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Modelling the transient effect of 1-MCP on 'Hass' avocado softening: A Mexican comparative study

Salvador Ochoa-Ascencio[a,*], Maarten L.A.T.M. Hertog[b], Bart M. Nicolaï[b]

[a] Facultad de Agrobiologia, Universidad Michoacana de San Nicolas de Hidalgo, Uruapan Michoacan, Mexico
[b] BIOSYST-MeBioS, Katholieke Universiteit Leuven, W. de Croylaan 42, B-3001 Leuven, Belgium

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ABSTRACT

In this study the effect of 1-methylcyclopropene (1-MCP) on the softening of avocado fruit (*Persea americana* Mill.) cv. Hass was modelled. Data were collected throughout the 2006 season by sampling 40 batches of fruit from 8 different commercial orchards in the region of Michoacan (Mexico). A simplified mechanistic model was developed to analyse the experimental data. Most of the model parameters were treated as being generic for all fruit while only two of the model parameters were identified as being unique to each individual fruit. The two fruit specific parameters characterised the maturity at harvest of an individual fruit and the sensitivity of an individual fruit to 1-MCP. Monte Carlo simulations were performed. The model was able to describe the individual fruit behaviour very well explaining more than 95% of the observed variation for most of the fruit. The model successfully quantified the effect of 1-MCP on avocado softening taking into account the stochastic nature of batch behaviour. The developed model can be utilised to predict the behaviour of a specific batch of 'Hass' avocado fruit given the distribution of the two fruit specific model parameters.

1. Introduction

The avocado differs from most other fruits in that ripening normally does not take place on the tree, but only after picking. The most obvious feature of avocado fruit ripening is softening. At harvest, the mesocarp firmness of avocado fruit measured as a non-destructive compression force is generally in the range of 80–100 N and initially declines at a moderate rate. The softening rate increases with time resulting in firmness levels of less than 5 N at a full ripe state. Previous studies have shown that avocado firmness is a good predictor of ripening stage and expected storage time (Lewis, 1978; Peleg et al., 1990).

It is well established that avocado fruit softening is the result of the activity of cell wall degrading enzymes with some pre- and postharvest factors affecting the rate of softening and final quality (Awad and Young, 1979; Bower and Cutting, 1988). Unpredictable ripening during storage, transport and distribution can result in spoilage before consumption. Furthermore, firmness heterogeneity in avocado fruit batches complicates the use of postharvest treatments to maintain quality.

Ethylene is believed to take a central role in regulating fruit ripening of avocado (Jeong and Huber, 2004). The application of 1-MCP is known to block ethylene binding sites (Sisler and Serek, 1997) and has been shown to be effective in inhibiting the ripening of avocado (Adkins et al., 2005). Depending on the timing of application relative to the climacteric development, the treatment can be more or less effective (Hershkovitz et al., 2005) as, once triggered, the ripening process is hard to stop.

If avocado fruit softening can be characterised during storage, an objective measurable at-harvest criterion can be developed to determine the potential postharvest life of avocado. This would allow early segregation of fruit into fast and slow ripening fruit enabling the industry to apply the appropriate marketing strategy to the different groups of fruit. This would facilitate inventory management and reduce fruit losses. The ability to predict the rate of fruit softening would benefit growers, packers, shippers, retailers and consumers alike.

The aim of this work is to characterise and quantify the transient effect of 1-MCP on 'Hass' avocado softening taking into account the inevitable variation introduced by batches coming from different harvests, growers and dry matter contents throughout the season.

2. Material and methods

2.1. Produce

Experimental data were collected during studies in 2006 which assessed the response of avocado fruit (*Persea americana* Mill.,

* Corresponding author. Tel.: +52 4525236474; fax: +52 4525247007.
E-mail address: salvadorochoa@prodigy.net.mx (S. Ochoa-Ascencio).

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cv. Hass) from commercial orchards in the region of Michoacan (Mexico) to 1-MCP treatment. During the 2006 season, fruit were collected at 14 different sample times from February to October, from 8 different locations in the region resulting in 40 different batches of 40 or 60 avocado fruit (Table 1). Fruit from all batches were of export quality (count size 20) and commercially packed into single-layered trays. Fruit were couriered to Michoacan University and placed in 117.3 L gas-tight containers (Rubbermaid®) at 5 °C and subsequently treated with 0, 200 or 300 nL L^{-1} 1-MCP for 12 h (Table 1). 1-MCP was released by adding a buffering agent to a calculated number of SmartFresh™ research tablets (a.i. 25 μg; Agrofresh Ltd.) according to the manufacturer's instructions. A circulating system ensured rapid diffusion of the gas. After the 1-MCP treatment, fruit were kept at 5 °C and 90% relative humidity for 18 to 32 d depending on the batch (Table 1).

