Life Science Press

Publishing press
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Research

Variation of physical properties of fruits with drying and kinetic study

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Received: *May 22nd, 2018*
Accepted: *June 11th, 2018*
Published: *June 11th, 2018*

Citation
Guiné RPF. variation of physical properties of fruits with drying and kinetic study. *Life Sci Press*. 2018; 2(1): 40-47. doi: 10.28964/LifesciPress-2-106

ABSTRACT

Background: Food drying, despite being a very ancient practice for food preservation, is still one of the most important processing operations in the food industry.
Objective: In this work was studied the drying of two fruits (kiwi and apple) with respect to the physical properties of texture and colour, and the drying kinetics was also evaluated with adjustment to thin layer models.
Method: For drying, a convection chamber was used at 80 °C and with an air flow of 0.5 m/s. Before and after drying the fruits were analysed with respect to their colour and texture, for being properties that are greatly affected by this type of thermal process. The colour measurement was done with a colorimeter in the CIELab coordinates and for the analysis of the texture profile a texturometer equipped with a 75 mm probe was used.
Results: The results showed that the drying caused very noticeable colour differences in both cases, with values of ΔE equal to 8.6 and 10.7, respectively for kiwi and apple. In the case of kiwi, there were important differences between the pulp, the inner part of the fruit and the seeds (L* varying between 42 and 62, a* between -8 and -1, b* between 17 and 33). Regarding the texture, drying produced important changes in the structure of the fruits, with decreasing hardness (40-62%) and chewiness (13-42%), counterbalanced by an increase in resilience (226-131%), cohesiveness (17-25%) and elasticity (20-23%). In relation to the kinetics, the two fruits tested had a similar behaviour, taking 2.5 hours to reach a moisture content of about 20%. The Wang & Singh model, with correlation coefficients of 0.997 and 0.999, respectively, for kiwi and apple, was the most suitable to fit the experimental data.
Conclusion: Drying significantly affected colour and texture of both fruits and the fitting of the drying data to both kinetics models was successful.

Keywords: colour, texture, thin layer, drying constant, kinetic model.

INTRODUCTION

Drying of food products is widely used to preserve food and to ensure food safety, as it considerably reduces chemical, enzymatic and microbial changes during the storage period, thus extending the shelf life of the product [1], [2].

Drying is a complex process involving the simultaneous transfer of heat and mass. The practice of drying a product sample in a single layer of particles or slices is known as thin-layer drying. Currently, three types of mathematical models are used to define the thin-film drying process of agricultural products, which are: theoretical models, which only study the internal resistance to transfer moisture between heating air, semi-theoretical models and experimental models that only take into account external resistance[3].

Some examples of semi-theoretical type thin-layer drying models include: the Henderson and Pabis model, the Lewis model, the two-term model, the Page and modified Page models. Examples of empirical models are the Wang and Singh model and the Thompson model [4].
The quality of dried or dehydrated products corresponds to a set of specific characteristics that are

acceptable to the consumer. Colour is one of the most important quality factors when it comes to product acceptability, because it is immediately detectable. Browning reactions occur during fruit drying, and this has a significant impact on the colour of the final product. These browning reactions are more intense when increasing the drying temperature of the product and this increase is faster when the product contains high sugar contents, as with fruits[5].
Dried products retain a significant proportion of their nutritional value, but are often less appreciated because of their texture. Because of the loss of large amounts of water, these products are characterized by low porosities and high apparent densities. In fact, drying impairs the texture of the product to an appreciable extent and, in many cases, causes loss of integrity. By controlling the texture characteristics during drying, it is necessary to take into account the changes that occur in the product, which are often determined by its composition as well as the drying conditions[6].

The objective of this work was to evaluate the changes in colour and textural properties of two fruits (kiwi and apple) during convective drying, as well as to determine the drying kinetics and to calculate the corresponding drying constant.

