 38°C/28°C, and treatment durations of 3 d, 6 d, 9 d, and 12 d, respectively, using 25°C/18°C as the control (CK). Two days after the completion of each treatment, external morphology, SPAD values, dry and fresh weights per plant, and contents of crude fiber, soluble sugars, soluble protein, and vitamin C were measured. Regression models were established between the leaf rolling rate and yield per unit area of pakchoi and the maximum temperature, minimum temperature, average temperature, and duration of treatment, and the simulation accuracy of the models was validated using measured data. The results showed that dry weight per plant, fresh weight per plant, leaf fresh weight, leaf length, leaf width, petiole width, SPAD values, and yield per unit area of pakchoi all exhibited a decreasing trend with the intensification of high temperature stress and the extension of stress duration. With increasing temperature and prolonged duration, petiole length and leaf rolling rate gradually increased. High temperature stress increased the crude fiber content of pakchoi. Under short-term high temperature stress, the contents of soluble sugars, soluble protein, and vitamin C showed no significant changes, but gradually decreased with prolonged stress duration and increased stress temperature. Using multiple regression methods, relationship models were separately constructed for the leaf rolling rate and yield per unit area of pakchoi with the maximum treatment temperature, minimum treatment temperature, average treatment temperature, and the corresponding duration of each treatment. Model validation results indicated that the model constructed for leaf rolling rate using minimum treatment temperature and duration of minimum temperature showed the best simulation performance, with a regression standard error and relative error of 7.59% and 0.1894, respectively; the model constructed for yield per unit area using max-

imum treatment temperature and duration of maximum temperature showed the best simulation performance, with a regression standard error and relative error of $274.02 \text{ g} \cdot \text{m}^{-2}$ and 0.073%, respectively. This study concluded that with intensified high temperature stress and prolonged stress duration, pakchoi yield decreased, taste quality deteriorated, and nutrient content reduced, indicating that high temperature stress degrades pakchoi quality.

Full Text

Preamble

Chinese Journal of Eco-Agriculture, Jul. 2017, 25(7): 1042-1051

DOI: 10.13930/j.cnki.cjea.161141

Effect of High-Temperature Stress on Pakchoi Quality and Its Simulation

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Abstract: To investigate the effects of high-temperature stress on greenhouse pakchoi quality and yield, a series of experiments was conducted from October 2015 to May 2016 using the ‘Huawang’ cultivar. Three daytime/nighttime temperature gradients were established ($32^{\circ}\text{C}/22^{\circ}\text{C}$, $35^{\circ}\text{C}/25^{\circ}\text{C}$, and $38^{\circ}\text{C}/28^{\circ}\text{C}$), with treatment durations of 3, 6, 9, and 12 days, using $25^{\circ}\text{C}/18^{\circ}\text{C}$ as the control (CK). Two days after each treatment, measurements were taken for plant morphology, SPAD values, individual plant fresh and dry weights, and contents of crude fiber, soluble sugar, soluble protein, and vitamin C. Regression models were developed to relate leaf curl rate and yield per unit area to maximum, minimum, and mean temperatures along with treatment duration, and these models were validated using independent experimental data.

The results demonstrated that individual plant dry weight, fresh weight, leaf fresh weight, leaf length, leaf width, petiole width, SPAD values, and yield per unit area all decreased with intensifying high-temperature stress and prolonged treatment duration. Conversely, petiole length within the leaf blade and leaf curl rate increased progressively with rising temperature and extended exposure. High-temperature stress elevated crude fiber content, while soluble sugar, soluble protein, and vitamin C contents remained relatively stable under short-term stress but declined gradually with prolonged exposure and higher temperatures.

