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Drying Kinetics and Physico-Chemical Quality of Mango Slices

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Mango (*Mangifera indica* L.) is an important tropical fruit consumed worldwide and grown in Italy only in Sicily, where the areas of the Tyrrhenian coast have proved to be suitable to produce valuable fruits. Mango fruit has a pleasant aroma and taste, which are important qualities for consumer's sensorial acceptance. However, they are highly perishable, prone to progressive undesired changes if stored untreated, resulting in around 25% postharvest losses, which is further increased during storage and transportation. An alternative for reducing the above-mentioned undesired changes is the dehydration of the cut fruit, which reduce the fruit water activity, thereby avoiding the deteriorative process and extending the shelf-life. This study investigates the effect of dehydration at different temperatures (50, 60 and 70°C) on drying kinetics and volatile compounds of two cultivars (*Keitt* and *Osteen*) of mango fruits cultivated in Sicily. Significant losses of volatile constituents of fresh mango occurred at higher temperature, especially for the *Osteen* cultivar. A diffusion model including the effect of shrinkage is also proposed, which may be used to describe drying behaviour of fruits and to define the optimal drying conditions.. Experimental data of the moisture ratio during drying were well predicted by the model.

1. Introduction

Mango (*Mangifera indica* L.), member of the cashew family (Anacardiaceae) is an evergreen tree cultivated on an area of approximately 3.7 million ha worldwide with a production of over 42 million tons concentrated in tropical countries. Recently, European market request increased and mango cultivation has spread outside the traditional geographical regions to the Mediterranean areas. Along the coastal areas of Sicily, characterized by a mild climate, mango cultivation is quickly increasing (Farina et al., 2017). Sicilian mango fruit are well coloured, sweet and rich of bioactive phytochemicals (Gentile et al., 2019). According to Bonneau (2016), mango is a climacteric fruit with a very short shelf life due to its rapid ripeness after harvest causing texture, flavour and taste deterioration.

For this reason, fruits are mainly consumed fresh or are processed into juice, puree, jam and dried fruit with low water activity and long shelf life (Önal et al., 2019; Fratianni et al., 2018). The fruit flavour is an important quality factor that influences consumer acceptability and, for this reason, its study is relevant in the dried food product. The volatile compounds that are involved in the fruit flavour depend on many factors related to the species, variety and type of technological treatments. In this paper, the influence of different drying temperatures on drying kinetics, colour and volatile profile of two cultivars of mango cultivated in Sicily were analysed. Moreover, a diffusion model considering the shrinkage of the mango fruit during drying is used to describe the drying kinetics and to obtain the diffusion coefficient.

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2. Materials and methods

2.1 Plant materials

Late ripening Mango fruit (*cvs Keitt* and *Osteen*) were collected at Cupitur Farm located in Acquedolci, province of Messina (Sicily, Italy; 38°3' N, 14°33' E). A sample of 30 fruits per cultivar (5 fruits x 6 tree x CV) were handpicked at commercial ripening, twenty of these fruits were used for physico-chemical analysis, while the other 10 fruits were dried.

2.2 Physico-chemical Analyses

Flesh hardness (FH), total soluble solids content (TSSC), titratable acidity (TA), flesh colour (FC) were analyzed. FH was analyzed by a durometer Durofel XF, (Agrosta); TSSC (Brix°) was measured in juice by digital refractometer Atago Palette PR–32 (Atago Co., Ltd, Tokyo, Japan) and TA (g/L of citric acid) using a CrisonS compact tritator (Crison Instruments, SA, Barcelona, Spain); FC using a CR-300 Chroma Meter Minolta, which recorded the spectrum of reflected light and converted it into a set of colour coordinates (L*, a* and b* values) (Albanese et.al, 2014). Hue angle is how an object's colour is perceived, where 0° = red, 60° = yellow, 120° = green and was calculated as follow:

$$H° = tan^{-1}\, b^*/a^* \quad (1)$$

The total colour difference (ΔE) was used to express the overall colour change during the thermal process (Önal et al., 2019) and was calculated by using the following equation:

$$\Delta E: \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2)$$

Volatile organic compounds (VOCs) were determined using the headspace solid phase microextraction (SPME) technique coupled with gas chromatography with mass spectrometric detection (GC/MS). The SPME fibre was inserted directly into a Finnegan TraceMS for GC/MS (Agilent 6890 Series GC system, Agilent 5973 NetWork Mass Selective Detector, Milan, Italy) equipped with a DB-WAX capillary column (Agilent Technologies, 30 m, 0.250 mm i.d., film thickness 0.25 μm, part no. 122–7032) (Corona et al., 2016).