MATERIAL AND METHODS

Sample preparation

The fruits used in this study were kiwi (*Actinideadeliciosa*), Hayward variety, and apple (*Malusdomestica*), Golden delicious variety. The samples were acquired at a local market, and the selection was based on some parameters, including uniformity in size. For drying, both the apple and the kiwi were cut into 5 mm thick slices using an automatic cutter and then laid on trays.

Drying procedure

The drying was carried out in a WT Binder chamber with air circulation, the temperature being set constant at 80 ° C and air velocity at 0.5 m/s.

The moisture was periodically measured on a HG53 Halogen Moisture Analyzer, Mettler Toledo, operated at speed 5 (on a scale between 1 = very fast to 5 = very slow) and at 120 °C. For the assessment of the mean values, three repetitions were made at the beginning and also at each time point along drying.

Measurement of colour

Colorimetry is the science that studies the colour according to standard human perception. Colorimeters use sensors that simulate the way the human eye sees colour and quantify colour difference between a standard and a sample. A colorimeter (Chroma Meter - CR-400, Konica Minolta) was used to determine the colour, which measured the Cartesian coordinates L * a * b * in the CIELab colour space. The dimension L* represents the brightness on a scale from 0 (black) to 100 (white) and the dimensions a* and b* are chromaticity coordinates, with a* ranging from green (-a) to red (+a) and b* ranging from blue (-b) to yellow (+b)[7], [8].

All determinations were made in triplicate, and in the case of kiwifruit, due to non-uniformity, measurements were made in three distinct regions: interior, core bow and outer pulp, as indicated in Figure 1.

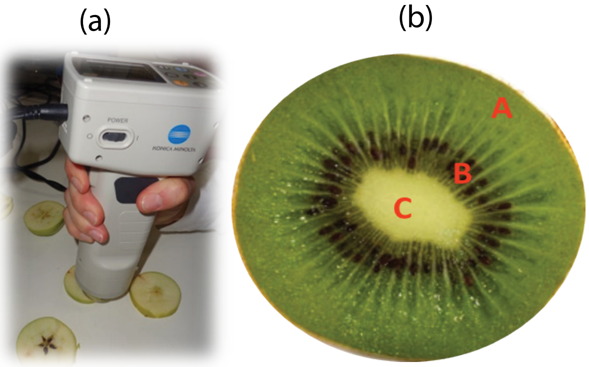

Figure 1. (a) Measurement of colour in the apple slices, (b) Areas considered for the evaluation of colour in the kiwi slices.

To make an overall assessment of the change in colour due to exposure to air or drying, the colour difference was calculated (ΔE) using Equation (1) [9], where the chromatic coordinates with the index 0 correspond to the reference values, which in this case refer to the values obtained shortly after the cutting operation, i.e., before oxidation could occur:

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \quad (1)$$

A higher value of ΔE corresponds to a larger colour difference than the reference sample. A typical scale for assessing the colour difference is as follows: ΔE in the interval [0.0;2.0] corresponds to unrecognizable differences, in the interval] 2.0;3.5] corresponds to possible differences to recognize by an experienced observer and more than 3.5 corresponds to clear colour differences [10].

Evaluation of textural properties

The instrumental Texture Profile Analysis (TPA) is a test which uses the principles of compression, and tries to simulate the mandible action compressing the sample in a reciprocating motion twice. Based on the force-time curve it is possible to estimate textural properties. The texture analysis was performed using a texturometer (model TAXT Plus from Stable Micro Systems) in order to obtain the texture profiles (TPA), as exemplified in Figure 2. The texture profile analysis comprised two cycles of compression, spaced by a 5-second interval, using a flat probe of 75 mm diameter. The load cell used was 30 kg and the test and post-test rates were both 0.5 mm/s.