Using multiple regression analysis, mathematical models were constructed to predict leaf curl rate and yield per unit area based on maximum treatment temperature, minimum treatment temperature, mean treatment temperature, and corresponding treatment duration. Model validation revealed that the leaf

curl rate model based on minimum temperature and its duration performed best, with a standard error of estimate of 7.59% and relative error of 0.1894. Similarly, the yield model based on maximum temperature and its duration showed optimal performance, with a standard error of 274.02 g · m² and relative error of 0.073. These findings indicate that increasing high-temperature stress intensity and duration reduce pakchoi yield, deteriorate taste, and decrease nutritional content, thereby compromising overall quality.

Keywords: High-temperature stress; Pakchoi; Quality; Growth period; Simulation model

Introduction

Pakchoi (*Brassica campestris* L. *Chinesis* L.), a member of the Brassicaceae family, is an annual or biennial herb cultivated for its green leaves. Also known as non-heading Chinese cabbage, common cabbage, or green vegetable, it originated in China and represents one of the most popular vegetables in southern China, accounting for 30–40% of total annual vegetable production in the Yangtze River Delta region. High-temperature stress constitutes the most common environmental constraint affecting pakchoi production in southern China, where summer heat causes quality deterioration, bitter taste, yellowing, and premature aging, resulting in significant yield and economic losses.

Previous research has documented similar effects in other crops. For instance, Wang et al. reported that pepper (*Capsicum annuum* L.) exposed to temperatures above 35°C exhibited faded leaf color and reduced above-ground and below-ground biomass. High temperature also affects leaf coloration, with studies showing that heat stress reduces SPAD values and relative chlorophyll content in rice (*Oryza sativa* L.) during both seedling and heading stages. High-temperature stress increases cell membrane permeability, leading to electrolyte leakage. To mitigate excessive electrolyte loss, plants adjust the types and contents of osmotic regulation substances. Soluble sugars and soluble proteins serve as important intracellular osmotic substances that accumulate under water stress conditions, altering cell sap concentration and osmotic potential.

Currently, most crop quality models are ecological prediction models developed through mathematical regression methods based on how environmental conditions affect the accumulation of internal quality indicators. Stenzel et al. simulated the accumulation of soluble sugars, organic acids, and sugar-acid ratios during citrus development to establish fruit maturity curves, with maturity predicted based on deoxyacid quality calculations. Slaughter developed non-destructive methods for assessing mango maturity through color and aroma indicators. Domestic and international researchers have made significant progress in greenhouse crop modeling, essentially creating quantitative descriptions and predictions of crop growth processes and their relationships with environmental factors, thereby enriching and advancing the field of crop modeling.

Despite these advances, few studies have specifically examined the effects of high-temperature stress on pakchoi quality or developed corresponding simulation models. This study investigates the impacts of varying high-temperature levels and durations on pakchoi yield and quality, constructs regression models relating yield per unit area and leaf curl rate to daily minimum, maximum, and mean temperatures, and compares model performance. The research defines a high-temperature stress index and classifies stress levels, providing a theoretical basis for predicting pakchoi yield and appearance quality.

1.1 Experimental Design

The experiment was conducted in June 2015 at the Nanjing University of Information Science and Technology using controlled-environment growth chambers (TPG-2009, Australian) within a Venlo-type greenhouse. Six successive planting trials were carried out using the ‘Huawang’ pakchoi cultivar. Plants were grown in nutrient pots (12 cm diameter) and subjected to treatments when they reached 8–9 true leaves. Three high-temperature treatments were established with daytime/nighttime temperatures of 32°C/22°C, 35°C/25°C, and 38°C/28°C, applied for durations of 3, 6, 9, and 12 days. Each treatment comprised 16 plants with three replicates, and all plants received normal water and fertilizer management. During the experimental period, relative humidity was maintained at 75% and photosynthetic photon flux density at $800 \text{ mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$. Control plants (CK) were maintained under optimal conditions (24°C daytime, 18°C nighttime). Two days after each treatment concluded, measurements were taken for individual plant fresh and dry weights, water content, appearance quality, and nutritional content, and leaf curl rate and yield per unit area were calculated.

