Experimental study on the effect of different air supply temperature on forced-air precooling of lettuce

Yan Li[1, 2], Sheng Liu[1*2], Zhongyang Fan[1], Junyan Wang[1,] Lijun Sun[1, 2], Xiaoming Duan[1]

1. *Key Laboratory of Urban Agriculture (North), Ministry of Agriculture/Key Laboratory of Vegetable Postharvest Processing, Ministry of Agriculture/Key Laboratory of Vegetable Postharvest Processing, Ministry of Agriculture/Beijing Key Laboratory of Fruit and Vegetable Storage and Processing, National Engineering Research Center for Vegetables, Beijing Academy of Agriculture and Forestry Sciences, Beijing, 100097, P. R. China*
2. *Shanghai Ocean University, Shanghai, 201306, P.R.China.*

E-mail: 380469845@qq.com

Abstract: During the forced-air precooling, the air supply temperature was the cold storage environment temperature. The air supply temperature was the most important factor to impact the fruits and vegetables precooling time and energy consumption in the condition of constant wind speed. In this experiment, the head lettuces precooled from 22℃ to 3℃. From 22℃ to half cooling time, it was selected 0℃, 2℃ and 4℃ as the air supply temperature in the precooling process of lettuces. Next the precooling was carried out from the half cooling time to 3℃ at the blowing temperature of 0℃. The results were indicated that the air supply temperature changed from 2℃ to 0℃ was the best pre-cooling program to cooling down and save energy. In the actual production, it could develop the changed air temperature pre-cooling technology vigorously.

Keywords: forced-air precooling; air supply temperature; energy consumption; precooling technology.

1. Introduction

The pre-cooling is called the cold chain logistics for the first mile. Precooling, temperature management and fast delivery are all important for freshly harvested fruits and vegetables. Storing fruits in cool conditions retards respiration and ripening, changes in texture and color, and moisture loss [1]. Forced-air precooling technology is developed on the basis of cold storage precooling technology. It is use of the pressure caused by the differential pressure fan on the both sides of the boxes. The cold air passes through the boxes and forced convective heat transfer with fruits and vegetables.

Many scholars were carried out on different fruits and vegetables forced-air precooling experiment. It was found that the effect was good but the energy consumption was large [2-4]. Zhang Xianhong found that the air supply temperature reduced from 2℃ to 0 ℃ when the tomato taken forced-air precooling, the pre-cooling time was shortened by 46.36% [5]. Through experimental data analysis she found that the increased air supply speed reduced the cooling time, but the cooling time did not change significantly when the air supply speed exceeded 1.5 m/s [6]. Lambrinos G studied the wind speed of precooled, the results showed when the pre-cooling wind speed increases from 0.2 m/s to 3.6 m/s, the pre-cooling time was shortened by 2 to 3 times, but the increase in wind speed would increase the fan energy consumption [7].

In this experiment of lettuce forced-air precooling process, before half-cooling time the air supply temperature were selected 2℃, 4℃ and 6℃, and after half-cooling time the air temperature become 0℃. It was gotten the best solution by comparing the three precooling strategies of precooling time, power consumption. It had a sense of meaning in the future production practice.

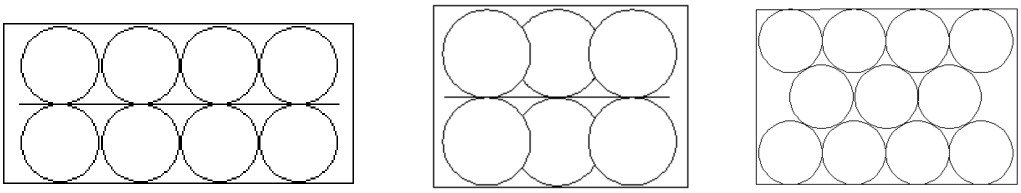
2. Materials and methods

2.1 Materials and equipment

Lettuces were bought from a Beijing Guangtai suburb farm. Moving high humidity and variable air volume forced-air cooling device. The device has the function of humidification and frequency adjustment wind speed. It was used programmable logic controller (PLC) as a CPU to achieve intelligent control purposes. Multi-point thermometer. Temperature and humidity from the instrument (Model: WSZY-1B, Beijing Tianjian Huayi Technology Development Co., Ltd). Hydraulic electronic scales. A number of 600×400×330mm plastic baskets.