Three TPAs were obtained for each fruit in the fresh and also in the dried states. The textural parameters hardness, adhesiveness, springiness, cohesiveness, resilience and chewiness were

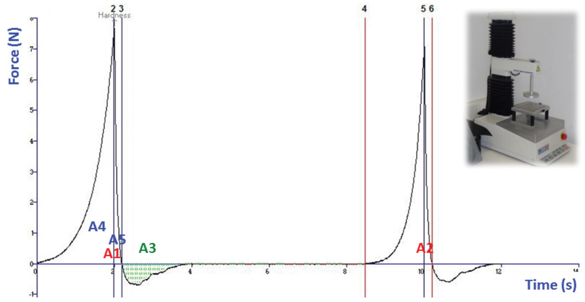

Figure 2.Texture profile analysis for one sample of fresh kiwi.

calculated through Equations (2) to (7) taking into account Figure 2[11]:

$$Hardness\ (N) = F1 \qquad (2)$$

$$Adhesiveness\ (N.s) = A3 \qquad (3)$$

$$Springiness\ (\%) = \frac{T2}{T1} x\ 100 \qquad (4)$$

$$Cohesiveness\ (\%) = \frac{A2}{A1}\ x100 \qquad (5)$$

$$Resilience\ (\%) = \frac{A5}{A4}\ x100 \qquad (6)$$

$$Chewiness\ (N) = F1\ x\ \frac{T2}{T1} x\ \frac{A2}{A1} \qquad (7)$$

Modeling of drying kinetics

The thin layer models are mathematical expressions that relate the variations of humidity along drying with some parameters, such as the drying constant, k [s^{-1}] or the lag factor, k_0 [dimensionless], which explain the combined effects of various transfer phenomena occurring during drying [12].The Handerson&Pabis model is an example of thin layer kinetic model, which is expressed in terms of the moisture ratio (MR) according to Equation (8)[13]–[16]:

$$MR\ = k_0 \exp(-k\ t) \qquad (8)$$

wherek_0 is the lag factor, k is the drying constant and MR is the moisture ratio, defined as:

$$MR = \frac{W-We}{W0-We} \qquad (9)$$

with W, W_0e We, respectively,the moisture contents expressed in g water per g dry matter at the generic instant t, the initial moment and at the equilibrium.

Equation (8) can be expressed in logarithmic form, resulting in a linear function of the type:

$$\ln(MR) = \ln(k_0) - k\ t \qquad (10)$$

that allows to calculate the drying constant from the slope and the lag factor from the intercept.

Alternatively, a second-order polynomial model, also known as the Wang & Singh model, was tested[17]:

$$MR = a\ t^2 + b\ t + c \qquad (11)$$

Statistical analysis

Differences between samples obtained for all properties evaluated with one-factor analysis of variance (one-way ANOVA), followed by multiple comparisons test (Tukey'sHonestly Significant Difference test) to identify differences between the different drying temperatures. Statistical analyses were tested at 0.05 level of significance.

To evaluate the model that best fits the experimental data was used the coefficient of determination (R^2), and also on different statistical test parameters, as described by Equations (12) to (17):

Mean absolute error: $MAE = \frac{1}{N}\sum_{i=1}^{N}\left|V_{\exp,i} - V_{pred,i}\right|$ (12)

Root mean square error:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(V_{\exp,i} - V_{pred,i}\right)^2} \qquad (13)$$

Standard error: $SE\ = \frac{\sqrt{\sum_{i=1}^{N}\left(V_{\exp,i} - V_{pred,i}\right)^2}}{N-1}$ (14)

Sum of square errors: $SSE = \frac{1}{N}\sum_{i=1}^{N}\left(V_{\exp,i} - V_{pred,i}\right)^2$ (15)

Chi square: $CS = \frac{1}{N-n_p}\sum_{i=1}^{N}\left(V_{\exp,i} - V_{pred}\right.$ (16)

Relative percent deviation:

$$RPD = \frac{100}{N}\sum_{i=1}^{N}\frac{\left|V_{\exp,i} - V_{pred,i}\right|}{V_{\exp,i}} \qquad (17)$$

Where N is the number of experimental observations and n_p is the number of parameters. Also, $V_{exp,i}$ and $V_{pred,i}$ are, respectively, the experimental and predicted values for the dependent variable, which is MR in the present case, for each observation i. The highest the value of R^2, approaching 1, the better is the fit, while lower values of CS and RMSE, tending to zero, are indicative of predictions more adequate to the experimental data. These last indicators (RMSE and CS) compare the differences between the experimental and predicted values of MR, whereas the RPD compares the absolute differences between them. Values of RPD under 10% are indicative of a good fit [18].