1.2 Measurement Methods

1.2.1 Leaf Curl Rate Determination For each treatment, the maximum width of all leaves was measured when fully expanded and again in their natural curled state. Following Qiao et al., leaves were considered curled when the ratio of leaf width to curled leaf projection width < 1 , and the leaf curl rate was calculated accordingly.

1.2.2 SPAD Measurement Three pakchoi plants were randomly selected from each treatment, and leaf SPAD values were measured using a SPAD chlorophyll meter.

1.2.3 Leaf Morphology and Individual Plant Dry/Fresh Weight Measurement Fresh weight was determined using destructive sampling. Leaf blades were separated from petioles using a clean blade, and measurements

were taken for leaf weight, leaf length and width, petiole length and width, and petiole length within the leaf blade. Samples were then oven-dried at 105°C for 2 hours and subsequently at 80°C to constant weight for dry weight determination.

1.2.4 Yield per Unit Area Measurement Nutrient pots were arranged at a density of 5 pots per square meter. For each treatment, three random 1 m² areas were selected, and pakchoi plants were washed with distilled water, surface moisture was removed, and the mass of plants per square meter of projected area was weighed using a 0.001 g precision electronic balance to determine yield per unit area.

1.2.5 Quality Determination Three pakchoi plants were randomly selected as replicates for each treatment. Crude fiber and soluble sugar contents were determined using the anthrone colorimetric method, vitamin C content by the 2,6-dichlorophenol indophenol method, and soluble protein content by the Coomassie brilliant blue colorimetric method.

1.3 Stress Level Classification

The high-temperature stress index (IHT) was calculated based on leaf curl rate (A) and yield reduction rate (R). Stress levels were classified as: mild stress (Level I) when IHT < 3, moderate stress (Level II) when IHT = 3-6, and severe stress (Level III) when IHT > 6.

1.4 Data Processing and Statistical Analysis

Data were compiled and analyzed using Microsoft Excel 2010 and SPSS 22.0 software.

2. Results

2.1 Effects of High Temperature on Individual Plant Dry Weight, Fresh Weight, and Leaf Fresh Weight

presents changes in individual plant dry weight, fresh weight, and leaf fresh weight under different high-temperature stress treatments. Under the same treatment duration, all weight parameters in the CK treatment exceeded those in the high-temperature treatments. As temperature increased, individual plant dry weight, fresh weight, and leaf fresh weight decreased progressively, with differences from CK becoming more pronounced with longer treatment durations. At 32°C/22°C for 3 days, these parameters did not differ significantly from CK.

However, after 12 days at 38°C/28°C, individual plant dry weight, fresh weight, and leaf fresh weight decreased by 64.23%, 84.32%, and 82.89%, respectively, compared to CK.

2.2 Effects of High Temperature on Leaf Morphology

As shown in , leaf length, width, and petiole width were greatest in CK plants and decreased gradually with increasing temperature and treatment duration. The most significant effects occurred under 38°C/28°C for 12 days, with leaf length and width reduced by 50.1% and 45.8%, respectively, compared to CK. Leaf length showed greater sensitivity to high-temperature stress than other morphological traits. Petiole length began to decrease significantly after 9 days at 38°C/28°C, showing reductions of 14.6% and 30.7% at 9 and 12 days, respectively, compared to CK. After 9 days at 38°C/28°C, some leaves exhibited yellowing and even desiccation, contributing to reduced petiole length. Within the 25–35°C daytime temperature range, petiole length within the leaf blade increased with temperature and treatment duration, though it decreased by 6.58% at 38°C/28°C for 12 days compared to 35°C/25°C for 12 days.

