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Understanding the physiological response of fresh-cut cauliflower for developing a suitable packaging system

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ABSTRACT

Wilting and decay are the general postharvest problems of fresh-cut cauliflower during marketing. The objectives of this study were; (i) to investigate the product physiological responses on transpiration and respiration rates (TR and RR) under different storage temperatures (1, 5, 10 and 15 °C) and relatively humidity (RH) (60, 76, 86 and 96%), in order to design packages; and, (ii) to evaluate the impact of packaging design (using PeakFresh (PF), poly-propylene (PP), and NatureFlex (NF)) on the quality of fresh-cut cauliflower at 5 °C for 12 days. Based on the physiological responses, two packages were designed; package-1 (20NF; 20% NF + 80% PP) and package-2 (40NF; 40% NF + 60% PP), while PF (100% PF) and PP (100% PP) served as control. Mathematical model adequately predicted respiration rates as a function of storage time and fitted to the experimental data (R^2 = 0.98). The RR of fresh-cut cauliflower was significantly higher than that of the uncut cauliflower and was within the range of 120 and 77.5 mg/kg.h at 5 °C for fresh-cut and uncut cauliflower, respectively. Transpiration rate for fresh-cut cauliflower was lowest at 96% RH across all storage temperatures ($p \leq 0.05$). Optimal package was achieved as a function of fresh-cut cauliflower physiological responses. At the end of storage day 12 at 5 °C, optimized 20NF package had the best performance compared to other packages; gas composition was within the range of 5% O_2 and 10% CO_2, with 0% in-package water vapour condensation but at expense of 7% weight loss.

1. Introduction

The consumption of fresh-cut fruit and vegetables that are ready-to-use and easy to prepare, is one of the greatest growing product categories due to increase in consumer requirement for convenience healthy food (Sloan, 2005). However, industry encounters challenges to maintain the shelf life and quality attributes (colour, texture, and flavour) of produce during marketing (Edelenbos, Lokke, & Seefeldt, 2017). Tissue browning, unpleasant odour, loss of firmness are major postharvest quality related problems that affect fresh produce and can be controlled to some extent by maintaining optimal storage conditions and using different forms of packaging systems (Tano, Kamenan, & Arul, 2005). Gas composition within a modified atmosphere packaging (MAP) system can be changed by using various barrier properties of different polymeric films that are specifically chosen based on respiration of the vegetables (Belay, Caleb, & Opara, 2016; Caleb, Ilte, Fröhling, Geyer, & Mahajan, 2016; Mahajan et al., 2017). The system provides an atmosphere that is different from the air (Wani, Singh, Gul, Wani, & Langowski, 2018), and can improve product preservation (Rux et al., 2015). However, inadequately designed MAP system could be unproductive or shorten the produce shelf-life. Most polymeric films normally used to package fresh-cut vegetables have lower water vapour transmission rate compared to the transpiration rates of fresh fruit and vegetables (Bovi, Caleb, Linke, Rauh, & Mahajan, 2016). Therefore, the excess water accumulated inside the package condenses (Volpe, Mahajan, Rux, Cavella, & Torrieri, 2018). Therefore, it is important to optimise the product-package system considering product respiration and transpiration.

Curd browning and/or bruising, anaerobiosis, and freezing injury can cause cauliflower heads or florets to become unmarketable. Curd browning is as a result of enzymatic browning due to the activity of polyphenol oxidase enzyme activity (PPO) that converts phenols into quinines (Brown, 2003). Commercially, MAP with 2–3% O_2 to 3–6% CO_2 is recommended to maintain the quality of the cauliflower heads but injury develops when stored at < 2% O_2 and/or < 5% CO_2 (Kader & Saltveit, 2003). If O_2 concentration within the package drops to < 0.5%, cauliflower will develop off-odours and flavours mainly due to the accumulation of volatiles such as methanethiol, dimethyl

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disulfide, and dimethyl trisulfide produced during the fermentative metabolism (Forney & Jordan, 1999).

Cantwell and Suslow (2009) reported that cauliflower heads and florets should be stored at 0 °C and 95–98% RH to maintain its quality. At 0 °C, the respiration rate of cauliflower florets slows down to ~8 mL CO_2/kg.h compared to ~42 mL CO_2/kg h at 22 °C (Cantwell & Suslow, 2009). Dependent on storage temperature and duration, if cauliflower is stored under RH conditions < 95%, the tissues dry out, and > 98% RH, it favours the microbial activity and spoilage (Hardenburg, Watada, & Wang, 1993). Although attempts to improve the shelf life and sustain post-harvest quality of minimally processed cauliflower have been made such as the use of LED light exposure, low temperature storage, packaging with anti-fog shrink film and hot/cold water treatment (Mohamed, Raja, Mohamed, & Habeeb, 2011). However, the application of these technologies is limited due to practical implications.

The integrated approach is needed to develop an optimum packaging system for fresh-cut cauliflower, related to the gas composition and water vapour changes with respect to the film properties (Mahajan et al., 2017; Bovi, Caleb, Ilte, Rauh, & Mahajan, 2018; Bovi, Caleb, Klaus et al., 2018). Thus, the objectives of this research were (i) to understand the physiological response of fresh-cut cauliflower, (ii) to develop a predictive model relating to respiration and transpiration rate, which will guide in package design; and (iii) to evaluate the performance of different packaging materials on the quality of fresh-cut cauliflower.