RESULTS AND DISCUSSION

Colour properties

Figure 3 shows the colour coordinates of the two studied fruits, namely L*, a* and b*. It is verified that drying did not practically change the luminosity (L*) in the case of kiwifruit, but in the case of apple the drying turned the samples slightly darker (lower L*). With regard to the parameter a*, in the case of kiwi, it presents negative values before and after drying, corresponding to the green colour. It was verified that the drying allowed to maintain the green colour and even to intensify a little in the case of the kiwi. Regarding the apple, the green colour prevailed before drying, but after drying it turned to red (a* positive), as a result of the browning reactions that occur during drying in the presence of oxygen. The coordinate b* was always positive, indicating that in both fruits yellow predominated instead of blue. The drying caused a decrease of b* in the case of kiwi, but an increase in the case of the apple. The difference in color (ΔE), calculated by Equation (1), was 8.6 in the case of kiwifruit and 10.7 in the case of apple, corresponding in both cases to very relevant and clearly identifiable differences, according to the classification suggested by Valdivia-López and Tecante[19]. Thus, drying under the conditions tested markedly influenced the colour of both fruits.

Figure 4 presents the colour coordinates for kiwi, corresponding to measurements made in three distinct regions: interior, arch where the seeds are located and outer pulp, as indicated in Fig-

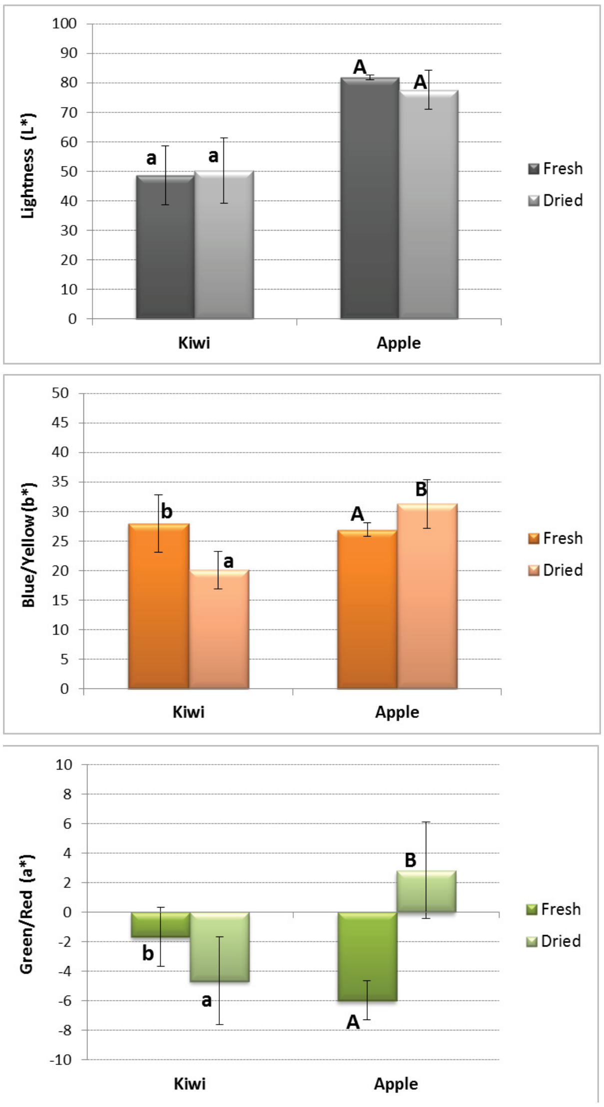

Figure 3. Colour coordinates in the fresh and dried fruits. Bars with different letters correspond to means significantly different for the same fruit: ANOVA with Tukey test ($p < 0.05$).