2.3 Effects of High Temperature on Leaf Curl Rate, SPAD, and Yield per Unit Area

illustrates changes in leaf curl rate, SPAD values, and yield per unit area under different temperature treatments. Leaf curl rate increased with temperature and treatment duration, reaching 100% after 9 days at 38°C/28°C. SPAD values were consistently highest in CK and decreased with rising temperature and extended treatment, showing reductions of 19.95%, 31.09%, 40.28%, and 53.82% at 38°C/28°C after 3, 6, 9, and 12 days, respectively, compared to CK. Yield per unit area decreased progressively with higher temperatures and longer durations, with reductions of 52.31%, 68.9%, and 86.38% after 12 days at 32°C/22°C, 35°C/25°C, and 38°C/28°C, respectively, relative to CK.

2.4 Effects of High Temperature on Pakchoi Quality

shows changes in internal quality under different temperature treatments. Crude fiber content increased with both temperature and treatment duration, with CK showing the lowest values. The most significant differences occurred at 38°C/28°C, where crude fiber content increased by 14.47%, 21.51%, 22.88%, and 18.75% after 3, 6, 9, and 12 days, respectively, compared to CK.

Soluble sugar content was lowest under 38°C/28°C at all treatment durations. After 3, 6, and 9 days, soluble sugar content initially increased then decreased with rising temperature, with 38°C/28°C showing significant differences from CK (reductions of 0.16%, 7.79%, and 32.69%, respectively). After 12 days, soluble sugar content decreased consistently with temperature, showing a 61.33% reduction at 38°C/28°C compared to CK.

Vitamin C content decreased with increasing temperature, with CK maintaining the highest values across all treatment durations. Significant differences emerged after 9 and 12 days, with 38°C/28°C showing the most substantial reductions of 11.54%, 10.97%, 32.22%, and 60.84% after 3, 6, 9, and 12 days, respectively, compared to CK.

Soluble protein content showed significant responses to temperature stress. After 3 days, it increased with temperature (2.83%, 4.92%, and 5.63% higher than CK at 32°C/22°C, 35°C/25°C, and 38°C/28°C, respectively). However, after 6, 9, and 12 days, it decreased with temperature, showing reductions of 9.13%, 41.94%, and 80.52% at 38°C/28°C compared to CK.

2.5 Relationships Between Leaf Curl Rate, Yield, Temperature, and Duration

Using multiple regression analysis with data from the first three experimental batches, models were developed to predict leaf curl rate and yield per unit area based on maximum treatment temperature (T_{max}), minimum treatment temperature (T_{min}), mean treatment temperature (T_{mean}), and treatment duration (t). The remaining three batches were used for model validation to identify optimal formulations, with results presented in .

The model for leaf curl rate based on minimum temperature and its duration demonstrated the best performance, with the lowest standard error (7.59%) and relative error (0.1894). In contrast, the model using maximum temperature and its duration showed the poorest performance (standard error 9.35%, relative error 0.233), representing 1.23-fold higher errors than the optimal model. The model based on mean temperature and its duration showed intermediate performance.

For yield per unit area, the model using maximum temperature and its duration performed best (standard error 274.02 $g \cdot m^{-2}$, relative error 0.073), while the minimum temperature-based model performed poorest (standard error 438.17 $g \cdot m^{-2}$, relative error 0.1167), with errors 1.6-fold higher than the optimal model. The mean temperature-based model again showed intermediate performance.

2.6 Classification of High-Temperature Stress Levels in Pakchoi

High temperature adversely affects pakchoi quality and yield. Since leaf curl rate (A) serves as the primary indicator of appearance quality and yield reduction rate (R) reflects the severity of impact, a high-temperature stress index was defined based on these parameters to classify damage levels.

As shown in , yield reduction rate increased progressively with temperature and treatment duration. From day 9 onward, all temperature treatments resulted in Level II or III damage, indicating moderate to severe stress, with yield reductions of 44.54%, 47.42%, 47.85%, 52.31%, 68.90%, and 86.38%. Correspondingly,

the high-temperature stress index exceeded 5 (except for 32°C/22°C at day 9). Overall, Level II stress occurred most frequently.

