Computers and Electronics in Agriculture 144 (2018) 209–215

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Optimization of vacuum cooling treatment of postharvest broccoli using response surface methodology combined with genetic algorithm technique

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ARTICLE INFO

Keywords:
Postharvest broccoli
Vacuum cooling process
Optimization
Response surface methodology
Genetic algorithm

ABSTRACT

In this paper, the effects of vacuum cooling factors on the weight loss of postharvest broccoli were initially investigated. In sequence, the vacuum cooling treatment conditions were optimized using the response surface methodology (RSM) combined with the genetic algorithm (GA) technique. Fresh broccoli samples were harvested from a Chinese farm, and the green heads of selected samples were cut into smaller pieces, with diameters approximately 3–4 cm, and sequentially equilibrated to room temperature. Pressure (200–600 Pa), broccoli weight (200–500 g), water volume (2–6%, v/v) and time (20–40 min) were used as factors, and weight loss and end temperature were recorded as responses. The GA was employed to find the optimal condition for processing broccoli, and its initial solution was obtained from the RSM. The results demonstrate a good performance of the GA for the optimization of the broccoli cooling process. The best conditions of vacuum cooling process were as follows: a weight between 273.5 g and 278.0 g, a water volume of 3.0% v/v, a processing time of 40 min, a pressure of 200 Pa, and a weight loss and end temperature of 0.34 ± 0.01% and 2.0 ± 0.0 °C, respectively, leading to a percentage of profit of 99.66 ± 0.01%.

1. Introduction

Broccoli is an important source of vitamins, mainly vitamin C, dietary fiber and multiple nutrients with potent anti-cancer properties. China and India are the main producers of broccoli in the world, producing a total of 9.1 and 7.9 million tons per year, respectively; together, they produce over 75% of the world's broccoli. However, at room temperature, broccoli has a short shelf life, due to use of inappropriate techniques of postharvest storage and genetic factors. Several changes occur in broccoli with senescence, and some of them are easily observed, including yellowing generated by the chlorophyll degradation, opening of the flower buds, loss of turgidity, development of off-odors, reduction in nutritional value and increase in peroxidase activity (Carvalho and Clemente, 2004; Zhang and Sun, 2006).

There are several techniques to improve the shelf life of food, such as drying, freezing and modified atmosphere packaging. However, many disadvantages on the use of these techniques have been cited, such as that they cannot apply to all foods, they modify nutrients, texture, flavor and aroma of food, and their processing times are very long (Alibas and Koksal, 2014; Carvalho and Clemente, 2004; Corcuff et al., 1996). To solve these problems, the application of vacuum cooling in food storage is currently being studied.

Vacuum cooling is obtained through rapid heat removal from the product by evaporation of water from its surface and pores (Mc Donald et al., 2002). The water evaporation is performed by the decrease of pressure within a chamber where the product is packaged. This technique is often used for cooling leafy vegetables, such as lettuce, mushrooms, fruits and flowers after harvest.

Therefore, vacuum cooling has been reported as a high-efficiency method to extend shelf life and enhance microbiological safety. This method can rapidly remove heat from a postharvest product through the evaporation of water directly from the product. However, because of this principle, vacuum cooling also has the disadvantage or potential weigh loss occurring during the vacuum cooling process (Zhang and Sun, 2006).

Until now, the water-spraying method was found to reduce the weight loss caused by vacuum cooling treatment. We relied on some works from the literature to define the range of amounts of spraying

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https://doi.org/10.1016/j.compag.2017.12.010
Received 1 April 2017; Received in revised form 20 September 2017; Accepted 8 December 2017
0168-1699/

water adopted in our experiments. In addition, preliminary studies indicated that many other factors, such as vacuum degree, weight of treated broccoli samples, and treatment time, can also significantly influence the weight loss of products (Zhang and Sun, 2006).

The vacuum cooling technique has been applied to other types of vegetables, including cauliflower (Alibas and Koksal, 2014), onions (Shanmugasundaram and Kalb, 2001) and carrots (Zhang and Sun, 2006). Fruits, such as strawberry, gooseberry and melon, and vegetables, such as cabbage, turnips, eggplant and cucumber, have also been objects of study for the application of vacuum cooling (Huber, 2004; Mc Donald et al., 2002).

Thus, the effects of pressure, cooling time, initial temperature or weight, water flow and food form or size are studied to improve the quality of food and its storage time. Therefore, several studies have been developed to improve the processes of food preservation, such as those presented below.

Carvalho and Clemente (2004) observed that, for vacuum cooled broccoli that weighed between 240 and 360 g, the best conditions to retain vitamin C, with low weight loss, low peroxidase activity and low turbidity, were those of broccoli with low weight. Similar effects were also observed by Corcuff et al. (1996) when using modified atmosphere packaging for the conservation of broccoli.

Furthermore, as described in Huber (2004), for processing times less than 40 min, there was a smaller loss of weight and a higher end temperature of the product, indicating that 40 min of contact time was sufficient to transfer heat in the cooling process and that there was no loss of water weight in the product. According to most of the studies found in the literature, the processing of vegetables by the vacuum cooling process occurs for hours. For example, Alibas and Koksal (2014) evaluated the weight loss of cauliflower for 1–3 h of processing time; Mc Donald et al. (2002) verified that the best time for the maintenance of quality of a cooked beef product is 50 min; and Carvalho and Clemente (2004) analyzed the weight loss of broccoli with days of processing.