2.2 Methods

2.2.1 Packing and palletizing



（a） (b) (c)

Figure 1. Front, left and top views of the lettuce boxing method

At 13:00, lettuces were arrived at the experimental site. Precooled crates used 600×400×330mm3 plastic baskets. Figure 1 showed the front, left and top views of the lettuce boxing method. Each basket net weight 16kg. A total of 20 plastic baskets were arranged symmetrically on both sides of the air outlet. The baskets would be arranged in two columns, five layers on the standard trays.

2.2.2 Temperature probe layout

According to the previous experimental experience, the air inlet temperature of the cargo was lower than the return air temperature. It had twelve cargo temperature measurement points and two ambient temperature measurement points. Place six of the measuring points in the air inlet and the remaining six in the return air outlet to ensure the accuracy of temperature monitoring. Basis for consideration would be based on the average temperature of 12 temperature points of the data processing. One of the boxes was arranged with four temperature points in diagonal form to monitor the inlet, outlet, the first layer, the second layer of lettuce temperature respectively.

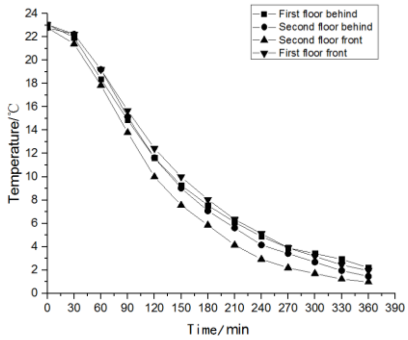
2.2.3 Lettuce forced-air precooling

Before the start of the experiment, the cold storage environment temperature dropped to the appropriate temperature first. The experiment was divided into three groups that each group had consistent pre-cold cargo volume. In the first group, lettuce was pre-cooling from 23℃ to 3℃, air temperature was 0℃. In the second group, the precooling divided in two stages by half the cooling temperature. First the air temperature used 2℃ then became 0℃. In the third group, the air temperature changed from 4℃ to 0℃. In the case where the initial temperature was almost the same, the half-cooling temperature was 11.5℃. During the experiment, the temperature change of lettuce and ambient temperature were recorded with the multi-point thermometer. And each group of each stage of power consumption and precooling time were recorded.

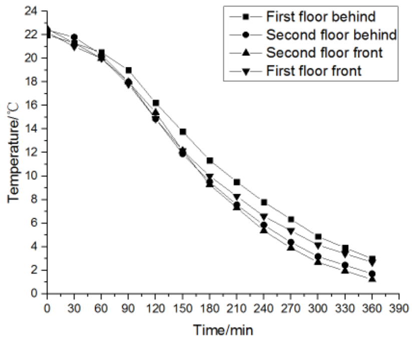
3. RESULTS AND DISCUSSION

Figure 2 showed the curve of the temperature of the measuring points inside the box. Figure (d), figure (e), and figure (f) were the first group, the second group and the third group of experimental results. It was clear that the slope of the temperature curve was decreasing. This represented a gradual slowdown in cooling rate. Figure (d), figure (e), and figure (f) showed a common law that the temperature of the return air outlet was higher than that of the air inlet and the temperature of the first layer was higher than that of the second layer. It was related to the speed and pressure of the air. The air inlet wind speed was greater than the return air outlet. The farther away from the fan, the lower the wind speed, the smaller the wind pressure. The farther away box from the axial fan caused the lower wind speed and the smaller wind pressure. The decrease in heat transfer coefficient leaded to a slowdown in heat transfer.