3. Discussion and Conclusion

This study demonstrated that increasing temperature and prolonged exposure reduced leaf length, width, individual plant dry and fresh weights, and leaf fresh weight, consistent with previous reports. High-temperature stress decreases leaf water uptake, causing transpiration to exceed absorption and resulting in wilting. Prolonged stress leads to leaf scorching, extended growth cycles, elongated internodes, narrower and thinner leaves, premature senescence, and rapid quality deterioration. SPAD values decreased with temperature and duration, aligning with Tao et al.'s findings that SPAD values in spring maize varieties decline with extended heat stress, with greater reductions following longer exposure.

Plants adapt to stress by regulating internal osmotic substances, with soluble sugars and proteins being primary osmoregulators. High temperature accelerates protein degradation, though heat-tolerant varieties show slower rates. This study found that short-term high-temperature stress increased soluble protein content, likely due to heat shock protein synthesis involved in thermotolerance responses. However, as stress intensified, soluble protein content decreased, possibly because high temperature disrupted membrane systems, reducing protein release from membranes or bound forms. The consistent reduction in protein content relative to controls confirms its close relationship with stress resistance.

Soluble sugars regulate intracellular osmotic balance during high-temperature stress while maintaining protein hydration and preventing protoplasm dehydration. Similar to soluble protein, soluble sugar content initially increased under short-term stress but decreased with prolonged exposure and higher temperatures, consistent with findings in heat-sensitive eggplant varieties where initial increases likely resulted from starch hydrolysis and subsequent decreases reflected impaired photosynthetic capacity.

This research defined a high-temperature stress index and classification system based on yield reduction and leaf curl rate. Stress levels reached Level II or higher after 9 days, with leaf curl rate being more sensitive to high temperature than yield reduction, exceeding 40% across all durations at 38°C/28°C.

In conclusion, high-temperature stress degrades pakchoi appearance and nutritional quality while causing severe yield losses under intensified stress. The optimal models for predicting leaf curl rate and yield per unit area were based on minimum temperature/duration and maximum temperature/duration, respectively. These models can inform management decisions for pakchoi production. However, this study did not differentiate among genotypes or include a comprehensive range of temperature treatments, warranting further investigation into effects on heat-tolerant and heat-sensitive pakchoi varieties.

References

- [1] Gao L H, Li S J. Physiological basis of heat tolerance in regenerated lettuce[J]. Journal of Nanjing Agricultural University, 1994, 17(2): 23-27
- [2] Hou X L, Cao S C, Guan X C, et al. A new heat-resistant non-heading Chinese cabbage variety ‘Dwarf Resistant 6’ [J]. Acta Horticulturae Sinica, 2003, 30(6): 762
- [3] Hu Q Q, Chen L Z, Zhang Y J, et al. Studies on heat tolerance identification method for non-heading Chinese cabbage [Brassica campestris L. ssp. Chinensis (L.) Makino var. communis Tsen et Lee][J]. China Vegetables, 2011, (2): 56-61
- [4] Zhang H Y. Nutrient regulation and vegetable quality[J]. China Vegetables, 2005, (S): 23-26
- [5] Zhao X D. Studies on physiological & biochemical indexes in thermotolerance and genetic diversity of Brassica campestris ssp. chinensis L.[D]. Nanchang: Jiangxi Agricultural University, 2013
- [6] Zhao S, Chen L, Zhou C Y, et al. Identification of heat resistance of Brassica rapa L.[J]. Heilongjiang Agricultural Sciences, 2014, (7): 86-91
- [7] Zhao X D, Zhang J Y, Fan S Y, et al. Research progress of heat-tolerance of Brassica campestris ssp. chinensis[J]. Agricultural Science & Technology, 2013, 14(2): 248-253
- [8] Wang X, Xu N L, Zhao Z L, et al. Effects of high temperature stress during flowering on morphological and physiological characters in linear hot pepper[J]. Journal of China Capsicum, 2016, 14(2): 18-21
- [9] Zhou W H, Xue D W, Zhang G P. Protein response of rice leaves to high temperature stress and its difference of genotypes at different growth stage[J]. Acta Agronomica Sinica, 2011, 37(5): 820-831
- [10] Patton A J, Cunningham S M, Volenec J J, et al. Differences in freeze tolerance of Zoysia grasses: . Carbohydrate and proline accumulation[J]. Crop Science, 2007, 47(5): 2170-2181
- [11] Cui X. Studies on physiological characteristics effects of Agapanthus africanus seedlings under high temperature stress[D]. Harbin: Northeast Forestry University, 2007
- [12] Wu B H, Génard M, Lobit P, et al. Analysis of citrate accumulation during peach fruit development via a model approach[J]. Journal of Experimental Botany, 2007, 58(10): 2581-2594
- [13] Stenzel N M C, Neves C S V J, Marur C J, et al. Maturation curves and degree-days accumulation for fruits of ‘Folha Murcha’ orange trees[J]. Scientia Agricola, 2006, 63(3): 219-225

