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# Organic apples (cv. Elstar) quality evaluation during hot-air drying using Vis/NIR hyperspectral imaging

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***Abstract***

*Organic dried apples are common snacks fulfilling functional as well as nutritional aspects. However, appearance of dried slices does not always satisfy consumer requirements, thus, improvements are needed. In this study, partial least squares (PLS) regression models were successfully developed to monitor changes in colour and moisture content in apple slices during the drying process over the Vis/NIR spectral range. The regression vector analysis results suggested that features at 580, 750 and 970 nm are better for predicting moisture content, while 580 and 680 nm allow to measure the (a*/b*) colour ratio.*

***Keywords:*** *Drying; Dried apple slices; Moisture content; Colour; PLSR modelling*

## 1. Introduction

The demand for organic dried agricultural products is increasing globally due to their health promoting aspects, ecological protection and biodiversity maintenance. [1,2] Organically grown fruits and vegetables contain a higher polyphenol content compared to conventionally grown ones, having anti-carcinogenic, anti-inflammatory, antimicrobial, antioxidant, antihypertensive, immune modulating, cardio protective, vasodilatory and analgesic proprieties. [3] The majority of people prefer fresh produce; however, it is difficult to preserve perishable foods owing to their high moisture content and high metabolic activity. Thus, drying is one of most important techniques to produce foods with an improved shelf-life, organoleptic quality, and nutritional value and to widen product availability and diversify the market throughout the years. Amongst food commodities, apple is the most common commercial fruit consumed globally [4] due to its nutritional properties. Dried apples be used as raw material in the production of snacks, integral breakfast foods, flour, chips and more, thus increasing in the global market. [5] However, maintaining a proper structure and appearance of dried organic products has been challenging.

Convective hot-air drying is one of the most common and energy intensive drying methods in the food industry. This leads to a dried product with a reduced weight making it suitable for transportation and a prolonged shelf-life with minimal nutrient deterioration during storage. However, the potential negative outcomes of this process are several physical and biochemical changes which might occur leading to quality degradation such as changes in colour, texture, size and shape as well as the organoleptic, nutritional and functional properties during the drying process. This will impact on the consumer acceptability. [6] Most of the quality parameters are highly temperature dependent. [5]

Moisture content measurement is a labour intensive and time consuming during the drying process. Therefore, a non-invasive and non-destructive method is both more useful and favourable to detect quality metrics in a production line setting. The presented method is based on models that were developed from measured data and hyperspectral data relating the products and quality parameters. Many studies have been carried out estimating dried apple quality characteristics. [7-10] However, very few studies have been carried out in the organic sector. Thus, the aim of this study was to determine the impact of the drying temperature on the drying behaviour and colour parameters of organic apple slices, as well as to investigate quality metrics predictions such as moisture content and chromaticity using the visible/near-infrared (Vis/NIR) spectroscopy during the drying process.

## 2. Materials and Methods

Apples (cv. *Elstar*) were purchased from the Hessische Staatsdomäne Frankenhausen, (Grebenstein, Germany) on the evening before each trial, where they had been stored at 8 ± 1 °C. Fruits of uniform size and colour were used and stored at room temperature overnight until the experiments were conducted. Apples were cored using an apple stainless steel corer of 2.5 cm (lurch, Schineklstrasse 6, Germany) and sliced to 4-mm thickness using an electrical slicer (Graef, Allesschneider Vivo V 20, Arnsberg, Germany). Apple slices were cut into equal diameter using a cookies dicer of 62-mm diameter (Flammable, Germany).

During drying experiments, the samples were dried at 60 ± 2 °C and 70 ± 2 °C for 6 and 4 h, respectively, in a tray dryer (HT mini, Innotech Ingenieursgesellschaft mbH, Germany). The dryer was pre-heated until set temperature was reached before being loaded with the sample. Four replications were performed for each assessment. Batch sampling was performed at 0, 15, 30, 60, 90, 120, 180, 240, 300 and 360 min for 60-°C drying temperature, while at 0, 15, 30, 60, 90, 120, 150, 180, 210 and 240 min for 70-°C drying temperature. In each drying interval, sample weighting, chromaticity and hyperspectral scans were performed and analysed following the procedure mentioned by Crinchton et al., 2017. In addition, the a*/b* ratio was calculated in this experiment.