2.3 Drying experiments

Freshness, uniform size and absence of any mechanical damage were used as the selection criteria for the samples. Prior to drying *Keitt* and *Osteen* mangoes were washed with tap water and peeled by using a knife. Cylindrical slabs with diameter of 30 ± 0.25 mm and thickness of 5 ± 0.10 mm were prepared using several raw materials from each cultivar. The drying experiments were conducted on mango slabs in a convective dryer (B80 FCV/E6L3, Termaks, Norway) at three different temperatures 50, 60 and 70 °C with an air velocity at 2.1 m/s until a constant weight was achieved. Drying tests were replicated three times at each temperature.

For drying kinetics, the weight loss of nine slabs was recorded at suitable time intervals by using a digital electronic balance (mod. Gibertini E42, Italy) during the drying process. Moisture ratio (M_t/ M_0) was calculated as the ratio between the actual (M_t) and the initial (M_0) moisture content on dry basis. (Adiletta et al., 2015a).

2.4 Shrinkage measurements

The initial volume (V_0) of both mango cultivars was calculated by measuring for each sample (about 10 slabs) diameter and thickness by means of a digital Vernier calliper (0.01 mm accuracy). At given times during drying experiments for the same slices, the diameter and the thickness of the sample were measured and the volume (V) was calculated. In order to reduce the measurement error during drying, both dimensions were measured at different positions of the sample and their average value was considered. For the evaluation of shrinkage during drying, the mean volume shrinkage (V/V_0) was reported as a function of the relative moisture ratio (Adiletta et al., 2018; Adiletta et al., 2015b).

2.5 Mathematical model

The drying process of agricultural products is described, under constant conditions, as a number of steps which consist of an initial constant rate period during which drying occurs as if pure water is being evaporated, and one or several falling rate periods where the moisture movement is controlled by combined external and internal resistances to heat and mass transfer. Many fruits and vegetables dry during the falling rate periods because the drying process is controlled by a diffusion mechanism. Indeed, drying in the falling rate period involves two processes namely; the movement of moisture within the material to the surface and removal of moisture from the surface. In literature, several models like the theoretical, empirical and semi empirical are mentioned for the analysis of the drying of food products.

A three-dimensional model of mass transfer is here adopted which assumes that mango fruit is an isotropic, homogenous and continuous solid. Moreover, since the characteristic time of thermal transient is far less than that of mass transport, isothermal condition are also considered. The mass diffusion phenomenon in cylindrical coordinates is described by Eq 3:

$$\frac{\partial \mathrm{M}}{\partial \mathrm{t}}=\frac{1}{r}\left\{\frac{\partial}{\partial r}\left(\mathrm{r}D_{\mathrm{eff}}\frac{\partial \mathrm{M}}{\partial r}\right)+\frac{\partial}{\partial \mathrm{z}}\left(\mathrm{r}D_{\mathrm{eff}}\frac{\partial \mathrm{M}}{\partial \mathrm{z}}\right)\right\} \tag{3}$$

where D_{eff} is the diffusion coefficient (m^2/s) and M is the moisture content on a dry basis (kg/kgd.b.). The initial and boundary conditions are disposed in Eq 4 to 7, where R_0 is the radius of the sample (m), ρ_s the solid density (kg/m^3) that it is kept constant; h_m the moisture transfer coefficient (m/s); M_{sur} the moisture at the surface and M_e the equilibrium moisture content (kg/kg d.b.):

