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Stalk length affects the mineral distribution and floret quality of broccoli (*Brassica oleracea* L. var. *italica*) heads during storage

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ABSTRACT

Broccoli stalks have almost the equivalent nutrient components as the florets of the broccoli head but they are usually discarded in home use or industrial processing. Moreover, little information is available regarding the effects of stalk length on the storage characteristics of broccoli heads. In this study, the effects of different stalk lengths, i.e., 1 cm, 3 cm, 6 cm, and 9 cm on the mineral content including N, P, K, Ca, Mg, Fe, Zn, and B of the stalks and florets of broccoli heads during storage at 10 °C were determined. The chlorophyll and ascorbic acid contents of the broccoli florets were also measured for determining the postharvest quality of the broccoli heads. The results showed that the stalk length significantly affected the mineral content and the distribution in the stalks and florets of broccoli heads during storage. Very short (1 cm) or very long (9 cm) stalk lengths had adverse effects on the broccoli floret quality during storage. A suitable stalk length (6 cm) maintained a balance in the mineral content and the nutritional content between the florets and stalks during storage and ensured that the broccoli florets, which are the metabolism center, had better postharvest quality during longer storage periods. The stalk length should be considered for better storage quality of the broccoli heads.

1. Introduction

Harvested broccoli (*Brassica oleracea* L. var. *italica*) heads usually consist of florets and stalks. The United States Department of Agriculture (USDA) nutrient database (USDA Database, 2018a) indicates that the protein, total lipid, and carbohydrate contents of 100 g broccoli florets are 2.82, 0.37, and 6.64 g, respectively. The contents of the minerals Ca, Fe, Mg, P, K, and Zn are 47, 0.73, 21, 66, 316, and 0.41 mg per 100 g broccoli florets, respectively (USDA Database, 2018a). The broccoli stalks have almost the equivalent nutrient values as the broccoli florets (USDA Database, 2018b). Even for vitamins, anticarcinogenic compounds, and antioxidants, there is little difference between the florets and stalks of the broccoli head. However, most broccoli stalks are discarded in home use or industrial processing (Wijngaard et al., 2009; Drewnowski, 2013), which results in tremendous waste in the broccoli industry.

Broccoli heads are highly perishable after harvest and this is especially noticeable as a loss of the green color and yellowing. Various storage and treatment techniques including temperature (Li et al., 2014), heat treatment (Funamoto et al., 2002), ultraviolet-C (UV-C) treatment (Costa et al., 2006), controlled atmospheres (Guo et al., 2013; Li et al., 2016), electrostatic atomization (Ma et al., 2012), and 1-methycyclopropene (1-MCP) applications (Yuan et al., 2010), have been tested to improve the postharvest quality and extend the shelf life of broccoli.

However, little information is available concerning the effects of stalk length on the storage characteristics of broccoli heads. Schäfer et al. (2017) only investigated the cell wall changes of the stalks during broccoli storage but did not determine the relationship between the florets and stalks. Perini et al. (2017) studied the effects of stalks treated with hot water on the senescence of the broccoli heads; the results showed that the heat treatment delayed the broccoli senescence and maintained the storage quality of the broccoli heads, which indicated that the stalk characteristics might affect the storage properties of broccoli heads.

Numerous studies demonstrated that the mineral content affected the postharvest characteristics of fruits and vegetables. Marvasi et al. (2014) confirmed that the susceptibility of tomatoes to Salmonella infection was correlated with the nitrogen fertilizer concentrations. A study by Liu et al. (2017) indicated that 1% calcium chloride treatment maintained the cell wall texture and extended the shelf life of apricots stored at 5 °C. Excess boron blocked the calcium uptake and caused premature softening of kiwifruit during storage (Smith and Clark, 1989). It is of interest to determine how the stalk length affects the storage properties of broccoli florets and to ascertain the interaction between the stalks and florets, especially with regard to the mineral

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presence and content.

In this study, we investigated the effects of different stalk lengths on the mineral distribution in the stalks and florets and on the storage attributes of broccoli florets stored at 10 °C and 90–95% relative humidity (RH). To our knowledge, this is the first report on the effects of stalk length on the storage attributes and the mineral distribution of broccoli heads during storage.

2. Materials and methods

2.1. Raw material

Broccoli (*Brassica oleracea* L. var. *italica*) seeds were provided by Sakata seed corporation, Japan. The row-spacing was 80–90 cm and approximate 40,000 plants per ha were cultured in open field at an experimental farm at the Shandong University of Technology, Zibo City, Shandong Province, China. Broccoli heads were harvested and individually sealed in polyethylene bags (30 × 25 cm, 0.3 mm thick) with small holes and were immediately transported to the postharvest laboratory at the Shandong University of Technology. After pre-cooling at 3 °C for 8 h, broccoli heads with a uniform size of 20–22 cm diameter and 0.6–0.7 kg without mechanical injury were selected for the experiments.

