Postharvest Biology and Technology 140 (2018) 27–33

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Modelling the influence of storage temperature and time after cutting on respiration rate of diced red onions (*Allium cepa* L. cv. *Vermelha da Póvoa*)

Susana C. Fonseca[a], Luísa Gil[a], Maria C. Manso[b], Luís M. Cunha[a,*]

[a] GreenUPorto & LAQV-REQUIMTE, DGAOT, Faculty of Sciences, University of Porto, Campus Agrário Vairão, Rua Padre Armando Quintas 7, 4485-661 Vila do Conde, Portugal

[b] Faculty of Health Sciences, UFP Energy, Environment and Health Research Unit (FP-ENAS), University Fernando Pessoa, & LAQV-REQUIMTE, University of Porto, Praça 9 de Abril 349, 4249-004 Porto, Portugal

ARTICLE INFO

Keywords:
Mathematical modelling
Minimally processed vegetables
Fresh-cut
Oxygen consumption rate
Carbon dioxide production rate

ABSTRACT

Ready-to-use diced onions are very convenient to final consumers and food service companies due to unpleasant pungency and lacrimation effects during bulb cutting. Nevertheless maintaining freshness and functional quality of diced onions is a challenge in the food industry. Thus it is important to know and model the influence of external factors on the product respiration phenomena in order to better control product deterioration. The respiration rate (RR) of diced red onions (*Allium cepa* L., cv. *Vermelha da Póvoa*) was studied over a period of storage time after dicing at different temperatures (4, 8, 12, 16 and 20 °C) under a normal atmosphere.

At each of the tested temperatures, RR for both O_2 and CO_2 showed an exponential increase over time. This effect was enhanced with temperature. It was further observed that both the initial RR and reaction rate constants changed with temperature according to an Arrhenius-type equation with identical activation energy. This effect was incorporated in the primary model and the fit of the global model to experimental data was good (R^2 = 0.94), with normal distribution of the residuals and correlation coefficients between the model constants below 0.85. Results helped establish a global mathematical model describing RR dependency on temperature over a period of storage time after dicing onions that will allow for a proper package design of this product.

1. Introduction

The distinctive flavour of onions has led to its incorporation in gastronomic cuisine across the globe (Lawande, 2012). Nonetheless, health benefits linked to it consumption (Griffiths et al., 2002; Kris-Etherton et al., 2002; Suleria et al., 2015) also underlies the increasing popularity of this produce. As a consequence, a wide diversification of the onion market has been observed by the introduction of new cultivars as well as the expansion of onion-based convenience products (dried, frozen, canned, pickled, and in particular minimally processed) as a form to approach nowadays consumer's needs.

The convenience of buying fresh-cut onion is consequently related to the maintenance of nutritional and sensorial properties of fresh onion as it allows for its raw consumption and to its enormous usefulness in avoiding the preparation hardness linked to onion pungency and lacrimation.

On the other hand, minimally processed products, that suffered tissue and cell integrity disruption as a consequence of processing operations, particularly peeling and cutting operations, evidence an increase in enzymatic, respiratory and microbiological activity, and a concomitant decrease in their shelf-lives comparing to the raw commodity (Watada et al., 1996; Toivonen and DeEll, 2002). Therefore, the ultimate importance of respiration studies in the postharvest field comes from the inversely proportional relation between respiration rate (RR) and the shelf-life of the produce (Kader and Saltveit, 2002).

Measured respiration rate (as CO_2 production rate (RCO_2) and/or O_2 consumption rate (RO_2)) of minimally processed products enclose cellular respiration: the metabolic process that provides energy to the plant through the oxidative breakdown of organic reserves (carbohydrate, lipids and organic acids) into simpler molecules, including CO_2 and water and an intense cascade of other oxidative processes, the so-called residual respiration, as a result of wound metabolism (Kader and Saltveit, 2002; DeEll et al., 2003). In addition to a physiological produce metabolism, microorganism activity, might also contribute to the apparent RR (Kang and Lee, 1997).

To these particularly sensitive products, with a remarkable increase in consumption, the preservation of quality is based on the use of hurdle technology that combines different processes, such as temperature control and modified atmosphere packaging (MAP). The MAP concept rests on the progressive reduction of RR verified under optimum

* Corresponding author.
E-mail address: lmcunha@fc.up.pt (L.M. Cunha).

https://doi.org/10.1016/j.postharvbio.2018.02.003
Received 9 October 2017; Received in revised form 7 February 2018; Accepted 8 February 2018

Nomenclature

Ea	activation energy (kJ mol^{-1})
Ea_k	activation energy regarding the reaction rate constant (kJ mol^{-1})
Ea_{Ro}	activation energy regarding the initial respiration rate (kJ mol^{-1})
k	reaction rate constant (h^{-1})
k_{ref}	reaction rate constant at the reference temperature (h^{-1})
M	mass of the product (kg)
MAP	modified atmosphere packaging
n	sample size
p	p-value, probability value associated with the statistical tests
p	number of estimated parameters
P	total pressure (Pa)
PPO	polyphenoloxidase
Q10	temperature coefficient for a 10 °C rise in a reaction rate
R	estimated respiration rate (μmol kg^{-1} h^{-1})
R_0	initial respiration rate (μmol kg^{-1} h^{-1})
R_{0ref}	initial respiration rate at the reference temperature (μmol kg^{-1} h^{-1})
R^2	coefficient of determination
R_c	universal gas constant (J mol^{-1} K^{-1})
RCO_2	CO_2 production rate (μmol kg^{-1} h^{-1})
RO_2	O_2 consumption rate (μmol kg^{-1} h^{-1})
RQ	respiratory quotient
RR	respiration rate
$RSS_{90\%}$	90% confidence residual sum of squares
RSS_{min}	residual sum of squares
T	temperature (°C or K)
t	time (h)
t_f	final time of the measuring period (h)
t_i	initial time of the measuring period (h)
T_{ref}	reference temperature (K)
V	volume of the jar (m^3)
V_f	free volume inside the jar (m^3)
$y^f_{CO_2}$	CO_2 volumetric concentration at time tf (% v/v)
$y^f_{O_2}$	O_2 volumetric concentration at time t_f (% v/v)
$y^i_{CO_2}$	CO_2 volumetric concentration at the initial time t_i (% v/v)
$y^i_{O_2}$	O_2 volumetric concentration at the initial time t_i (% v/v)
ρ	product volumic mass (kg m^{-3})