$$M(r,z,t=0)=M_0 \; for \; 0<r<R_0 \, , 0<z<h \tag{4}$$

$$\frac{\partial \mathrm{M}(\mathrm{r}=0,\mathrm{z},\mathrm{t})}{\partial \mathrm{r}}=\frac{\partial \mathrm{M}(\mathrm{r},\mathrm{z}=0,\mathrm{t})}{\partial \mathrm{z}}=0 \text{ for } \mathrm{t}>0 \tag{5}$$

and at r=R_0, z=h and for t>0

$$-D_{eff}\rho_s\frac{\partial M}{\partial r}=h_m\rho_s(M_{sur}-M_e) \tag{6}$$

$$-D_{eff}\rho_s\frac{\partial M}{\partial z}=h_m\rho_s(M_{sur}-M_e) \tag{7}$$

Introducing the following dimensionless variables:

$$\bar{r}=\frac{r}{R_0},\bar{z}=\frac{z}{R_0},\bar{M}=\frac{M}{M_0},\bar{M}_e=\frac{M_e}{M_0},\tau=\frac{t\,D_{eff}}{R_0^2}$$

and the dimensionless Sherwood number $Sh=\frac{h_m R_0}{D_{eff}}$ the Eq. 3-7 become:

$$\frac{\partial \bar{\mathrm{M}}}{\partial \tau}=\left(\frac{\partial^2 \bar{\mathrm{M}}}{\partial \bar{\mathrm{r}}^2}\right)+\left(\frac{\partial^2 \bar{\mathrm{M}}}{\partial \bar{\mathrm{z}}^2}\right) \tag{8}$$

$$\bar{M}(\bar{r},\bar{z},\tau=0)=M_0 \quad for\; 0<\bar{r}<1, 0<\bar{z}<\frac{h}{R} \tag{9}$$

$$\frac{\partial \bar{\mathrm{M}}(\bar{\mathrm{r}}=0,\bar{\mathrm{z}},\tau)}{\partial \bar{\mathrm{r}}}=\frac{\partial \bar{\mathrm{M}}(\bar{\mathrm{r}},\bar{\mathrm{z}}=0,\tau)}{\partial \bar{\mathrm{z}}}=0 \text{ for } \tau>0 \tag{10}$$

and at $\bar{r}=1,\bar{z}=\frac{z}{R}, for\; \tau>0$

$$\frac{\partial \bar{\mathrm{M}}}{\partial \bar{\mathrm{r}}}=\text{-Sh}\left(\bar{\mathrm{M}}_{\mathrm{sur}}\text{-}\bar{\mathrm{M}}_{\mathrm{e}}\right) \tag{11}$$

$$\frac{\partial \bar{\mathrm{M}}}{\partial \bar{\mathrm{z}}}=\text{-Sh}\left(\bar{\mathrm{M}}_{\mathrm{sur}}\text{-}\bar{\mathrm{M}}_{\mathrm{e}}\right) \tag{12}$$

The finite element method was applied to solve the non-linear partial differential equation (Eq. 8) with the initial and boundary conditions (Eq. 9-12). The convergence criterion assumed at each node of the computational domain was $|\bar{M}_k-\bar{M}_{k-1}|\ll 10^{-8}$ (where k represents the k-th iteration). In order to determinate the optimum value of the D_{eff}, the coefficient of determination of the fit (R^2) was used as target.
To consider the effect of shrinkage, a law of variation of the volume was introduced in the model. This law was expressed as an exponential decay law, equation (13).

$$\frac{V}{V_0}=y_0+a\exp(-b\tau) \tag{13}$$

The volume of the sample was adjusted at each time step during the calculation of the mass governing equation, and an adaptive grid was used for simulations.

3. Results and Discussion

3.1 Physico-chemical analyses

The two analysed cultivars, although both are late-maturing varieties, differ in several characteristics (Table 1). Flesh hardness is more elevated in the fruits of *Keitt*, but in both cases the values indicate a fruit that is compatible with post-harvest handling operations. The two cultivars of mango have different total soluble solid contents and titratable acidity. *Osteen* also has a lower TA content and a higher TSSC. The values are very high, comparable with those found in literature (de Cassia Mirela Resende Nassur et al., 2015) and compatible with immediate commercialization. With regards to the flesh colour, the parameters L* (luminosity) and b* (yellow index) are similar in both cultivars, while the different values of the a* parameter show the *Osteen* fruits have a more reddish shade that could positively influence consumer acceptance. Similar values were observed by de Cassia Mirela Resende Nassur et al. (2015).

