

Effect of Vacuum Cooling Operation Parameters on Cooling Time and Weight Loss of Chinese Cabbage

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ABSTRACT

The effect of vacuum pressure reserving operation mode on cooling time, weight loss percentage and temperature variation of Chinese cabbage were investigated. Vacuum cooling of Chinese cabbage packed in PE bags using different vacuum pressure reserving operation modes were experimented. The holding pressures for vacuum cooled Chinese cabbage packed in PE bags were set at five different levels; 5, 5.5, 6, 6.5 and 7 millibar; and at the 3 levels of the time reserving; 20, 25 and 30 minutes, respectively for each level of pressure. Cooling Chinese cabbage packed in PE bags to $4 \pm 1^\circ\text{C}$ with lower holding pressures consumed longer cooling times than higher holding pressures. The different operation conditions resulted in both effects on the cooling time and final temperature of Chinese cabbage packed in PE packages. Lower final pressure caused higher weight loss. The optimum condition for vacuum cooling process of Chinese cabbage packed in PE bags with initial temperature of $15\text{-}20^\circ\text{C}$ was at the final pressure of 6 mbar with pressure reserving of 30 minutes. The cooling time of Chinese cabbage packed in PE bags was 44 minutes and the weight loss percentage during vacuum cooling process was 2.29%.

Key words: Vacuum cooling, Chinese cabbage, Vacuum pressure, Pressure reserving, Weight loss

INTRODUCTION

Vacuum cooling has long been widely used as a rapid cooling method for vegetables, fruits and cut flowers (Sun and Brosnan, 1999; Brosnan and Sun, 2001). Chen (1986) revealed that vacuum cooling had the lowest energy cost per unit of cooled product compare with air cooling and hydro cooling. Vacuum cooling is a fast cooling process in which water is removed by water evaporation from the surface and within the products due to the low surrounding pressure. Water evaporation absorbs heat from the products and causes the temperature decrease. Vacuum cooling mainly depends on latent heat of evaporation to remove the sensible heat of the produce. Water boils at 100°C if it is subjected to the atmospheric pressure. However, reduction in the imposed pressure on water lower the boiling point temperature of water, that is, water can also boil at a temperature as low as 0°C , if the imposed pressure is reduced to 6.11 mbar. The imposed pressure on water determines the minimum temperature, which can cause water to boil to produce a cooling effect (Perry et al., 1984; Jin, 2007). If porous and moisture produce are subjected to vacuum pressure, part of water within the foods can boil out to achieve the cooling effect for the produce at a temperature as low as the saturation temperature of water related to the vacuum pressure. For vacuum cooling of packaged moisture foods, no matter where an individual food body may be located in a package of bulk container, a uniform temperature distribution can be achieved as a

result of the cooling effect directly which comes from water evaporation in local pores (Wang and Sun, 2001). Water loss during cooling has restricted the wider use of vacuum cooling. Prevention from moisture loss is of fundamental importance for the retention of fresh produce quality, as any reduction in moisture content will lead to shriveling, wilting, and loss of consumer appeal (Hackett et al., 1987).

Vacuum cooling process is a new technology that the Royal Project Foundation use as a technique to prolong the shelf life and improve the quality of vegetables. Unfortunately, no complete information on an appropriate use for Chinese cabbage in the Royal Project is obtainable so far. Therefore, research on what would be the parameters set-up was conducted in order to achieve the overall effectiveness should this new technique be implemented. In this study, vacuum cooling was applied to harvested Chinese cabbage. The effect of vacuum pressure reserving (holding pressure) and time reserving (holding time) on cooling time, weight loss percentage, produce center temperature variation of Chinese cabbage were investigated. The study results would finally contribute to an overall efficiency and cost-effectiveness of the entire system. This research is especially designed to investigate the effects of operating process parameters on weight loss percentage and final produce temperature, and cooling time (cycle time) during vacuum cooling of Chinese cabbage packed in PE bags. The objectives of the experiment were to find the optimum process parameters for Chinese cabbage vacuum cooled to $4\pm 1^{\circ}\text{C}$ in perforated PE bag (40 holes: diameter of 0.5 mm each) sized 15.2 x 17.8 x 29.2 cm.