Deng et al. (2011) observed that rapid vacuum cooling of steamed stuffed run for 15 min also provided a high weight loss (6–8%) and a high end temperature (7 °C). In the study from Huber (2004), a high weight loss and end temperature above 10 °C were observed for the vacuum cooling of chicken breast for 10 min.

Throughout experimental research, methods that describe a system behavior and/or allow for optimization of processes that make them feasible at an industrial scale are always welcome. In this way, the search for software and optimization techniques has intensified to provide a broader analysis of the system and to find the best condition of the factors that lead to the improvement of product quality.

In the last decades there has been increasing the development of computational and electronic approaches for agricultural tasks such as harvesting, seeding, grow monitoring, soil analysis and chemical treatments, among others. Such approaches, usually associated with precision agriculture, aim to reduce production costs, reduce the contamination of nature by the pesticides used and logically increase productivity (Funes et al., 2015).

One example of mentioned approaches is the use of hybrid algorithms for process optimization, especially for the reduction of search space to find the optimal conditions, and, thus, reduce the computational time (Chaves et al., 2007). Notably, the combination of optimization algorithms can be found in the solutions to problems in many fields of science. In this sense, Thyagarajan et al. (2000) proposed the use of fuzzy logic combined with the genetic algorithm (GA) to improve the control of air injection in a dryer. Benvenga et al. (2011) applied the simulated annealing (SA) technique and response surface methodology (RSM) to optimize the corn drying process.

Zafar et al. (2010) used the RSM combined with the GA in the optimization of naphthalene degradation by *Pseudomona putida* strain. A similar combination was also employed by Curvelo Santana et al. (2010) for the optimization of the corn malt drying process and by Benvenga et al. (2016) for the study of the economic viability of alcohol production from Cassava root.

The genetic algorithm (GA) is a technique for optimization, inspired by natural evolution theory, which has been used to solve optimization problems in several areas over the last decades, mainly because of its efficiency in different search spaces (Benvenga et al., 2016; Curvelo Santana et al., 2010). In addition, the GA is able to find the global optimal solution (or a near global optimal solution) in many complex, multi-modal search spaces. By means of competition, the most able individuals of the population (each one representing a solution of the problem) are selected and crossed with each other, thus generating new individuals that are better than those of the previous population. Therefore, in each generation, the probability that one or more individual(s) could be an optimal solution to the problem is increased (Benvenga et al., 2016; Curvelo Santana et al., 2010). Since the GA operates over a population in parallel and yields various solutions at the same time, it has been widely used for solving several optimization problems in engineering (Benvenga et al., 2016; Curvelo Santana et al., 2010), as well as in agricultural systems (Neungmatcha et al., 2013; Bergez, 2013; Hassanien et al., 2017).

This study focused on investigating the effects of vacuum cooling factors on the weight loss of postharvest broccoli and attempted to obtain the optimal conditions for vacuum cooling treatment on postharvest broccoli by combining the RSM with the GA technique. The main benefit of the approach proposed in this study is the reduction of the cost of the broccoli cooling process.

2. Materials and methods

2.1. Sample preparation

Fresh broccoli samples were harvested from a local farm in Hangzhou, Zhejiang Province, China. Only the samples without mechanical damage, plant disease or insects were selected. Prior to the tests, 200 g, 350 g, and 500 g of broccoli were weighed, according to the experimental design.

2.2. Vacuum cooling treatments

The vacuum cooling treatment was implemented by a self-developed vacuum cooler with a water-spraying unit that was connected with the water pipe and vacuum chamber. The water-spraying volume can be controlled in this system. The equipment was developed in chromed steel, with an internal volume of 1 m^3 and it was made in the Department of Food Science and Nutrition, School of Biosystems Engineering and Food Science, Zhejiang University, city of Hangzhou, Zhejiang Province, China. In this study, the pressure in the vacuum chamber (200, 400, and 600 Pa), the water-spraying volumes (3%, 4%, and 6%), and the processing time (20, 30, and 40 min) were varied for the purpose of investigating their synthetic effects on the weight loss (W_{Loss}) of broccoli during the vacuum cooling process (Alibas and Koksal, 2014; Deng et al., 2011; Zhang and Sun, 2006). The processing time is the cooling time required to reach the experimental design pressure conditions within the refrigerator. The weight loss was calculated according to Eq. (1).

$$W_{Loss} = 100*\left(\frac{W_{initial}-W_{end}}{W_{initial}}\right) \tag{1}$$

where $W_{initial}$ and W_{end} are the weights of the broccoli before and after the vacuum cooling process, respectively.

Each experiment was conducted in duplicate, and the mean values ± standard errors (SD) were calculated for the analysis. Experimental data were analyzed using SPSS v18.0 (Statistical Package for the Social Sciences, Chicago, IL, USA). A Tukey's test was applied to determine the significance of difference (P = .05).