Table 1: Physico-chemical traits of the two mango cultivars. Flesh hardness (FH), total soluble solid content (TSSC), titratable acidity (TA) and flesh colour as Lab values.

Cultivar	FH (%)	TSSC (Brix°)	TA (g/kg)	L*	a*	b*
Keitt	52.92 ± 5.24^{b}	15.1 ± 0.78^{a}	0.31 ± 0.02^{b}	68.79 ± 2.13^{a}	3.31 ± 1.29^{a}	66.57 ± 4.69^{a}
Osteen	40.50 ± 3.94^{a}	18.1 ± 0.65^{b}	0.10 ± 0.01^{a}	69.84 ± 2.56^{a}	4.99 ± 0.47^{b}	64.46 ± 3.96^{a}

Values represented as mean ± SD. For each column different superscript letters indicate significantly different at p≤0.05 as measured by Duncan multiple range test.

A total of seventy-three volatile compounds (VOCs) were identified in fresh and dried mangos. These include fourteen esters, ten monoterpene hydrocarbons and nine sesquiterpene hydrocarbons. *Osteen* fresh mango has the higher VOCs: about 53 mg/kg db, with respect to *Keitt* fruit with about 7 mg/kg db. Fresh fruit volatiles composition of both cultivars was dominated by monoterpene hydrocarbons (70.2% of VOCs in *Osteen* and 51% in *Keitt*), considered as being amongst the most odour-active compounds, while sesquiterpene hydrocarbons accounted only for about 1.0% of VOCs. After drying, new compounds were generated and substantial losses occurred. The total amount of monoterpenes decreased from about 64.0% at 50°C to 99% at 70°C in *Keitt* mango and from 78% at 50°C to 99% at 70°C in *Osteen* samples (Figure 1). It can be noticed, especially in the cultivar *Osteen*, the decrease of volatiles and terpenes with the increase of the temperature. No significant differences were observed for the cultivar *Keitt* at 50 and 60 ° C .

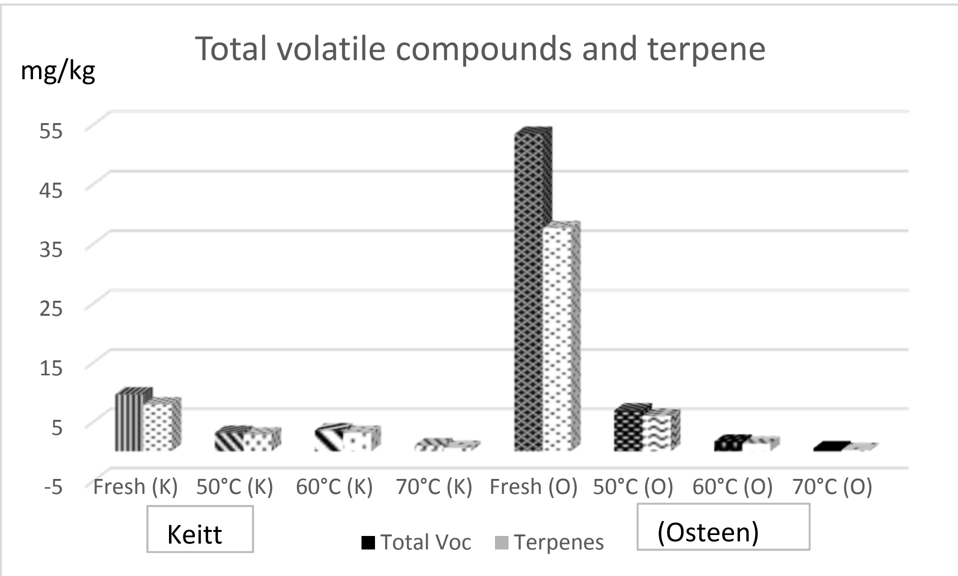

Figure 1: Total volatile compounds (VOCs) and terpenes changes (mg/kg) in Keitt (K) and Osteen (O) mango as fresh and after drying at 50, 60 and 70°C