2. Materials and methods

2.1. Processing and plant material

Cauliflower was harvested at commercial maturity stage (fully developed and compact head) directly from the farm and transported at the temperature of 1 °C to the Department of Horticultural Engineering Laboratory, Leibniz Institute for Agricultural Engineering and Bioeconomy, Potsdam, Germany. From the onset, the cauliflower curds were carefully stored in cold room of different designated temperatures (1, 5, 10 and 15 °C) before processing. Cauliflower processing (fresh-cut) was done under hygienic conditions at 5 °C, by cautiously separating the florets with the branch from the major stem to obtain branchlets.

2.2. Respiration rate

Respiration rate (RR) fresh-cut cauliflower was determined according to the method developed by Rux, Caleb, Fröhling, Herppich, and Mahajan, (2017); Rux, Caleb, Geyer, and Mahajan, (2017), at 1, 5 and 15 °C, using non-invasive in-house developed closed system by monitoring of carbon dioxide (CO_2) continuously. Respirometer with the sum of nine set-ups of respiration was utilized and respiration measurement for each temperature was carried out in triplicate. For each respiration cycle measurement, the respirometer set-up was designated to flush out the accumulated CO_2 automatically and take in the fresh air. The set-up fitted with a CO_2 infra-red non-dispersive sensor (Vaisala GmbH; Bonn, Germany) and has a measuring ability of 0–5000 ppm or 3 h cycle. One cycle consists of 150 min gas measurement with 30 min flushing-out gas and taking in fresh air. Fresh-cut (≈350 g) and uncut (trimmed with outer leaves) cauliflower heads (≈600 g) were placed into respirometer acrylic containers (8.2 L) (Rux, Caleb, Fröhling et al., 2017; Rux, Caleb, Geyer et al., 2017). The container was sealed hermetically by O-rings among the container and lid. RR was designed by Eq. (1):

$$y_{CO_2} = y^i_{CO_2} + \frac{RR\,W}{V_f}(t - t_i) \quad (1)$$

where RR is the CO_2 production rate (mg kg^{-1} h^{-1}), y^iCO_2 and yco_2 is CO_2 concentration (kPa) at the initial time t_i (h) (time zero) and at time t (h), respectively. W is the total weight of the sample (kg) and V_f is the free volume inside the jar (L) is determined by subtracting the volume of product from the total volume of the glass jar.

2.3. Transpiration rate

Mass loss approach was adopted to determine transpiration rate (TR) as reported by Caleb, Mahajan, Al-Said, and Opara, (2013). The experiment was carried out using full factorial design with two factors; RH and temperature, at four levels of 60, 76, 86 and 96% RH, and 1, 5, 10 and 15 °C, respectively. The experiment consisted of four test chambers placed within the cold storage set at the designated temperatures. Saturated salt solutions of $NaNO_2$ (60%, RH), NaCl (76%, RH), KCl (86%, RH) and KNO_3 (96%, RH) was used within the test chambers to independently control the RH, while temperature and RH within the test chambers were continually monitored using battery-powered sensor (HMP50; Campbell Scientific Inc., Utah, USA). These set-ups maintain a constant RH during the experimental run. Fresh-cut cauliflower (30–36 g) was placed on a petri-dish of known weight and fresh-cut cauliflower mass loss was daily measured with minimal exposure of the chambers in order to maintain RH. Mass loss was measured using an electronic balance (BOSCH-Wägesysteme. GmbH, Jungingen, Germany), with measuring range of 0 to 2000 g and accuracy of ± 0.01 g. Transpiration rate was calculated from the changes in mass over time and expressed as changes in fresh-cut cauliflower mass (g) per initial mass of cauliflower (kg) per unit time (h) as shown in Eq. (2):

$$TR = \frac{M_i - M}{t \times (\frac{M_i}{1000})} \quad (2)$$

where TR is the transpiration rate in mg/kg.h, M_i is the initial mass of the fresh-cut cauliflower in g and *M* is the mass of fresh-cut cauliflower in g at a weighed time (t) in hours. Five replicates were used for each storage condition and all measurements were taken at regular intervals. Transpiration rate model as a function of temperature and RH was developed by modifying the model reported by Sousa-Gallagher, Mahajan, and Mezdad, (2013) and by adding the term for transpiration rate at 100% RH as reported by Mahajan et al. (2016) (Eq. (3)):

$$TR = k_i \times (1\text{-}a_w)\,(1\text{-}\,e^{-\,aT}) + 8.6\ RR/2 \quad (3)$$

where a_w is the water activity (RH/100) of the container; T is the temperature (°C); and k_i is a coefficient related to the mass transfer coefficient, and a, b and c are empirical parameters. The factor 2 was used to convert respiration rate value from mg/kg h to ml/kg h.

It is important to underline that even under water saturated conditions of 100% RH, transpiration occurs due to respiratory heat generation (Rux et al., 2015; Mahajan et al., 2016). This increases the product surface temperature, thereby creating a gradient for water vapour pressure deficit between the product surface and the ambient air.

2.4. Integrated package design

Integrated packaging approach was implemented to select packaging material based on the understanding of the moisture evolution due to transpiration and respiration process of fresh-cut cauliflower and estimating the water vapour flux needed to maintain 95–100% RH. For base packaging material, bi-axially oriented polypropylene (PP) was used, which was fitted with varying area/ratio of cellulose film (NF) as to control transmission of water vapour, gas composition and in-package RH (Table 1). Double-sided hermetic sealing tapes were used to attach cellulose-based film windows to PP films and edges of the attached film were sealed again to ensure complete airtightness.

Polymeric films selected for this experiment contain distinctive permeability to water vapour and gases: Polypropylene Propafilm™