FEASIBILITY OF COMPUTER VISION AS PROCESS ANALYTICAL TECHNOLOGY TOOL FOR THE DRYING OF ORGANIC APPLE SLICES

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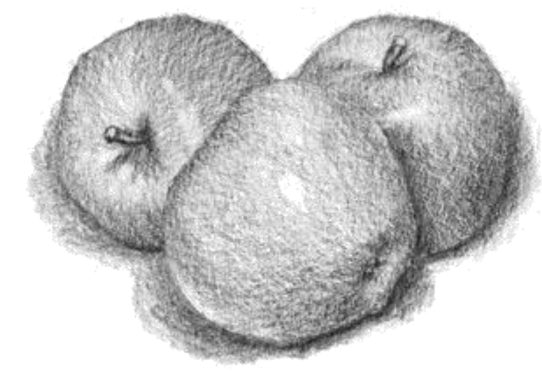


Abstract

Usage of computer vision (CV) as Process Analytical Technology tool in drying of apple slices was tested. Samples were subjected to various anti-browning treatments at sub- and atmospheric pressures, and dried at 60°C up to a moisture content (dry basis) of 0.18 g/g. CV-based prediction models of changes in moisture content (wet basis) were developed and promising results were obtained ($R^2P > 0.99$, RMSEP = 0.01÷0.06 and BIASP < 0.06 in absolute value), regardless of the anti-browning treatment.

Keywords

Image analysis; dipping treatments; vacuum impregnation; chemometrics; smart drying

Introduction

Apples are the fourth most consumed commercial fruit with a growing trend in their consumption as snacks, chips or integral breakfasts (Aghilinategh *et al.,* 2015; Vega-Gàlvez *et al.,* 2012). In this context, food drying plays a major role for processing and storage. To alleviate discolouration during hot-air drying of apple pre-treatments are recommended which may affect product drying kinetics and modelling of thin-layer behaviour (Sturm *et al.,* 2012). Among emerging drying techniques, smart drying is one of the recent and most promising technology to evaluate ideal drying conditions (Moscetti *et al.,* 2018). It enables to proactively monitor quality changes in product as well as dryer operating conditions, through an interdisciplinary approach such as chemometrics (Pomerantsev and Ye, 2012), artificial intelligence (Sun *et al.,* 2018), biomimetics (e.g. electronic nose, tongue and mucosa), computer vision (Sturm *et al.,* 2014) as well as single-point spectroscopy and hyper/multi-spectral imaging (Moscetti *et al.,* 2018).

The objective of this study was to evaluate both feasibility and robustness of computer vision as Process Analytical Technology tool for modeling the drying kinetics of apple slices subjected to various anti-browning treatments.

