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Research Paper

Measurement and modelling of transpiration losses in packaged and unpackaged strawberries

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Transpiration and respiration are physiological processes well-known as major sources of fresh produce mass loss. Besides causing impairment of external quality, it is associated with economic loss since it inevitably decreases saleable weight. To prevent postharvest mass losses, by improved modified atmosphere and humidity packaging, comprehensive knowledge on the mechanistic basis of both processes and their interactions is essential. The objective of this study was to evaluate the contribution of these processes on mass loss of packaged and unpackaged strawberries. Experiments on a single strawberry were performed at 4, 12 and 20 °C; and 76, 86, 96 and 100% RH. Mass loss was also investigated as a function of number of strawberries and package volume at 12 °C. A combined model based on Arrhenius equation and Fick's first law of diffusion for an unpackaged single strawberry and a model based on degree of filling was developed and validated with packaged strawberries. These models have potential application towards the selection of optimal moisture control strategies for strawberries.

1. Introduction

Modified atmosphere packaging (MAP) systems have been extensively used to reduce physiological activity of fresh produce by modifying in-package gas composition as well as to reduce mass loss by maintaining high in-package air humidity (Caleb, Mahajan, Al-Said, & Opara, 2013a). Most of the packaging materials used for MAP have low water vapour permeability, and, therefore, the water vapour released by the product due to transpiration remains trapped inside the package, often leading to undesirable condensation (Bovi, Caleb, Linke, Rauh, & Mahajan, 2016). Thus, in order to lessen in-package water vapour condensation it is essential to

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Nomenclature

DOF	Degree of filling
MAP	Modified atmosphere packaging
MAHP	Modified atmosphere and humidity packaging
RH	Relative humidity (%)
TR	Transpiration rate
RR	Respiration rate
VPD	Water vapour pressure deficit
TR_m	Transpiration rate on mass basis (g kg^{-1} h^{-1})
m_i	Initial mass of the product (g)
m_t	Product mass (g) at a determined time (t) in hours (h)
P_s	Saturation vapour pressure (kPa)
P_a	Actual vapour pressure (kPa)
T	Surrounding temperature (°C)
BOPP	Bi-axially oriented polypropylene
K_i	Mass transfer coefficient
a_{wi}	Water activity of the commodity
a_w	Water activity of the storage air
a	Model constant coefficient
M_{sub}	Mass loss due to substrate
TMLR	Total mass loss rate
$V_{product}$	Product's volume (mL)
$V_{package}$	Package's volume (mL)

shift the system design from MAP to modified atmosphere and humidity packaging (MAHP). The main challenge of MAHP is to reduce condensation while still maintaining produce water loss as low as possible (Rodov, Ben-Yehoshua, Aharoni, & Cohen, 2010). The design based on MAHP not only takes into account the gas composition but also the in-package air humidity and moisture control strategies to maintain desirable relative humidity (RH) and thus reduce condensation (Bovi & Mahajan, 2017).

In order to design appropriate MAHP it is essential to understand how much water is released by the product. Water loss in fresh produce is commonly measured by quantifying the amount or the mass of water lost per unit of time, the transpiration rate (TR). Many models based on Fick's first law of diffusion have been proposed to calculate the TR of a wide range of horticulture products such as strawberry (Sousa-Gallagher, Mahajan, & Mezdad, 2013), pomegranate arils (Caleb, Mahajan, Al-Said, & Opara, 2013b), whole mushroom (Mahajan, Oliveira, & Macedo, 2008), tomatoes (Xanthopoulos, Athanasiou, Lentzou, Boudouvis, & Lambrinos, 2014), and pears (Xanthopoulos, Templalexis, Aleiferis, & Lentzou, 2017). These models are efficient and valid for single unpackaged products, but their application in a dynamic system to estimate the TR of packaged products have not yet been tested.

Furthermore, the quantity of mass loss over a given period of time has long been accepted as being the TR of fresh produce. This was based on the assumption that mass loss due to the oxidative breakdown of organic reserves (substrate loss) and the effects that respiration exerts on TR, by generating metabolic heat and by supplying additional water that can be lost in transpiration, are negligible (Shirazi & Cameron, 1993; Xanthopoulos et al., 2017). Recent studies, however, have pointed out the important role respiration plays on TR of fresh produce, under water vapour saturated environments which is normally seen in packaged fresh produce (Bovi, Caleb, Herppich, & Mahajan, 2018). For instance, Mahajan et al. (2016) developed a model to calculate TR based on respiration rate (RR). The authors calculated this effect on TR by multiplying RR with a conversion factor of 8.6 obtained from the respiratory heat and adding it to model of TR calculations based on Fick's first law of diffusion. Furthermore, the authors indicated that the heat of respiration increased the surface temperature of fresh mushroom above that of the surrounding air, thereby creating a water vapour pressure deficit (VPD) that may further drive transpirational water losses. In addition, Xanthopoulos et al. (2017) developed a model that analyses the contribution of transpiration and respiration on water loss using pears as a model product. Water loss indirectly resulting from respiration accounts for 39% of the total water loss as a result of water vapour pressure deficit at an air temperature of 20 °C and 95% RH.

The critical challenge in modelling TR and, consequently, water loss in fresh produce is that the parameters and/or coefficients of the model are product specific. Similarly, the appropriate moisture control strategy also needs to be product specific and has to be optimised considering the transpirational properties of each fruit or vegetable (Bovi, Caleb, Klaus, et al., 2018). This challenge implies that the respective physiological features of each type of fresh produce needs to be studied in detail and individually under each different storage condition and packaging system. In this context, the aim of this work was to develop a model to predict water loss from packaged fresh produce, with the potential application towards the selection of optimal moisture control strategies. With this aim, a comprehensive case study was carried out on the mass loss of packaged and unpackaged strawberries.

2. Materials and methods

2.1. *Sample preparation*

Freshly harvested strawberries were obtained from a commercial supplier (Obst und Gemüse Großhandle, Beusselstraße, Berlin) and immediately transported to the Department of Horticultural Engineering, Leibniz Institute for Agricultural Engineering and Bioeconomy, Potsdam, Germany. The strawberries were carefully sorted for uniformity in size and colour, and damaged, overripe and poor quality samples were discarded.

CO_2-based respiration rates (RR) of strawberries were determined by continuously monitoring rates of CO_2 production by a novel closed-system respirometer previously described by Rux, Caleb, Geyer, and Mahajan (2017). The respirometer consisted of acrylic glass cuvettes (8.2 l), each fitted with non-dispersive infrared CO_2 sensor (GMP222, Vaisala GmbH, Bonn, Germany). The RR was calculated as the amount of CO_2 per unit mass of the fruit per unit time (mg CO_2 kg^{-1} h^{-1}). Measurements were carried out for 6 h at 4, 12 and 20 °C.