atmosphere (usually reduced O_2 and elevated CO_2 levels) until a steady-state is achieved, when O_2 consumption/CO_2 production rates equals the package permeability of these gases (Kader et al., 1989; Al-Ati and Hotchkiss, 2002; Laurila and Ahvenainen, 2002).

The RR modelling is crucial to the design of MAP for fresh fruits and vegetables and requires the development of equations relating respiration rate to various influencing factors of the package-environment-commodity system (Al-Ati and Hotchkiss, 2002; Hertog, 2003). As a result of the complex nature of the respiratory process, the usual approach to develop predictive models concerns empirical modelling of data obtained for each type of commodity as a function of controllable variables (Fonseca et al., 2002b). Further, empirical models, generally described by a simple equation (or set of equations), have revealed to be a valuable way of making deductions about physiological mechanisms (Thornley and France, 2007). Regardless of the physiological basis responsible for the alteration of the surrounding atmosphere composition, knowledge of the final effect in the system is of primary importance for MAP designing and so is the accurate prediction of the apparent respiration.

For each type of product, temperature, followed by gas composition, is by far the most determinant factor for the postharvest physiological evolution (Kader et al., 1989). The modelling of the temperature increasing effect on the respiration rate was simplified beforehand by the Q10 temperature coefficient that represents the factor by which the rate of a reaction increases for every 10 °C rise in the temperature, only valid within certain temperature ranges (Kader and Saltveit, 2002). Published works used some form of the Arrhenius equation to describe the exponential effect of temperatures practiced over the distribution chain on respiration rate (Brash et al., 1995; Hertog et al., 1998; Varoquaux et al.,1999; Jacxsens et al., 2000). Regarding statistical considerations, the development of adequate models for the effect of temperature should be comprised of a range of temperatures as large as possible and within interest (Sousa et al., 2017).

Contrasting with the effect of temperature, alterations of the RR over a period of storage time after cutting the product are different according to the type of product or the treatment applied and are not considered in RR predictive models, although its interest is growing in recent years. Different models (negative exponential, Weibull, 2nd order polynomial and linear) were already used to describe the effect of time on the respiration rate of different products (Yang and Chinnan, 1988; Brash et al., 1995; Smyth et al., 1998; Böttcher et al., 1999; Zhu et al., 2001; Fonseca et al., 2002a; Martínez-Romero et al., 2003; Nourian et al., 2003; Surjadinata and Cisneros-Zevallos, 2003; Uchino et al., 2004; Iqbal et al., 2005; Del Nobile et al., 2006; Nei et al., 2006; Iqbal et al., 2009; Waghmare et al., 2013; Waghmare et al., 2014; Azevedo et al., 2015), even though no previous studies on respiration rate modelling of diced onions have been found in literature.

The aim of this study was to investigate the effects of storage temperature and time on the respiration rate of diced red onions under a normal atmosphere, and to develop a predictive mathematical model accounting for the effect of both, time and temperature.

2. Material and methods

2.1. Sample preparation and storage conditions

Red onions (*Allium cepa* L., cv. *Vermelha da Póvoa*) were bought from a local retailer in Porto (Portugal). Onions were sorted, peeled, washed with cold water (1 °C), towel-dried, diced with a manual cutter (± 0.7 cm × 0.7 cm), washed with a sodium hypochlorite solution (124 mg/L of free or available chlorine; pH = 7 adjusted with HCl − 37% PA-ACS-ISO, Panreac Quimica, Spain-) in a still bath for 1 min in a product/solution ratio of 1:5 and centrifuged with a salad spinner to remove excess water. Diced onions were weighted (approximately 250 g) with a decimal balance and stored in straight cylindrical glass jars (V = 1.9 L).

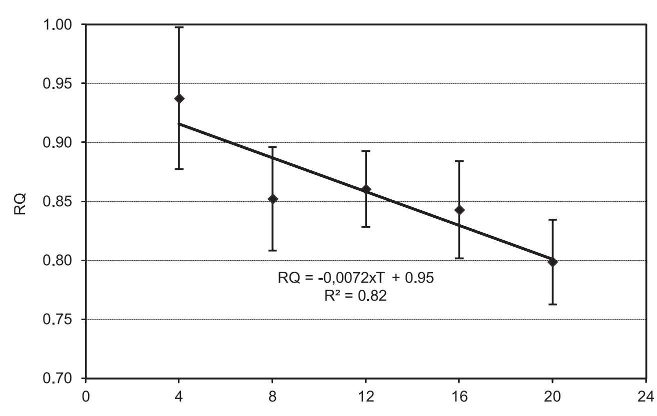

Fig. 1. Effect of temperature on respiratory quotient (RQ) of diced red onions. Dots represent experimental data (average ± 95% confidence interval) and the line representing the fit of the model.