Methodology

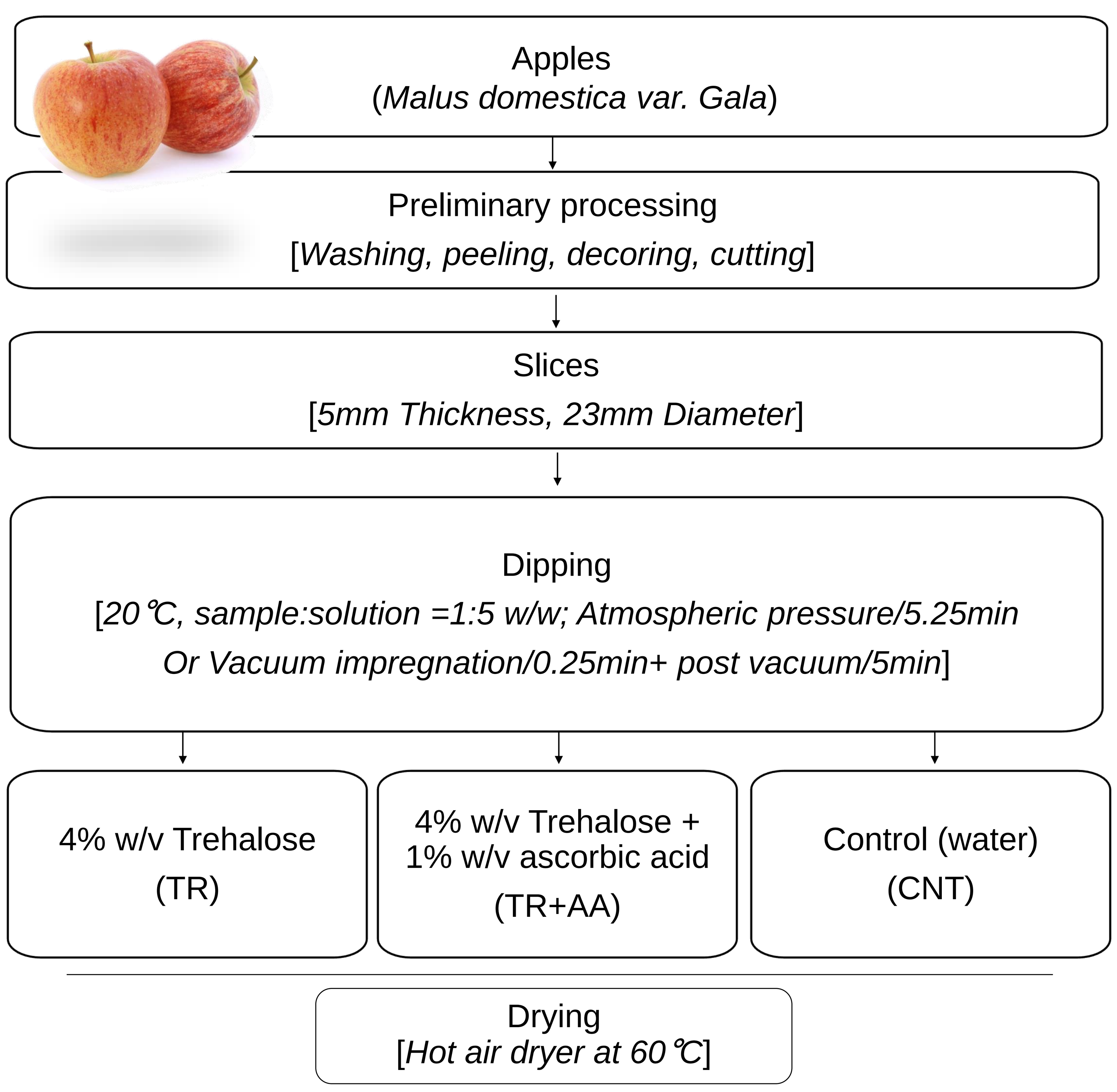


Figure 1 Schematic for experimental set-up for pre-treatment and drying of apple slices

Drying monitoring and Control set-up

- Hot-air dryer mod. Biosec (Tauro Essicatori, Italy) added with ad-hoc digital balance mod. HT1500 (NHU, Germany), a camera mod. EOS 400D (CANON, Japan) with 4200K illuminant source.
- Single-board computer mod. Raspberry Pi B+ (Raspberry Foundation, UK) combined with a self-made Jupyter Notebook (Project Jupyter, USA).

Data collection

Image, surface morphological features and weight of samples at constant time intervals of every 5 min and 4 sec, respectively.

Relative area shrinkage: $S_b = \frac{S_t}{S_0}$

where S_b is 'relative area shrinkage', S_t is the 'surface area' in pixels at the drying time 't', and S_0 is the 'surface area' in pixels of the fresh sample.

Statistical analysis

MC_{wb} *vs.* relative area shrinkage Linear prediction (PLS) models by R software v3.4.1. Model performances evaluated by Root Mean Square Error (RMSE), BIAS and coefficient of determination (R^2) of calibration (Cal.) and prediction (Pred.).