- [14] Slaughter D C. Nondestructive maturity assessment methods for mango: A review of literature and identification of future research needs[D]. Davis, California, USA: University of California, 2009: 1-18
- [15] Marcelis L F M. A simulation model for dry matter partitioning in cucumber[J]. *Annals of Botany*, 1994, 74(1): 43-52
- [16] de Koning A N M. Development and dry matter distribution in glasshouse tomato: A quantitative approach[D]. Wageningen: Wageningen Agricultural University, 1994
- [17] Tap R F, van Straten G, van Willigenburg L G. A dynamic model for the optimal control of greenhouse tomato crop production[D]. Wageningen: Wageningen Agricultural University, 2000
- [18] Dayan E, Presnov E, Fuchs M. Prediction and calculation of morphological characteristics and distribution of assimilates in the ROSGRO model[J]. *Mathematics and Computers in Simulation*, 2004, 65(1/2): 101-116
- [19] Chen D, Liu Y, Lu M. Microclimate evaluation and regulation on greenhouse fruit cucumber planted in early spring over summering in Nanning[J]. *Journal of Changjiang Vegetables*, 2011, (4): 47-50
- [20] Qiao Z X, Shen H L, An Y. The research on identifying methods in tolerance to high temperature of tomato[J]. *Acta Agriculturae Boreali-occidentalis Sinica*, 2006, 15(6): 114-120
- [21] Yuan W Q, Hu D. Measurement of leaf blade length and width based on moment[J]. *Computer Engineering and Applications*, 2013, 49(16): 188-191
- [22] Yue X. Studies on the analysis of dietary fiber content and physiology and biochemistry characteristics in non-heading Chinese cabbage (*Brassica campestris* ssp. *chinensis* Makino)[D]. Nanjing: Nanjing Agricultural University, 2009
- [23] Guo Y H, Yang W H, Yu Y Z, et al. Determination of total sugar contents in mature cotton fiber using anthrone colorimetry[J]. *China Cotton*, 2011, 38(12): 23-26
- [24] Zhuang X P, Zhang W, Zheng C X, et al. Effect of glucose, sodium glutamate and ethephon on synthetic quantity of lycopene in tomato fruits[J]. *Journal of Anhui Agricultural Sciences*, 2007, 35(19): 5664-5665
- [25] Cao J K, Jiang W B, Zhao Y M. Physiological and Biochemical Experimental Guidance of Postharvest Fruits and Vegetables[M]. Beijing: China Light Industry Press, 2007
- [26] Jin Q Y, Ouyang Y N, Yu S M, et al. Influence of soil drought stress on leaf rolling index in different rice varieties[J]. *Chinese Journal of Rice Science*, 2003, 17(4): 349-354