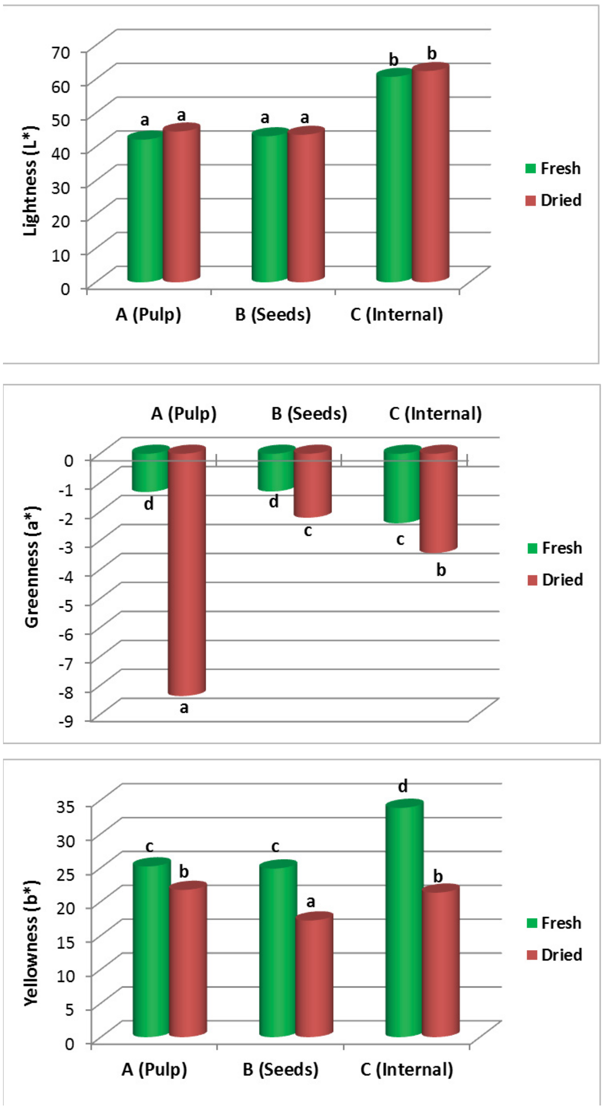

Figure 4. Colour of kiwi in the different points of analysis.Bars with different letters correspond to means significantly different: ANOVA with Tukey test ($p < 0.05$).

ure 1. It is verified that the internal part always had values of b* higher, i.e.was the lighter part, either before or after drying. Concerning the coordinate a*, the external part of the pulp intensified green colour after drying, but on the other hand it was the one that suffered less variation in the yellow colour (coordinate b*).

Textural properties

Figure 5 presents the results obtained for the texture parameters evaluated in the two fruits before and after drying. Hardness is the force required to compress a food between the molar and the teeth (for solids) or between the tongue and the palate (for semi-solid foods) [20], [21]. Chewiness represents the energy required to disintegrate a solid food to the point of being swallowed [22]. It was verified that drying decreased hardness and chewiness in both fruits, with variations of 40 and 62% in the case of hardness and 13 and 42% in the case of chewiness, respectively for kiwi and apple. Similar results were observed for drying apples at different temperatures [23].