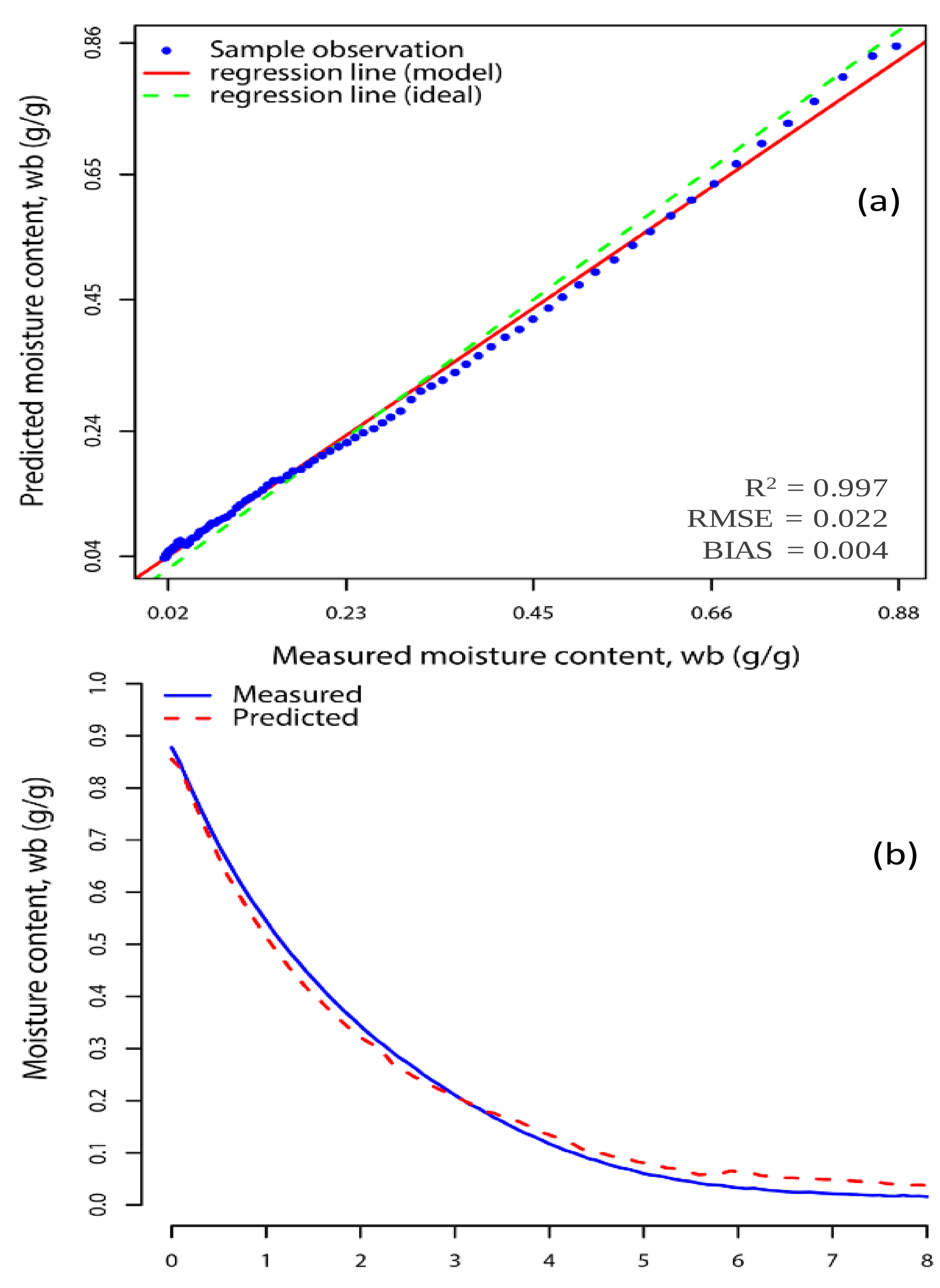
Results and discussion

- The wet-basis moisture content (MC_{wb}) was successfully predicted using spatial information with excellent prediction capabilities (table 1).
- VI treatments exhibited higher initial moisture content than atmospheric dipping treatments with the initial MC_{db} between 8.90 and 7.01 g/g.
- The models for VI samples had lower predicting performances and were less robust due to the high porosity of apples and subsequent texture alteration by VI.

Table 1. Summary of performance metrics of the linear regression models.

Dipping solution	VI[a]	RMSE[b] Cal.	RMSE[b] Pred.	BIAS[c] Cal.	BIAS[c] Pred.	R^{2d} Cal.	R^{2d} Pred.
CNT[e]	No	0.009	0.019	$-2.98\ 10^{-17}$	-0.008	0.998	0.993
TR[f]	No	0.014	0.017	$-1.15\ 10^{-17}$	0.007	0.997	0.996
TR+AA[g]	No	0.008	0.022	$1.59\ 10^{-17}$	0.004	0.999	0.997
CNT	Yes	0.008	0.058	$-1.79\ 10^{-17}$	-0.055	0.999	0.999
TR	Yes	0.010	0.051	$-2.64\ 10^{-17}$	-0.049	0.998	0.999
TR+AA	Yes	0.005	0.011	$1.33\ 10^{-17}$	-0.041	1.000	0.999

[a] *VI: Vacuum Impregnation (Yes and No stay for sub-atmospheric and atmospheric pressure, respectively).*
[b] *RMSE: Root Mean Squared Error of calibration (Cal.) and prediction (Pred.).*
[c] *BIAS: difference between the moisture content's expected value and the true value of the moisture content.*
[d] *R^2: coefficient of determination of calibration (Cal.) and prediction (Pred.).*
[e] *CNT: control (i.e. water dipping solution).*
[f] *TR: trehalose 4% w/v aqueous dipping solution.*
[g] *TR+AA: trehalose 4% w/v + ascorbic acid 1% w/v aqueous dipping solution.*



- All the samples irrespective of pre-treatment consisted of 3 drying phases during which the drying rate rapidly increased:
  (1) A constant drying period,
  (2) A linear constant decrease and
  (3) A falling drying rate.
- Fig. 2a represents regression model for MC_{wb} for TR+AA dipping treatment under atmospheric pressure with evident BIAS issue at the event of second falling rate drying period ($MC_{wb} < 0.1$g/g of fresh weight).
- As represented in Figure 2b, the moisture content of the samples decreased consistently following a first order kinetics irrespective of the type of pre-treatment.
- Also, all the samples reached the threshold moisture content value of 0.18 g/g in approximately 8h, with an average higher drying rate for VI samples.

Figure 2. Linear regression plot (2a) and first-order plot (2b) of measured and predicted MC_{wb} values for the TR+AA dipping treatment performed at atmospheric pressure.

- Image analysis quantified the moisture content of apple slices as function of change in the relative area shrinkage (S_b) of product during drying.
- VI samples exhibited higher shrinkage rate whereas use of TR lowered it with more pronounced effect in sub-atmospheric treatment.
- Also, dipping in TR led also to a reduction in the area shrinkage and to a lower drying rate as a result of case hardening effect.

Conclusions

- Simple linear regression models developed with *Shrinkage area* as explanatory variable have excellent prediction metrics.
- Computer vision is a potential smart process tool to monitor quality changes in real-time during hot air drying with possibility to develop forecast models for drying time prediction with spatial data.
- Future perspectives are to develop robust models with HSI and DNN comprehensive of pre-processing and drying parameters for high quality dried product through a QbD approach.

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