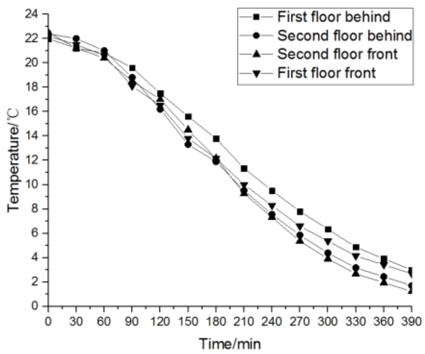
Figure 4 showed the time when three sets of experiments reached the half-cooling temperature. The time was 125 min, 160 min and 200 min, respectively. Obviously, it affected the lettuce pre-cooling rate when the air temperature changed from 0℃ to 2℃ or 4℃. When the temperature was higher, the longer it took to reach the half-cooled temperature. Figure 4 and Figure 3 can be compared to find that the cooling curve would show a convergence trend when the air supply temperature becomes 0℃ after half-cooling temperature. It was because of the heat transfer coefficient became larger after the temperature change. Compared to the conventional program at 0℃, the temperature became 2℃ didn't affect the pre-cooling time, the temperature became 4℃ only increased by half an hour. It was fully reflected the use of the temperature strategy for the possibility of pre-cooling. Figure 5 showed the power consumption at the end of the pre-cooling. Using the full pre-cooling strategy for 0℃, the power consumption was 0.106kwh per kilogram. Using the strategy of 2℃ to 0℃, the power consumption was 0.094kwh per kilogram. Using the strategy of 4℃ to 0℃, it was 0.088kwh per kilogram. It showed a trend of reduced energy consumption. The energy consumption was the lowest when the airs supply temperature from 4℃ to 0℃.



(d)



(e)



(f)

Figure 2. The curve of the measuring points temperature in the boxes

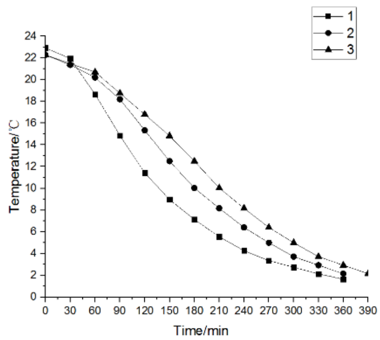


Figure 3. The comparison curve of the lettuce average temperature in the three groups.

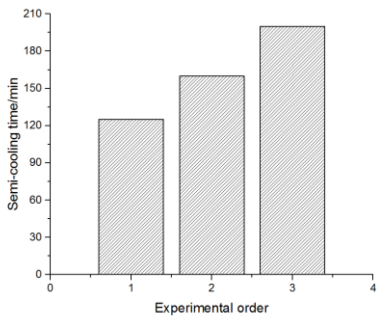


Figure 4. The time to reach the. half-cooling temperature

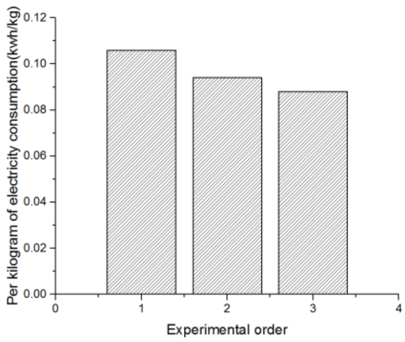


Figure 5. The power consumption at the end of the pre-cooling

The experiment could draw the corresponding conclusion, before the half-cooling temperature, using the higher air supply temperature was conducive to comprehensive energy conservation on the basis of not significantly affecting the pre-cooling time. It was known that the pre-cooling curve would have a convergent process at high temperature to low temperature. The best solution requires would be found with a lot of experimentation. At this stage of the experiment provided a good idea, the temperature could be divided at 0 ℃, 2 ℃ and 4 ℃ after the half-cooling temperature at each air supply temperature in the next experiment. It could be divided into nine groups of experiments. Through the next experiment it could be find the best pre-cooling program. It could provide the guidance in the energy saving during the pre-cooling for fruits and vegetables.

4. References

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