2.2. Quality measurements

After the 1-MCP treatment and the subsequent storage period, both at 5 °C, fruit were moved to shelf-life conditions at 22 °C (±1 °C). During this shelf-life period, non-destructive fruit firmness was measured with a Fruit Texture Analyzer (Model GS-14) fitted with a convex tip (8 mm diameter), trigger threshold of 0.50 N and measuring speed of 10 mm s^{-1}. The compression force was recorded in newtons (N) at 2 mm deformation and was determined at three equidistant points on the equatorial region of each whole fruit. Repeated measurements were taken from the same fruit every day until they reached the full-ripe stage. Depending on the actual batch and the 1-MCP treatment applied shelf-life covered a period of between 3 and 9 d.

2.3. Data analysis

As indicated above, the experimental design was the same for all batches except for some details on timing and shelf-life temperature. However, data from all batches were analysed taking into account these batch-to-batch differences in terms of the length of the actual cold storage period (ranging from 18 to 32 d) and the actual length (ranging from 3 to 9 d) and temperature (ranging from 20.7 to 23.4 °C) of the shelf-life period. In this way, these variations in the experimental setup cannot obscure the statistical outcome of the analysis.

The developed model was implemented and model parameters were estimated using OptiPa (Hertog et al., 2007a; http://perswww.kuleuven.be/~u0040603/optipa/), a dedicated optimisation tool which was developed for use with Matlab (Matlab R2006b, The MathWorks, Inc., Natick, MA, USA). Monte Carlo simulations were performed using OptiPa as well; generating values for the stochastic Monte Carlo model parameters (t_{age} and t_{MCP}) based on the previously collated distributions of the estimated values of these parameters. The technique used for random generation of correlated non-Gaussian model parameters was described in detail by Hertog et al. (2008).

3. Model development

3.1. Modelling softening

Softening of avocado generally follows a logistic trend and has been modelled using a simple logistic model (Hertog et al., 2003). Comparable model equations have been previously applied successfully to describe both colour and firmness changes as a function of time (Schouten et al., 1997; Tijskens et al., 2000; Hertog, 2002; Hertog et al., 2003, 2004, 2007b). Such a logistic model can be interpreted as a simplified representation of an autocatalytic process as

Table 1
Overview of all 40 batches involved (ID) showing their origin, the dry matter content, the start date of the 1-MCP treatment, the 1-MCP levels applied and the duration of the cold storage period (5 °C) preceding shelf-life at 22 °C

ID	Growing region	Dry matter content (%)	Start 1-MCP application	1-MCP levels applied (nL L^{-1})	Length of cold storage (d)	ID	Growing region	Dry matter content (%)	Start 1-MCP application	1-MCP levels applied (nL L^{-1})	Length of cold storage (d)
1	San Juan Nuevo	32.8	10/02/2006	200–0	21	21	Tacambaro	36.9	2/06/2006	300–0	23
2	Tancitaro	32.9	10/02/2006	200–0	21	22	Tancitaro	33.6	2/06/2006	300–0	23
3	Tacambaro	35.3	10/02/2006	200–0	21	23	Uruapan	30.5	2/06/2006	300–0	23
4	Uruapan	33.6	24/02/2006	200–0	23	24	Tancitaro	29.1	16/06/2006	300–0	21
5	Tancitaro	30.5	24/02/2006	200–0	23	25	San Juan Nuevo	38.7	16/06/2006	300–0	21
6	Salvador Escalante	35.3	24/02/2006	200–0	23	26	Uruapan	33.4	16/06/2006	300–0	21
7	Ario de Rosales	34.4	10/03/2006	300–0	21	27	Uruapan	33.6	30/06/2006	300–200–0	23
8	Tancitaro	30.2	10/03/2006	300–0	21	28	Tancitaro	32.0	30/06/2006	300–200–0	23
9	Tacambaro	34.6	8/04/2006	200–0	20	29	Tancitaro	35.1	13/07/2006	300–200–0	16
10	Uruapan	33.8	8/04/2006	200–0	20	30	Acuitzio	32.6	13/07/2006	300–200–0	16
11	Tancitaro	31.9	8/04/2006	200–0	20	31	Salvador Escalante	35.7	13/07/2006	300–200–0	16
12	Tancitaro	38.3	20/04/2006	200–0	24	32	Periban	26.1	29/09/2006	300–200–0	23
13	Uruapan	35.9	20/04/2006	200–0	24	33	Uruapan	25.7	29/09/2006	300–200–0	23
14	Salvador Escalante	34.8	20/04/2006	200–0	24	34	Ario de Rosales	25.2	29/09/2006	300–200–0	23
15	Tancitaro	37.8	5/05/2006	200–0	21	35	Salvador Escalante	30.3	13/10/2006	300–200–0	24
16	San Juan Nuevo	36.8	5/05/2006	200–0	21	36	Periban	26.0	13/10/2006	300–200–0	24
17	Ario de Rosales	36.7	5/05/2006	200–0	21	37	Uruapan	25.4	13/10/2006	300–200–0	24
18	Uruapan	35.7	19/05/2006	200–0	21	38	Uruapan	27.4	27/10/2006	300–200–0	31
19	Tancitaro	39.0	19/05/2006	200–0	21	39	Ario de Rosales	28.1	27/10/2006	300–200–0	31
20	Tancitaro	36.6	19/05/2006	200–0	21	40	Tancitaro	24.9	27/10/2006	300–200–0	31