With regard to the adhesiveness, which represents the force re-

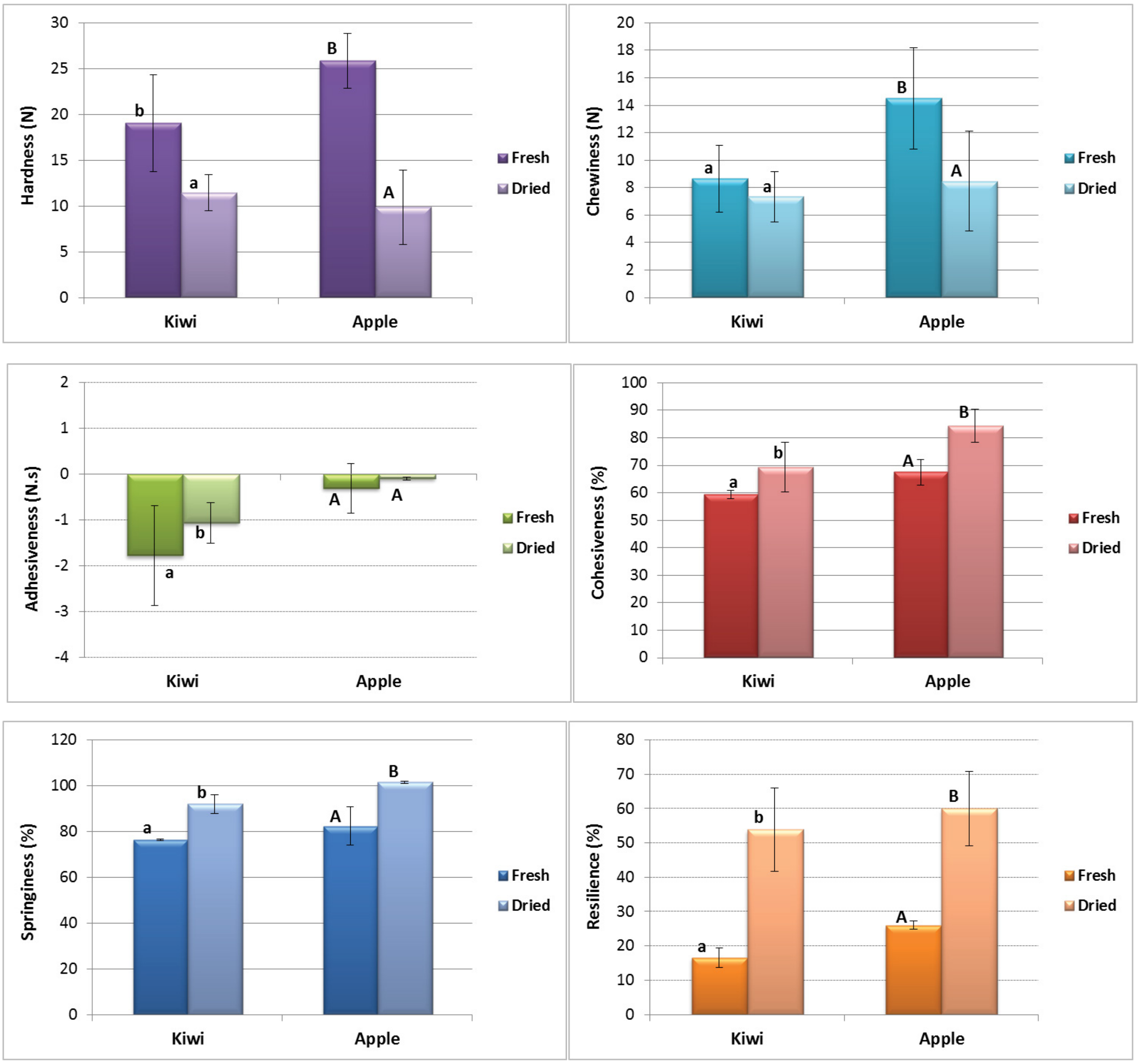

Figure 5. Textural parameters in the fresh and dried products.Bars with different letters correspond to means significantly different for the same fruit: ANOVA with Tukey test ($p < 0.05$).

quired to remove the material adhering to a specific surface (for example, lips, palate, teeth), the values obtained in both cases (Figure 5) were very small (less than 0.2 N.s - absolute value), and therefore these results indicate that these two fruits do not have measurable adhesiveness, as it was previously observed forother food products, such as cucumbers, pears or apples [6], [24], [25].

The cohesiveness (or cohesion) represents the strength of the inner bonds, which make the food remain cohesive [21]. Resilience is how well a product struggles to regain its original position. It can be seen as an instantaneous elasticity, since resilience is measured when the first penetration is withdrawn, before the start of the waiting period [21]. Elasticity or springiness defines the ability of a food to recover its original shape after removal of the force that caused the compression [21]. Figure 5 shows that these three parameters (cohesiveness, resilience and elasticity) increased with drying for both fruits. Increases were in the ranges 17-25% for cohesiveness, 226-131% for resilience and 20-23% for elasticity, respectively for kiwi and apple. Cruz et al. [23]also observed an increase in elasticity in the case of apple drying.