- [27] Xu K, Xu X Y, Li A H, et al. Assessing agricultural drought disaster risk in Chengde City using stochastic method[J]. Transactions of the CSAE, 2013, 29(14): 139-146
- [28] Liu J J. Influence of cultivation environment and fertilizer on pakchoi growth and quality[D]. Shanghai: Shanghai Jiao Tong University, 2013
- [29] Qin R C. Flora Reipublicae Popularis Sinicae: Book [M]. Beijing: Science Press, 1959
- [30] Li W G. Study on rice growth simulation and decision support system[D]. Nanjing: Nanjing Agricultural University, 2005
- [31] Dou Q Q, Sui D Z, He X D, et al. Effects of heat stress on leaf morphology and photosynthetic characteristics of twenty *Acer palmatum* Thunb. cultivars[J]. Journal of Jiangsu Forestry Science & Technology, 2014, 41(4): 1-6
- [32] Li L L. A study over the water stress sensitivity and water suitability of summer maize[D]. Nanjing: Nanjing University of Information Science and Technology, 2015
- [33] Zhang J M, Xie X M, Dong Z X. An evaluation on the heat tolerance of cool-season turf grasses under field heat stress[J]. Pratacultural Science, 2007, 24(2): 105-109
- [34] Jin B H. Research on drought stress affect morphological and physiological characteristic of different cultivars of bluegrass[D]. Harbin: Northeast Agricultural University, 2009
- [35] Liu W X, Cao S C. A study on evaluation and related characteristics of nonheading Chinese cabbage under summer high temperature[J]. Journal of Shandong Agricultural University, 1993, 24(2): 176-182
- [36] Zhao X D, Zhang J Y, Fan S Y, et al. Research progress of heat-tolerance of *Brassica campestris* ssp. *chinensis*[J]. Agricultural Science & Technology, 2013, 14(2): 248-253
- [37] Wang X Z, Zhao Y G, Wu Y Y, et al. Effect of high temperature stress on the chlorophyll fluorescence kinetics, SPAD and net photosynthesis rate of rice (*Oryza sativa* L.) in jointing stage[J]. Journal of Anhui Agricultural Sciences, 2011, 39(33): 20337-20339
- [38] Tao Z Q, Chen Y Q, Zou J X, et al. Spectral characteristics of spring maize varieties with different heat tolerance to high temperature[J]. Spectroscopy and Spectral Analysis, 2016, 36(2): 520-526
- [39] Wu Z H, Qin R C. Genera of Pteridophytes in China[M]. Beijing: Science Press, 1991: 47-565
- [40] Han R L, Li L X, Liang Z S. Seabuckthorn relative membrane conductivity and osmotic adjustment under drought stress[J]. Acta Botanica Boreali-occidentalia Sinica, 2003, 23(1): 23-27

- [41] Song X L, Han F X, Hu J J. Effect of drought and heat cross-stress on protein expression in wheat leaves[J]. Acta Agriculturae Boreali-occidentalis Sinica, 2012, 21(10): 22-27
- [42] Shen D T. Preliminary study on heat tolerance of spinach (*Spinacia oleracea* L.)[D]. Shanghai: Shanghai Jiao Tong University, 2012
- [43] Compiling Group of Flora of Fujian. Flora of Fujian: First volume Revised Edition[M]. Fuzhou: Fujian Science Press, 1982: 1-265
- [44] Tu S S, Qin T C. Effect of heat stress on the contents of free proline, soluble sugar and malondiadehyde in *Dioscorea zingiberensis* leaves[J]. Hubei Agricultural Sciences, 2004, 37(4): 98-100
- [45] Li Y Y, Wang J Q, Li Z L, et al. Effect of short-term high temperature on the main physiological index and anatomical structure of leaves in eggplants with different thermo-tolerance[J]. Chinese Journal of Tropical Crops, 2016, 37(9): 1774-1780

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