MATERIALS AND METHODS

Plant materials

Chinese cabbage (*Brassica rapa* L.) harvested at commercial maturity stage in November, 2010 through January, 2011 from Chiang Mai province and immediately transported by truck to the collection center in Chiang Mai, the Royal Project Foundation.

Experimental setup

The vacuum cooling system used in this experiment included vacuum chamber, vacuum pumping system, condenser, refrigerator, and automatic control and operation system. The details of the vacuum cooling system are presented in Figure 1. The system was built by Hussmann Co., Ltd. (USA).

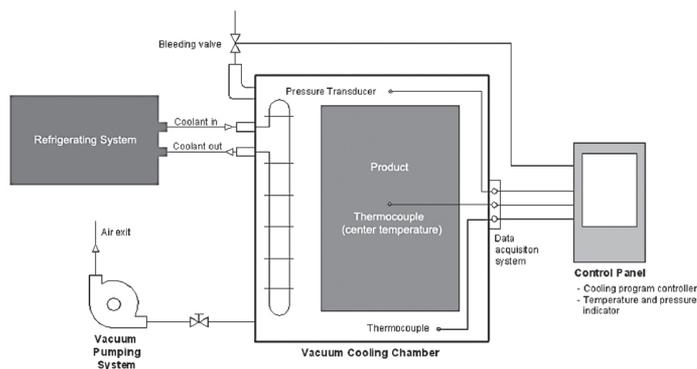


Figure 1. The schematic diagram of the research vacuum cooler.



Figure 2. Arranging the plastic baskets in vacuum chamber.

Chinese cabbage were graded, trimmed off defects and undesirable parts, then put into ready-to-sell packages. Weighing approximately 500 grams of Chinese cabbage in each PE (polyethylene) sized 15.2 x 17.8 x 29.2 cm, making in it 40 holes with the diameter of 0.5 mm. Spread total of approximately 5 kilograms of produces in each polypropylene basket for total of 60 baskets. The initial weight and temperatures of Chinese cabbage were measured and recorded, then placed all baskets inside the cooling chamber (Figure 2 and 3). The holding pressures for vacuum cooled Chinese cabbage packed in PE bags were set at five different levels; 5, 5.5, 6, 6.5 and 7 millibar; and at the 3 levels of the time reserving; 20, 25 and 30 minutes, respectively for each level of pressure. Each treatment was experimented with three replicates. Chamber pressure, temperature, relative humidity percentage and produce center temperature were recorded every 1 minute from the beginning through the end of the cooling process. After immediate removing the produce from the cooling chamber, Chinese cabbage were weighed and recorded. Energy consumption of vacuum cooling process was measured and electrical expense in Thai baht was calculated.