Drying kinetics

Figure 6 shows the evolution of moisture (wet basis and dry basis) of the two fruits during drying, both of which present a very similar behaviour, only with a greater loss of water in the case of the apple, which had a higher moisture content at the outset. Both fruits tested took 2.5 hours to reach a moisture content of about 20%.

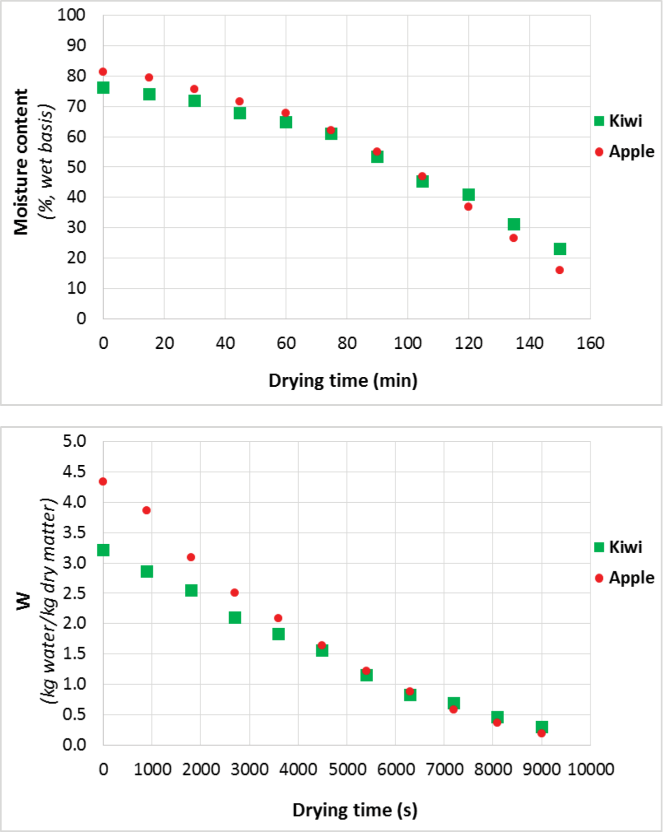

Figure 6. Variation of moisture along drying in wet basis (top) and dry basis (bottom).

Figure 7 shows the adjustment of the experimental points obtained for the moisture ratio (MR) to the Handerson&Pabis thin layer model, described by Equation (8). The adjustments were obtained through the linear form of the model (Equation (10)), and are described by the following equations, whose parameters are in Table 1:

For kiwi:

$$MR=1.326\exp(-2.91\times10^{-4}\,t) \qquad [R= 0.971] \quad (18)$$

For apple:

$$MR=1.405\exp(-3.55\times10^{-4}\,t) \qquad [R = 0.968] \quad (19)$$

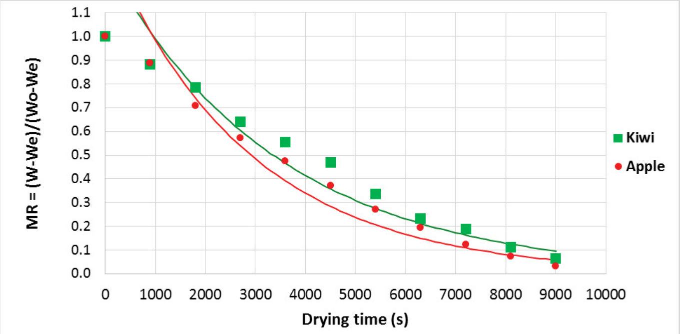

Figure 7. Fitting with kinetic modelHenderson &Pabis.