The spectral data were analysed using Partial least squares regression (PLSR) in relation to the moisture content (gw/gDB) and the CIELab coordinates. PLSR is a regression technique used to find linear relationships between the reflectance spectra and specific qualitative measurement values. The train-test (calibration-prediction) split for the complete dataset was on a 70:30 basis. The classification performance of each PLS model was determined in terms of regression vector (RV).

One-way analysis of variance (ANOVA) was performed to evaluate statistical differences among the drying times. The Tukey's pairwise comparison method was performed, and the Honestly Significant Difference (HSD) was calculated for an appropriate level of interaction ($P < 0.05$). Results were reported as the mean and standard error of the mean.

## 3. Results and Discussion

### 3.1. Drying Behaviour

Fig 1. shows the moisture content of the organic apple slices as a function of drying time at 60-°C and 70-°C drying temperatures. As expected, the moisture content decreases gradually with drying time and the drying rate is higher at the highest temperature. [8- 10] The drying time to reach the final moisture content of 0.11 g $H_2O$/ g D.M were 360 min and 240 min at the drying air temperatures of 60 and 70 °C, respectively. ANOVA indicates significant effect of drying time on moisture content. The free water content reduced significantly at higher temperature causing higher internal moisture diffusion resistance during the drying process. [4-6]

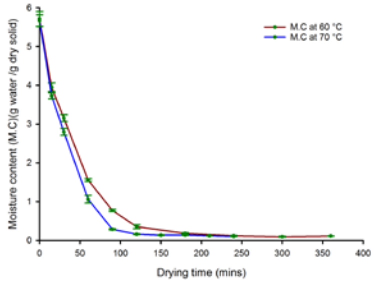


***Fig 1. Effect of drying air temperature on moisture content of slices over drying time***

## 3.2. Colour changes

Table 1 depicts the a*/b* ratio of slices at two different drying temperatures. Tukey's test of comparison revealed significant differences at different stages of the drying process for a*/b* value. The greatest change loss occurred at 210 min which was significantly different to that at 0-, 15-, 30- and 60-min drying times. At 210 min, Maillard reaction might occur causing the slices to brown faster (Table.1). Moreover, the enzymatic reaction due to polyphenol oxidase (PPO) is first very likely to occur and afterwards non-enzymatic browning that contributing to changes in colour. The browning reactions occurring during drying can have a significant impact on the final colour of the product. [6]

***Table 1. Effect of drying time on a*/b* ratio of organic apple slices. Mean values with no common letters are statistically different according to HSD of ($p \leq 0.05$).***

| Drying at 60- °C and 70- °C | |
|---|---|
| **Drying time (min)** | **a*/b ratio** |
| 0 | -0.23$^{d}$ ± 0.007 |
| 15 | -0.14$^{c}$ ± 0.006 |
| 30 | -0.13$^{bc}$ ± 0.006 |
| 60 | -0.12$^{bc}$ ± 0.005 |
| 90 | -0.11$^{abc}$ ± 0.006 |
| 120 | -0.10$^{abc}$ ± 0.009 |
| 150 | -0.09$^{abc}$ ± 0.011 |
| 180 | -0.09$^{abc}$ ± 0.006 |
| 210 | -0.07$^{a}$ ± 0.010 |
| 240 | -0.08$^{ab}$ ± 0.007 |
| 300 | -0.09$^{ab}$ ± 0.010 |
| 360 | -0.09$^{abc}$ ± 0.006 |