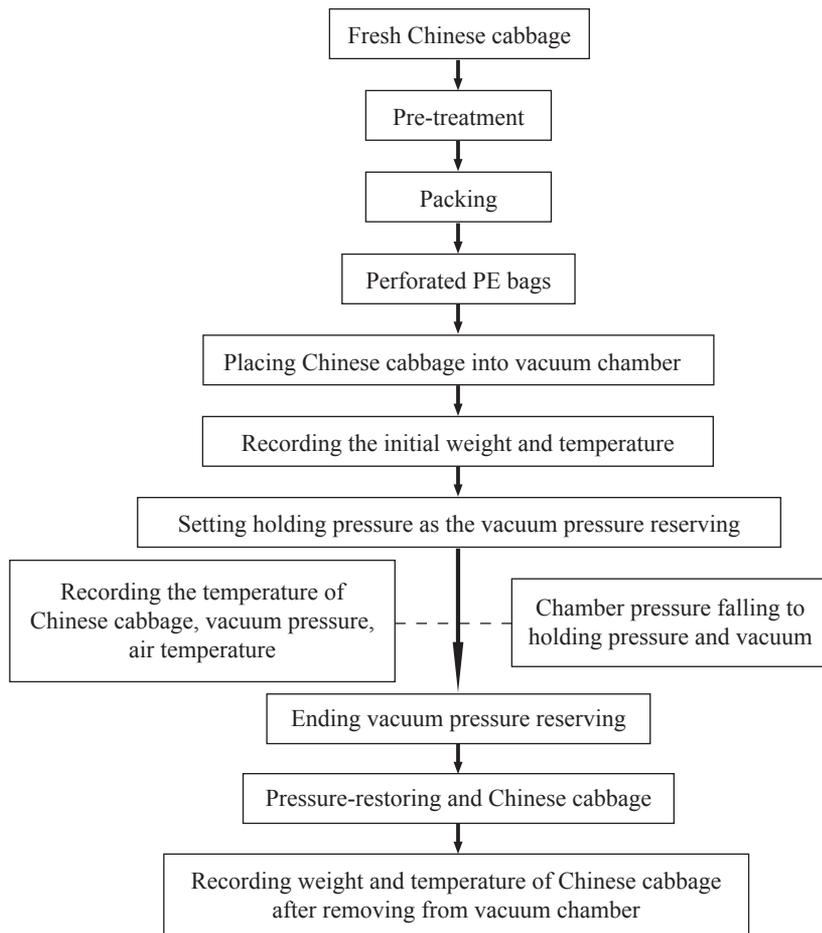


Figure 3. The flow chart of vacuum cooling process.

RESULTS AND DISCUSSION

The total pressure in the vacuum chamber is the sum of the partial pressure of air and water vapor. During vacuum cooling, the air is evacuated by vacuum pump, water vapor condense into water in the vapor-condenser. The total pressure in the vacuum chamber is reduced from atmospheric to the set holding pressure. With the reduction of pressure in vacuum chamber, the time at the beginning of water boiling in the produce, is called the “flash point”. The variation of temperature in the vacuum chamber during the vacuum cooling process of Chinese cabbage packed in perforated PE bags, was shown in Figure 4. From the graph, the initial temperature in the vacuum chamber was 16.9°C and the temperatures in the vacuum chamber have some fluctuations during the vacuum cooling process. The variation of chamber temperature can be divided into three different parts: part I, part II and part III as shown in Figure 4.

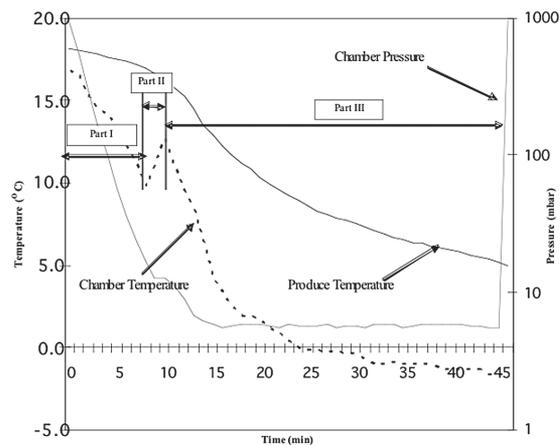


Figure 4. Temperature, pressure history in the vacuum chamber and cooling curve of Chinese cabbage package in perforated PE bags during vacuum cooling at 6 mbar with 30 minutes reserving time.

In the first part, most of vapor is condensed in the vapor-condenser. Together with the reduction of the temperature of produces and the vacuum pressure in the vacuum chamber, the temperature in the vacuum chamber decreased from 16.9 to 9.8°C (part I). In part II, the temperature rose from 9.8 to 11.3°C. It can be explained by the fact that since the initial temperature of Chinese cabbage was at 17.76°C and the chamber temperature was 16.9°C, the water vapor was able to evaporate from the plant at this temperature, which can increase the temperature in the vacuum chamber as opposed to the chamber relative humidity. The third part (part III) as shown in Figure 4, the pressure in the vacuum chamber, which was dropped from 12.6 to 6.0 mbar rapidly, reached the reserving pressure of 6.0 mbar and reserved it for 30 minutes. During the time of pressure reserving, the temperature in the vacuum chamber decreased sharply from 11.3 to -1.6°C, it due to both of compressors in the refrigerating system were working. The cooling rates of Chinese cabbage in packages was low (0.12°C per minute at the beginning, however, after 7 min, cooling rates of the produces became high (0.30°C per minute) since “flash point” was reached. The vacuum pressure decreased continuously until it reached the reserving pressure, then reserved at the holding pressure for the reserving time set of 30 minutes. When the bleeding air valve was switched on, air at a room temperature entering into the vacuum chamber caused the increasing of the temperature in vacuum chamber. The final temperature in the vacuum chamber was -1.6°C. Weight loss occurs during vacuum cooling since the chamber cooling effect directly comes from water evaporation from the produce. Weight losses of Chinese cabbage during vacuum cooling for two different holding pressures, which no sign of wilting appeared on the produce, were displayed in Table 1. Weight loss percentage was significantly affected by holding pressure ($P \leq 0.05$). Holding time (in the range of 20, 25 and 30 minutes) did not significantly affect weight loss percentage ($P > 0.05$). There was no significant interaction effect between holding pressure and holding time on weight loss percentage ($P > 0.05$). For the same holding time, the lower pressure was used, the higher weight loss was experienced (Boonprasom and Boonyakiat, 2010).