Henderson &Pabis	Kiwi	Apple
Parameters		
k_0	1.326	1.405
k	2.91e-4	3.55e-4
Statistics		
R^2	*0.971*	*0.968*
MAE	*0.078*	*0.084*
RMSE	*0.118*	*0.137*
SE	*0.039*	*0.045*
SSE	*0.014*	*0.019*
CS	*0.017*	*0.023*
RPD	*18.00*	*23.08*
Wang & Singh	**Kiwi**	**Apple**
Parameters		
a	4.32e-9	7.76e-9
b	-1.46e-4	-1.79e-4
c	1.01	1.01
Statistics		
R^2	*0.998*	*0.999*
MAE	*0.014*	*0.008*
RMSE	*0.017*	*0.012*
SE	*0.006*	*0.004*
SSE	*0.000*	*0.000*
CS	*0.000*	*0.000*
RPD	*5.77*	*3.02*

These results show that the adjustments are acceptable, given the high values of the regression coefficients, close to 1, that would correspond to the perfect fit.

The Handerson&Pabis model allows to estimate the drying constant, which was in this case 2.91x10^{-4} and 3.55x10^{-4} s^{-1}, respectively for kiwi and apple. These values are more or less in the ranges reported by Kholmanskiy et al. [26]for various food products, including also apples.

Figure 8 shows the adjustment of the experimental points to Wang & Singh's empirical model, described by Equation (11), which corresponds to a 2nddegree polynomial function, resulting for the two fruits in the following equations:

For kiwi:

$$MR = 4.32\times10^{-9}\,t^2 - 1.46\times10^{-4}\,t + 1.01 \quad [R = 0.998] \quad (20)$$

For apple:

$$MR = 7.76\times10^{-9}\,t^2 - 1.79\times10^{-4}\,t + 1.01 \quad [R = 0.999] \quad (21)$$

These results indicate that the latter model allows a better adjustment to the experimental points, both in the case of kiwi and in the case of apple, with R values of 0.998 and 0.999, respectively. However, because it is a purely empirical model, it does not allow to estimate parameters of interest for the knowledge of the process, as in the case of the previous model.

Table 1 further confirms that the adjustment with Wang & Singh's empirical model is better in view of the statistical indicators calculated, because the values of MAE, RMSE, SE, SSE, CS and RPD are considerably lower for both fruits when compared to those of the Henderson and Pabis model. Furthermore, the values of RPD are lower than 10 %, being 5.77% and 3.02% respectively for kiwi and apple, indicating a very good quality of the fit.

CONCLUSIONS

The results obtained in this work indicate that drying affected the colour of both fruits in a very relevant way, and also induced important changes in texture, namely with a decrease in hardness and chewiness and an increase in resilience, cohesiveness and springiness.

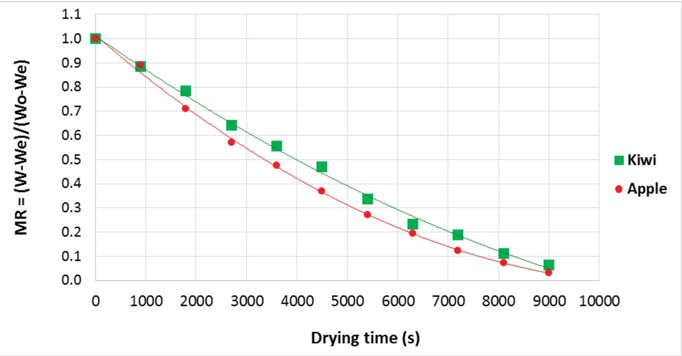

Figure 8. Fitting with kinetic model Wang & Singh.

The kinetic data were well fitted to two thin-layer models, the Handerson&Pabis semi-theoretical model and Wang & Singh's purely empirical model. It was possible to estimate the drying constants from the first model: 2.91x10^{-4} and 3.55x10^{-4} s^{-1}, respectively for kiwi and apple.

CONFLICT OF INTEREST

No conflicts of interest to declare.

ACKNOWLEDGMENT

Thanks to the students from master Degree in Food Quality and Technology, at ESAV: Cristina Sousa, Jéssica Carmo, Suzanna Ferreira, Carla Pereira, Ivone Marques.

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