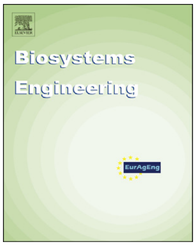
BIOSYSTEMS ENGINEERING 124 (2014) 16–23

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110



Research Paper

Modelling of transpiration rate of grape tomatoes. Semi-empirical and analytical approach

Georgios T. Xanthopoulos [a,*], Athanasios A. Athanasiou [a], Diamanto I. Lentzou [a], Andreas G. Boudouvis [b], Grigorios P. Lambrinos [a]

[a] Agricultural University of Athens, Department of Natural Resources Management, and Agricultural Engineering, 75 Iera Odos Str., 11855 Athens, Greece

[b] National Technical University of Athens, School of Chemical Engineering, 9 Heroon Polytechniou Str., 15780 Zografou, Greece

ARTICLE INFO

Article history:
Received 15 November 2013
Received in revised form
20 May 2014
Accepted 2 June 2014
Published online 20 June 2014

Keywords:
Water loss
Grape tomato
Cold storage
Transpiration rate
Water vapour pressure deficit

Transpiration is a well known physiological process of water loss from fresh products, associated with visual and texture degradation and loss of market value. A loss of 3–5% of the initial mass may cause in fresh products loss of freshness and visual attractiveness. Grape tomato has been increasingly accepted by consumers as "snacking tomato" and as an ingredient in mixed salads of fresh-cut vegetables. An experimental procedure was developed to record the associated with transpiration, water loss in grape tomatoes (*Solanum lycopersicum*, *Lobello F1*), at temperatures 10, 15 and 20 °C and relative humidity 70, 80 and 92%. Water activity was calculated and correlated with the respective mass loss; its average value was found 0.988 ± 0.01. The mean transpiration rates ranged between 0.012 and 0.058 mg cm^{-2} h^{-1} for water vapour pressure deficit range of 0.061–0.662 kPa. A semi-empirical and an analytical model were developed to correlate the mass loss of grape tomatoes with the storage conditions (temperature and relative humidity) and storage time. Both provided satisfactory fit to the experimental data. Finally, the air-film mass transfer coefficient (k_a) and skin mass transfer coefficient (k_s) were calculated and the k_s coefficient correlated efficiently with an exponential equation with the respective water vapour pressure deficit.

1. Introduction

Water contributes more than 90% of the mass of ripe tomatoes (Ho, Grange, & Picken, 1987). Fresh agricultural products continue to lose water after harvest due to transpiration and respiration, but unlike the mother plant, they cannot replace it from the soil. Post-harvest water loss causes visual degradation due to shrinkage and mass loss which is associated with financial loss. According to Ben-Yehoshua (1987), 3–10% loss of the fresh mass is enough to initiate wilting and to make products unusable. To extend products self-life, the rate of water loss must be controlled as much as possible. Therefore, appropriate packaging and optimal storage conditions should be applied to extend the shelf-life of both fresh and fresh-cut products.

---

* *Corresponding author*. Tel.: +30 210 5294031; fax: +30 210 5294032.
E-mail address: xanthopoulos@aua.gr (G.T. Xanthopoulos).

http://dx.doi.org/10.1016/j.biosystemseng.2014.06.005

Nomenclature

K'_i	Pre-exponential mass transfer coefficient, cm h^{-1} or g kg^{-1} h^{-1}
A_s	Surface area of grape tomato, cm^2
a_w	Water activity
b, d	Parameters of Eq. (3a)
d_e	Effective diameter of grape tomato, 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 grape tomato at time t, g
R	Gas constant, J mol^{-1} K^{-1}
r_c	Effective radius of the product, m
RH	Relative humidity of air, %
R_v,	Gas constant of water vapour, J kg^{-1} K^{-1}
T	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
WVPD	Water vapour pressure deficit, kPa
ρ_w	Water density at T_r, mg cm^{-3}

Transpiration has been well accepted as one of the critical physiological processes in fresh fruits and vegetables. 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 product. Transpiration rate during post-harvest handling and storage, 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, stomata, etc), as well as maturity stage, and extrinsic factors such as temperature, relative humidity, air velocity (Sastry & Buffington, 1982, 1983). Mathematical models for the prediction of transpiration rate in fresh and fresh-cut products are limited in the literature. This is due to the complex interaction between moisture evaporation on the product surface as result of water vapour pressure difference and also due to product metabolic activity (Song, Vorsa, & Yam, 2002).

Grape and cherry tomatoes known also as 'snacking' tomatoes have grown in popularity the recent years. In USA supermarkets, the trade value of grape tomatoes is estimated at 1/4 of the total value of all traded tomatoes. New marketing opportunities, in the packaging of mixed salads of fresh-cut vegetables, expose fruit to temperatures of 5 °C or lower, often in combination with modified atmospheres, with an expected shelf-life of 14–18 days. These conditions are at odds with post-harvest recommendations for good tomato quality (Cantwell, Nie, & Hong, 2009). A few studies have characterised the changes in small tomatoes stored at lower than recommended temperatures, with or without modified atmosphere packaging (Akbudak, Akbudak, Seniz, & Eris, 2007; Ilic & Fallik, 2007). The small grape tomatoes are susceptible to water loss during handling and storage, and symptoms of shrivel, dehydration and softening are highly correlated with weight loss. Mass loss of near ripe grape tomatoes in vented plastic consumer packaging contributes to changes in overall visual quality and also loss of firmness (Cantwell et al., 2009).

The objectives of this study are the measurement and modelling of the water loss in fresh whole grape tomatoes due to transpiration and the development of predictive models to relate transpiration rate to storage temperature, relative humidity and storage time. Based on the tested conditions, the skin mass transfer and air-film mass transfer coefficients are calculated and a relationship associating the skin mass transfer coefficient with the water vapour pressure deficit is determined.

2. Materials and methods

2.1. *Raw material*

Grape tomatoes (*Solanum lycopersicum*, *Lobello F1*) of maturity stage "pink", grown in a greenhouse at Marathon area, Attica, Greece were hand-picked and transported to the laboratory in chilled conditions. The picked tomatoes were of uniform mass, 11.6 ± 1.3 g and volume 10.7 ± 1.2 cm^3. In the laboratory, defective tomatoes were discarded and the remaining cleaned with kitchen cloth. No pre-treatment was applied.

2.2. *Experimental setup*

The experimental setup (cf. Fig. 1) consisted of nine test containers (70 L each) located within three cold rooms (16 m^3 each) with adjustable room temperature. Three temperature levels were tested 10, 15, 20 °C and three relative humidity levels (RH) 70, 80 and 92%. The relative humidity levels in the containers were independently adjusted using the static method of saturated salt solutions of sodium bromide and sodium chloride as well as deionised water according to Greenspan (1977). The relative humidity levels in the containers were found higher by 5–8% (RH values) than those reported by Greenspan (1977) due to increased number of tested samples per container and the produced water vapour, and the chosen experimental rig. Salt solutions were placed in two large glass pans (Fig. 1), covering the base of the container, under a wire mesh serving as the supporting frame where grape tomatoes were placed sufficiently apart. The containers were equipped with a small diameter tube which communicated with the cold storage atmosphere to ensure that the internal atmosphere composition (O_2 and CO_2) did not change due to tomatoes respiration. The atmosphere in the containers was monitored, throughout the experiments, using a