In terms of weight loss percentage during cooling process, the research also exemplified that produce packaged in perforated PE bags under higher reserving pressures had a significantly slight amount less weight loss percentage than produce precooled with lower pressure ($P \leq 0.05$) (Boonyakiat and Boonprasom, 2010). Energy consumption of the cooling cycle was 0.09 kWh per 300 kilograms of Chinese cabbage. Economic analysis showed that the vacuum cooling had an additional cost of 0.003 baht/kg for PE package (32.00 baht = 1 USD).

As illustrated in the Table 1, cooling time depends on holding pressure and holding time.

Optimum process parameters for Chinese cabbage vacuum cooled in perforated PE bags and measuring indices of vacuum cooling processes were displayed in Table 2. In intended to cooled Chinese cabbage to $4\pm 1^{\circ}\text{C}$ several sets of parameters were investigated. The experimental results showed that the optimum condition for vacuum cooling process of Chinese cabbage in perforated PE bags with the initial temperature of $15\text{-}20^{\circ}\text{C}$ precooled with the best parameters obtained for the holding pressure at 6 mbar with holding time of 30 minutes.

Table 1. Holding pressure, holding time, cooling time and weight loss percentage (mean of \pm S.E.) of Chinese cabbage packed in PE bags during the vacuum cooling process.

Holding pressure (mbar)	Holding time (min)	Initial center temperature of Chinese cabbage ($^{\circ}\text{C}$)	Final center temperature of Chinese cabbage ($^{\circ}\text{C}$)	Cooling time (min)	Weight loss (%)
5.5	25	19.2 ± 0.6	5.2 ± 1.1	41	$2.14\pm 0.12^{\text{ab}}$
	30	17.4 ± 0.8	5.1 ± 0.9	46	$2.30\pm 0.30^{\text{a}}$
6.0	25	18.5 ± 0.5	6.5 ± 0.8	39	$1.88\pm 0.08^{\text{b}}$
	30	18.3 ± 0.8	4.1 ± 0.2	44	$2.01\pm 0.30^{\text{ab}}$

Different letters in the same column denote significant differences at $P = 0.05$.

Table 2. Optimum process parameters for Chinese cabbage vacuum cooled in a polypropylene basket and Chinese cabbage vacuum cooled in polyethylene bag and measuring indices of vacuum cooling processes.

Process Parameters/Measuring Indices	Chinese cabbage vacuum cooled In PE bags
Holding pressure (mbar)	6 mbar
Holding time (min)	30 min
Cycle time (min)	44 min
Initial center temperature of chinese Cabbage ($^{\circ}\text{C}$)	$15\text{-}20^{\circ}\text{C}$
Final center temperature of chinese Cabbage ($^{\circ}\text{C}$)	4.61°C
Weight loss (%)	2.29%
Energy consumption (kWh)	0.09 kWh

CONCLUSION

The optimum condition for vacuum cooling process of Chinese cabbage in perforated PE bags with the initial temperature of $15\text{-}20^{\circ}\text{C}$ precooled with the best parameters obtained for the holding pressure at 6 mbar, the holding time of 30 min, respectively. The different operation conditions resulted in both effects on the cooling time and final temperature of Chinese cabbage packed in perforated PE packages. In term of weight loss percentage, the research also exemplified that produce packaged in PE bags precooled under the higher holding pressure had a slight amount less weight loss percentage of 2.29 than produces precooled under lower pressure with the same reserving time. Weight loss percentage was affected by the holding pressure, holding time, and initial produce temperature.

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