### 3.3. Spectral Analysis

PLS regression models with excellent predictability were obtained to monitor changes in moisture content and colour parameters of apple slices during drying process. The model performances for moisture content and a*/b* ratio are presented in Table 2. The prediction model on the test (prediction) set achieved good moisture content predictions with highest $R^2$ (0.98) and lower RMSEP (0.27 g Water/g D.M) and for a*/b* ratio with $R^2$ (0.82) and lower RMSEP (0.23). The selection of optimal wavebands was performed using Regression vector (RV) to find the most vital information for moisture content distribution (Fig 2b) and a*/b* ratio (Fig 2c). For moisture content prediction, the highest peak was observed at wavelengths 580 nm and two downward peaks at 750 nm and 970 nm. At 970 nm, there might be the non-bonded O-H stretching second overtone vibration in water and free water molecules in the apple slices. [11,12] In case of the a*/b* ratio, 580 nm and 680 nm were found to be important wavelengths using RV analysis (Fig 2c). Specifically, 680 nm is related to change in chlorophyll content. [9] Moreover, as moisture evaporates during drying, different pigments such as anthocyanins concentration might increase leading to a


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change in colour. Noteworthy, moisture content in the product and changes in colour seem to be correlated to each other which have to be optimised during the drying processes to produce acceptable dried slices.

***Table 2. Calibration models based on quality metrics using PLSR method***

| **Parameter** | **Spectral pretreatment ($P_t$)** | | | **LV**[a] | **RMSE**[b] | | **$R^2$** | |
|---|---|---|---|---|---|---|---|---|
| | $P_t$-1 | $P_t$-2 | $P_t$-3 | | C[m] | P[n] | C | P |
| Moisture content | MSC (Mean) | 2nd Der | Mean Center | 4 | 0.24 | 0.27 | 0.98 | 0.98 |
| a*/b* | MSC (Mean) | 2nd Der | Mean Center | 3 | 0.021 | 0.023 | 0.81 | 0.82 |

[a] Latent Variables

[b] Root Mean Squared Error

[m] Calibration

[n] Prediction

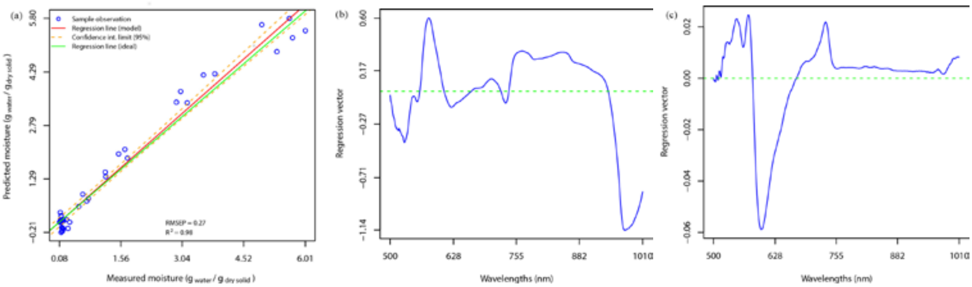

***Fig 2. PLS model at full –wavelength range in the spectral range of 500 – 1010 nm . (a) Plot of predicted versus measured moisture content (b) Plot of regression vector for moisture content (c) Plot of regression vector for a*/b* ratio***

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## 4. Conclusions

Drying temperature, time and product quality are the important considerations for drying processes. Lowering the drying temperature reduces the drying potential and increases drying time. Colour (a*/b* ratio) parameter changed periodically as the onset of drying. RV of moisture content showed the importance of three wavelengths (i.e. 580, 750, 970 nm) and for colour change (a*/b*) ratio at 580 and 680 nm. RV had a higher prediction accuracy indicating that wavelengths selected are more powerful in predicting the MC and a*/b* colour of organic apple slices. Thus, using this Vis/NIR based technique, can provide an efficient means of quality metric estimation such as moisture content and a*/b* colour prediction information of organic apple slices.

## 5. Nomenclature

| | |
|---|---|
| Vis/NIR | Visible to near infrared |
| PLS | Partial Least Squares regression |
| HSI | Hyperspectral imaging |
| RMSE | Root mean squared errors |
| RV | Regression vector |

## 6. Acknowledgements

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