The colour of dried products is an important quality parameter for consumers. The average values of the colour indexes, L* (lightness), a* (redness), b* (yellowness), Hue angle (H°) and total colour change (ΔE), for dried samples are reported in Table 2. Among all samples analysed, the highest total colour changes were found in the *Osteen* samples especially when dried at 70°C. On the contrary, the *Keitt* samples showed the lowest ΔE after the drying process at 60 and 70°C. These results were dependent on fruits carotenoid content (data not reported), responsible of yellow-orange colour. Heat treatment promotes isomerization of the carotenoids, from trans to cis isomeric forms, to an extent which is directly correlated with the intensity and duration of heat processing. In *Keitt* samples the time effect is prevalent, in fact greater variations in colour were found at low temperatures, increasing the level of oxidation. On the contrary, for *Osteed*, characterized by a redder colouring (perhaps with carotenoids more sensitive to heat), it was evident a greater colour variation at the highest temperature (70 °C).

Table 2: Colour parameters on Keitt and Osteen mango samples dried at 50, 60 and 70 °C.

Cultivar	T (°C)	L*	a*	b*	H°	ΔE
Keitt	50	57.70 ± 0.18^{a}	1.30 ± 0.03^{d}	46.81 ± 0.15^{a}	88.41 ± 0.05^{c}	14.63 ± 1.30^{c}
	60	62.95 ± 0.03^{b}	2.29 ± 0.15^{f}	62.57 ± 0.12^{c}	87.91 ± 0.14^{a}	9.88 ± 0.10^{b}
	70	66.13 ± 1.05^{b}	2.15 ± 0.15^{e}	62.60 ± 1.29^{b}	88.03 ± 0.10^{b}	7.25 ± 1.04^{a}
Osteen	50	76.78 ± 0.38^{d}	-2.03 ± 0.11^{c}	72.94 ± 0.03^{f}	91.59 ± 0.09^{d}	16.08 ± 0.03^{d}
	60	86.39 ± 0.03^{e}	-7.81 ±0.02^{a}	63.93 ± 0.11^{d}	96.96 ± 0.10^{f}	15.31 ± 0.15^{cd}
	70	75.55 ± 0.69^{c}	-2.49 ± 0.06^{b}	69.94 ± 0.32^{e}	92.03 ± 0.04^{e}	28.51 ± 1.32^{e}

Values represented as mean ± SD. For each column different superscript letters indicate significantly different at p≤0.05 as measured by Duncan multiple range test.

3.2 Shrinkage

The results of mean volume shrinkage during drying are reported in Figure 2 for both cultivars. At the end of the drying the slabs have a volume that is about 20-30% of the initial one, the smaller at the higher temperature. The data profile showed an exponential decay trend which was introduced in the model to consider the effect of shrinkage on the drying kinetics.

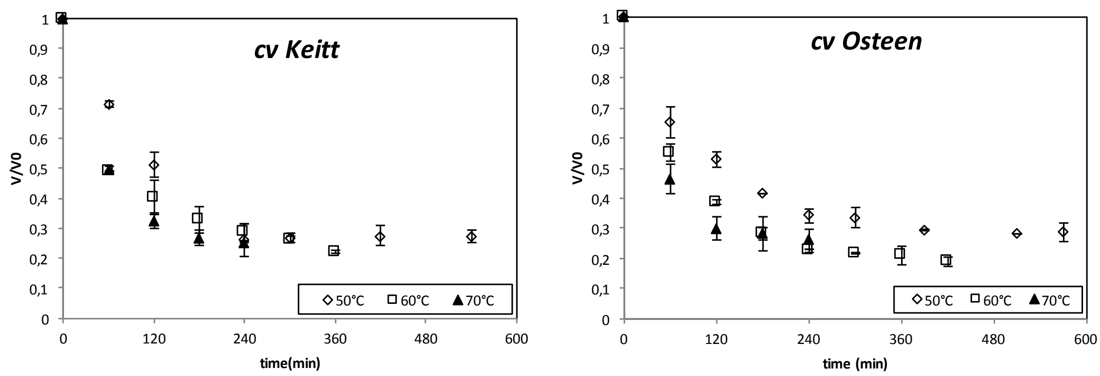

Figure 2: Volume ratio (V/V_0) vs drying time during Keitt and Osteen mango drying at: 50, 60 and 70°C

