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Research Paper

The contribution of transpiration and respiration in water loss of perishable agricultural products: The case of pears

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Transpiration and to a lesser degree respiration are two well-known processes of water loss from fresh agricultural products, associated with visual and texture degradation. Neglecting respiration as a water loss mechanism leads to erroneous results at saturation where, although the water vapour pressure deficit is zero and therefore water loss should be zero, on the contrary a finite water loss exists. In this context an experiment was set up to analyse the water loss associated with transpiration and respiration in pears (*Pyrus communis* L., *Kontoula*) at 0, 10 and 20 °C and 70%, 80% and 95% RH, as well as the air humidity of the cold storage. The choice of pears was based on the fact that they rank third among the most important tree fruits. The estimated transpiration rates ranged between 0.03 and 0.28 mg cm^{-2} h^{-1} for water vapour pressure deficit range of 0.0–0.52 kPa. The mean respiration rates were calculated at 0, 10 and 20 °C as 0.48 ± 0.1, 1.27 ± 0.2 and 3.48 ± 1.1 mL[CO_2] 100 g^{-1} h^{-1}. Quantification of the two sources of water loss showed that, close to saturation (20 °C and 95% RH), the water loss due to respiration accounts for 39% of the water loss due to water vapour pressure deficit while, on average, the water loss due to respiration accounts for 8%, 14% and 23% of the water loss due to water vapour deficit at 0, 10 and 20 °C. These findings justify why water loss due to respiration should not be neglected under certain environmental conditions.

1. Introduction

Pears are fresh agricultural products characterised by high moisture content (85–95% w.b) which makes them prone to water loss and hence perishable during unpackaged cold storage. The water loss takes place after harvest, driven by the mechanisms of transpiration and respiration, but unlike on the mother plant, it cannot be replaced from the root-soil system. Post-harvest losses originating from this water loss cause visual degradation, firmness loss and loss of succulence due to shrivelling which are associated with marketable loss. According to Ben-Yehoshua (1987), 3–10% loss of fresh mass is enough to initiate wilting and make products unusable. To extend shelf-life of perishable products, the rate of water loss must be controlled. Therefore, appropriate packaging, waxing

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Nomenclature

K'_i	pre-exponential mass transfer coefficient, $cm\ h^{-1}$ or $g\ kg^{-1}\ h^{-1}$
A_s	surface area of pear, cm^2
a_w	water activity
b, d	parameters of Eq. (4a)
d_e	effective diameter of pear, cm
D_v	diffusion coefficient of water vapour in air, $m^2\ s^{-1}$
E_a	activation energy, $J\ mol^{-1}$
k_a	air-film mass transfer coefficient, $mg\ cm^{-2}\ h^{-1}\ kPa^{-1}$
k_s	skin mass transfer coefficient, $mg\ cm^{-2}\ h^{-1}\ kPa^{-1}$
k_t	transpiration coefficient of the commodity, $mg\ cm^{-2}\ h^{-1}\ kPa^{-1}$
ML	mass loss, %
M_t	mass of pear at time t, g
r_e	effective radius of the product, m
R	gas constant, $J\ mol^{-1}\ K^{-1}$
RH	relative humidity of the surrounding air, %
RR	respiration rate, $mL[CO_2]\ 100\ g^{-1}\ h^{-1}$
R_{ref}	pre-exponential of respiration rate, $mL[CO_2]\ 100\ g^{-1}\ h^{-1}$
R_v	gas constant of water vapour, $J\ kg^{-1}\ K^{-1}$
T	absolute air temperature, K
t	storage time, h
T_r	reference temperature, K
TR_s	transpiration rate per unit surface area, $mg\ cm^{-2}\ h^{-1}$
TR_m	transpiration rate per unit of initial mass, $g\ kg^{-1}\ h^{-1}$
V	volume of lost water from the product during transpiration, cm^3
WL	water loss due to respiration rate, g[water] $kg^{-1}\ h^{-1}$
WVPD	water vapour pressure deficit, kPa
a, b, n	parameters of the temporal RR, Eq. (6b)

and optimal storage conditions (temperature and relative humidity) should be applied to extend the shelf-life of both fresh and fresh-cut agricultural products.

Transpiration has been well accepted as the most important process of water loss from fresh fruits and vegetables. However, in most of the cited cases of transpiration estimation, respiration is not considered as a self-contained mechanism of water loss, instead it is assumed that the respiration contribution to the overall water loss is very small compared to that originating from the water vapour deficit and therefore is negligible. According to Veraverbeke, Verboven, Oostveldt, and Nicolai (2003), transpiration involves water transport as liquid and vapour from intercellular spaces to cuticle, solubilisation and diffusion of water molecules in and across the cuticular membrane and desorption of water at the outer surface of the produce. Sastry and Buffington (1982, 1983) discussed how transpiration is influenced by *intrinsic factors* such as surface-to-volume or surface-to-mass ratio, surface injuries, morphological and anatomical characteristics (cuticular wax, cracks, lenticels, etc.), as well as maturity stage, and *extrinsic factors* such as air temperature, relative humidity and velocity. Song, Vorsa, and Yam (2002) and Mahajan et al. (2016) stressed the complex nature of water loss during postharvest handling and storage, pointing out the interaction between moisture evaporation taking place on the product's surface as a result of water vapour deficit and the concurrent respiratory activity. Bovi, Caleb, Linke, Rauh, and Mahajan (2016) reviewed the work that had been done on transpiration and how this can be used to improve postharvest life of agricultural products, packaged and unpackaged. For packaged products, understanding and dynamic quantification of transpiration under controlled environments is of great importance since it is associated with the condensation on the packaged products and the inner packaging surface, which in turn leads to quality degradation.

Respiration is the oxidative breakdown of complex substrate molecules (starch, sugars organic acids, etc.) into simpler molecules such as CO_2 and H_2O with production of energy and intermediate molecules to maintain the numerous anabolic reactions essential for the maintenance of cellular organisation and membrane integrity of living cells (Kader & Saltveit, 2003). Respiration is affected by a number of factors that can be divided into *internals* (commodity) such as type of product and genotype, stage of development at harvest, climacteric nature, the chemical consistence and *externals* such as temperature, O_2 and CO_2 levels in the storage atmosphere, C_2H_4 levels especially in climacteric fruits and finally the presence of wounds and bruises in combination with high storage temperatures as well as water stress inducing physical stress.

The objectives of this study are the analysis and quantification of the water loss in fresh whole fruits due to transpiration and respiration mechanisms and modelling of transpiration rate regarding the storage temperature, relative humidity and time as well as modelling respiration rate regarding the storage temperature and time. Based on the stoichiometric analysis, the water loss due to oxidative respiration is estimated and compared to the water loss related to water vapour pressure deficit.

2. Materials and methods

2.1. *Raw material*

Pear fruits (*Pyrus communis, var. Kontoula*) of a summer grown variety were bought from a producer in northern Peloponnese, Greece. The fruits were picked based on their maturity stage to ensure uniformity. The initial average mass was 106.8 ± 7.9 g and the respective volume 100.9 ± 13.9 cm^3 (mass range 96.6–127.8 g). The fruits were transported under refrigerated conditions to the laboratory where defective fruits were discarded and the remaining fruits cleaned with kitchen tissue. No pre-treatment was applied.