2.2. Postharvest treatments

The broccoli heads were disinfected with 1% (v/v) sodium hypochlorite for 3 min, rinsed with tap water, and air-dried. The broccoli heads were randomly divided into 4 groups of 30 processed broccoli heads according to the stalk lengths of 1, 3, 6, and 9 cm, respectively. Each group was separately placed into three 0.5 m^3 plastic containers, corresponding to three replicate lots of 10 heads for each treatment. The broccoli heads were stored at 10 °C and 90–95% RH and the broccoli heads in each treatment were randomly taken out from storage at 0, 2, 4, 6, 8, and 10 d for evaluating the storage properties and mineral contents as described below.

Fig. 1 shows the details of the stalks, florets, and the broccoli head described in this study. (delete)

2.3. Mineral determination

The stalk and floret samples were periodically collected and dried in an oven at 80 °C for 36 h and the dried samples were ground using a glass mortar and pestle. The ground powder was sieved through a 178-μm screen mesh and the sieved powder was used to determine the contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), boron (B), and zinc (Zn).

Two different procedures were applied for the extraction of the minerals from the stalks and florets of the broccoli heads. For the analyses of N, P, and K, the Kjeldahl method (Nielsen, 2010) was used. For the analyses of Ca, Mg, Fe, B, and Zn, the sieved samples were digested with 65% HNO_3 and 70% $HClO_4$. The N, P, K, and the Ca, Mg, Fe, B, Zn determinations were conducted using the procedure described by Bernstein et al. (2005). K was measured by flame photometry (FP6440, Shanghai Precision Instrument Co., Ltd., China). The other elements were measured by electric coupled plasma mass spectrometer (ICP-MS, 7500^{ce}, Agilent, USA). The mineral content was expressed as mg/kg dry weight (DW) and was also converted into the floret:stalk ratio (FSR) of the elements.

2.4. Chlorophyll and ascorbic acid content determination

The chlorophyll content was measured according to the method of Guo et al., (2013); Toivonen and DeEll (1998) with slight modifications (delete). In brief, an amount of 0.2 g of the broccoli floret/stalk (delete) samples were ground with a mortar and pestle in 10 mL 80% acetone at

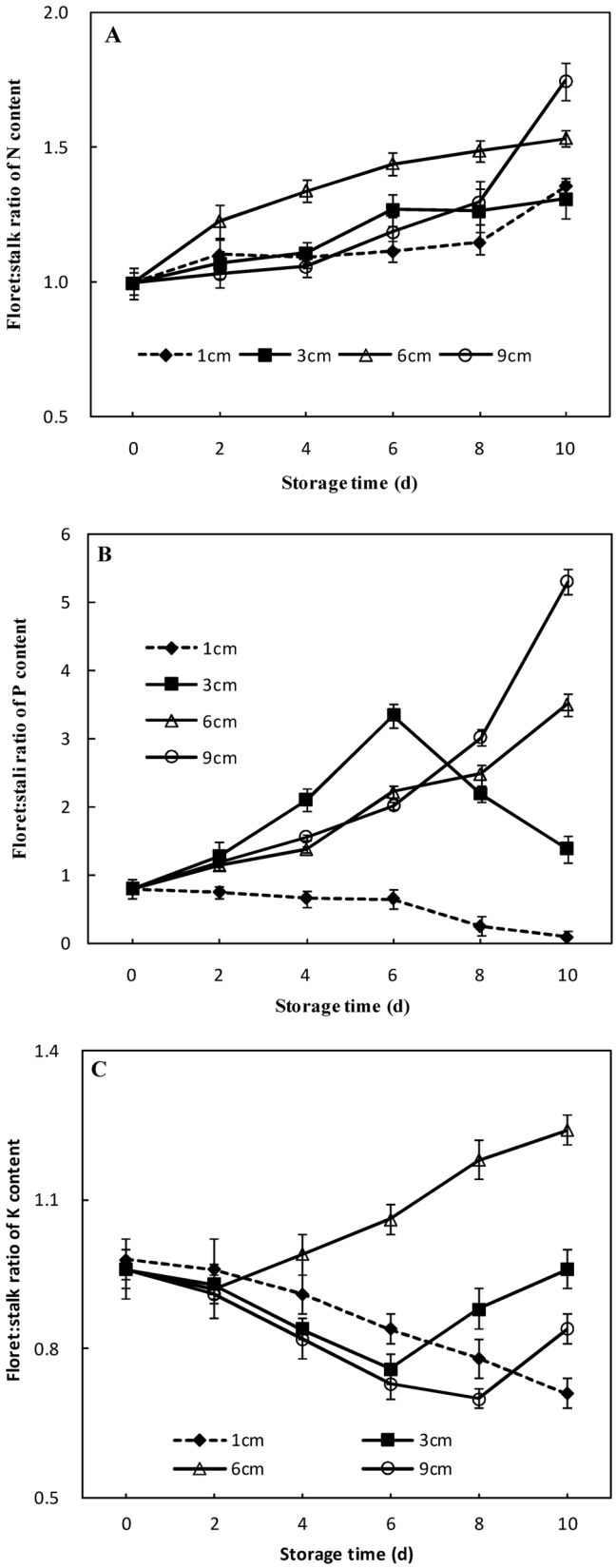

Fig. 1. Effect of different stalk lengths on the FSR of N (A), P (B), and K (C) of broccoli heads during storage at 10 °C. Vertical bars represent the standard deviation of the mean of three replicates.