3.3 Drying kinetics

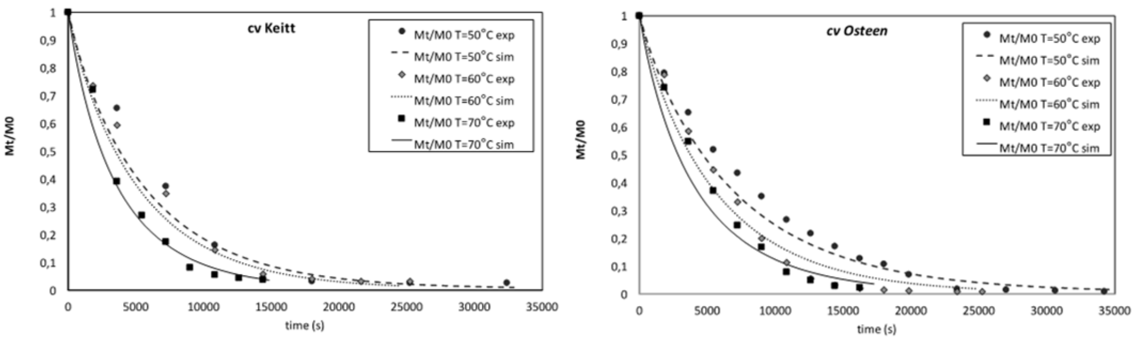

Figure 3: Moisture ratio of mango samples: cv Keitt and cv Osteen during drying at 50, 60 and 70 °C, from experiments and simulations.

Kinetics data of mango slabs for both cultivars at the temperatures considered in this work (50-70°C) were reported in Figure 3. In the same figure the results of the model were compared with experimental data. The results showed that the developed model well describes the experimental drying kinetics at all the temperatures (R^2>0.982). The value of the effective diffusion coefficient estimated by the model ranged from $4.3*10^{-10}$ to $5.5*10^{-10}$ m^2/s for cv *Keitt* and from $3.5*10^{-10}$ to $4.3*10^{-10}$ m^2/s for cv *Osteen* in the range of temperature 50-70 °C. The calculated values of effective diffusivity were slightly higher for cv *Keitt* than for cv *Osteen* and hence the slabs of cv *Keitt* dried slightly faster than those of cv Osteen. Values of D_{eff} were similar to that estimated by Hernandez et al. (2000) ($8.56*10^{-10}$ m^2/s at 60 °C). Since the initial moisture content was the same for the two cultivars, this behavior is probably related to the different structure of the two cultivars. This aspect will be further investigated in the future.

4. Conclusions

The drying process of mango slices at different temperature was investigated. Significant losses of volatile constituents of fresh mango occurred as consequence of the drying process especially at higher temperature. Drying reduced the amount of many volatile compounds, including monoterpenes, which are considered as impact odorants. After drying the content of volatile substances, although much higher in *Osteen* fresh fruits, were very similar in the two cultivars. Their decline may be explained by their evaporation and degradation during the drying process. Among the two cultivars, *Keitt* samples showed less variation in colour after the drying process at 60 and 70°C. On the other hand the volume shrinkage has a similar extent for both cultivars, but lower at higher temperature (70°C). Experimental data of moisture ratio during drying were well predicted by the diffusion model developed including the effect of shrinkage. The calculated values of effective diffusivity were slightly higher for *Keitt* mango slices than for *Osteen* ones. In conclusion, based on the quality parameters considered, the *Osteen* cultivar was more sensitive to the drying process at high temperature than the cv *Keitt*.

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