Experimental study of the shrinkage phenomenon during the static and open sun drying of apple slices

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Abstract

This paper presents an experimental study of the shrinkage phenomenon of apple slices during two types of drying, namely: static drying (in an electric regulated oven) and open sun drying (naturally, on one tray) under the meteorological conditions of Ouargla city in the south east of Algeria. In the oven, the experiments are performed with three different temperatures (50, 60 and 70 °C). The effect of the water content loss of the fruit samples on the dimensions (thickness and diameter) and on the volume are considered.

During the static and sun drying, the results show that the volume decreases by 80% and 86% of its initial values, respectively. During the static drying, the diameter of each apple slice shrinks by 20% and the thickness by 70 % of the initial values. Not far from these values, the diameter decreases by 25% and the thickness by 76% of the initial values during the open sun drying.

In addition, the drying of apple slices shows an anisotropic shrinkage independently of temperature and therefore a unique shrinkage equation is proposed for each of both methods of drying.

Finally, the importance of considering the phenomenon of shrinkage of the apple fruit during drying is shown in the Krischer curves.

Keywords: *Apple slices, Experimentation, Shrinkage. Static drying, Open sun drying.*

I. Introduction

Fruits are a source of fibers, vitamins, proteins, carbohydrates, lipids and minerals. Their seasonal production with high water content makes them perishable and, consequently, various technologies to protect and return them available throughout the year are needed [1, 2]. To this end, drying process is usually used, it preserves fruits in a stable and safe conditions, reduces water activity and extends shelf-life much longer than that of fresh state [3].

Several fruits were dehydrated using various methods of drying as: bananas [4, 5], apples [6], pears [7],

tomatoes [1, 2, 8, 9], watermelon [2,10], apricots [11], figs [12], strawberries [13] and grapes [14].

Apples are a significant source of pectin fiber (3g/medium apple), and they provide carbohydrates and vitamins while contributing few calories and no fat, sodium, or cholesterol [15]. Apples are also an important raw material for many food products and apple plantations are cultivated all over the world in many countries [3]. They are largely produced in Algeria and are commercialized both in internal and external markets. Many studies were carried out in drying but only few researchers considered the shrinkage phenomenon of fruits during drying. Such phenomenon helps predict well the packaging and the storage and is used as important data in the simulation and the modeling of the drying [2].

However, referring to literature the shrinkage phenomena had been considered in many research works [1, 2, 8, 16, 17, 18] where most of shrinkage curves in the food processing domain were determined manually by means

of compass or by means of rules, or by volume measurement moved during a dumping.

This work was an experimental study of shrinkage phenomenon of apple slices during two various drying namely: the static drying (in an oven) and the natural drying. The influence of the moisture content loss on the fruit dimensions and the temperature effect on the shrinkage were considered.

II. Materials and Methods

II.1 Materials

- ***Fruit***

Good quality of apples were purchased from a local market of Ouargla and then cut into slices of 0.60 cm average thickness and of 5.71 cm average diameter. For more precision, several samples were used and the experiments were multiplied. Results of this research were based on average values.

- ***Devices***

A regulated oven operating between ambient temperature and 350 °C, and one clay were used during the static and sun drying, respectively.

II.2 Methods

- ***Measurements***

During the sun drying experiments, the ambient temperature and the ambient humidity were measured with a thermo-hygrometer. The solar radiation was measured with a Kipp and Zonen pyrometer.

- ***Data analysis***

The drying process was continued until the product achieved its final mass at which the mass does not decrease significantly with increasing drying time. Then, the dry mass of the fruit was determined by introducing its equilibrium wet mass into the oven at

105 °C (during 24 hours), the authors [1, 2, 9] followed the same procedure.

The instantaneous moisture content on dry basis (X(t)) which is the mass of water present in the product per unit mass of the dry matter in the product was defined, classically, by using Eq.(1):

$$X(t) = \frac{M_w(t) - M_d}{M_d} \quad (1)$$

Where: $M_w(t)$ is the instantaneous wet mass (kg) and M_d is the dry mass (kg).

The equilibrium moisture content (X_{eq}) was also calculated classically as follows:

$$X_{eq} = \frac{M_{wf} - M_d}{M_d} \quad (2)$$

Where: M_{wf} is the final wet mass (kg) and M_d is the dry mass (kg).

The drying rate during the drying process was determined by using Eq. (3):

$$DR = \frac{X(t) - X(t+\Delta t)}{\Delta t} \quad (3)$$

Where: X(t) is the instantaneous moisture content on dry basis (kg water/kg d.m.), $X(t+\Delta t)$ is the moisture content on dry basis at the instant $t+\Delta t$ (kg water/kg d.m.) and Δt is the step of time (s).

The samples (apple slices) were considered as disks [2] and by using the two Equations (4 and 5), the external surface, S (m^2), and the volume, v (m^3), were calculated.

$$S = \pi \frac{D^2}{2} + (D \times e \times \pi) \quad (4)$$

$$v = \pi \left(\frac{D^2}{4}\right) \times e \quad (5)$$

Where: D and e are the diameter and the thickness of the slice (m), respectively.

It should be noted that in the paper [18], the author had used the same procedure when she had determined the shrinkage equations during sludge drying.

III. Results and Discussions

III.1 Determination of shrinkage

- ***Shrinkage during static drying***

Figure 1 shows the variation of the diameter ratio (D/D_0) of the fruit samples during static drying versus water content ratio (X/X_0) at three different air temperatures, namely: 50, 60 and 70 °C. In this temperature range, the curves present the same linear trend and, consequently, no influence of the drying temperature on the diameter shrinkage was observed. The diameter shrunk by 20%, approximately.

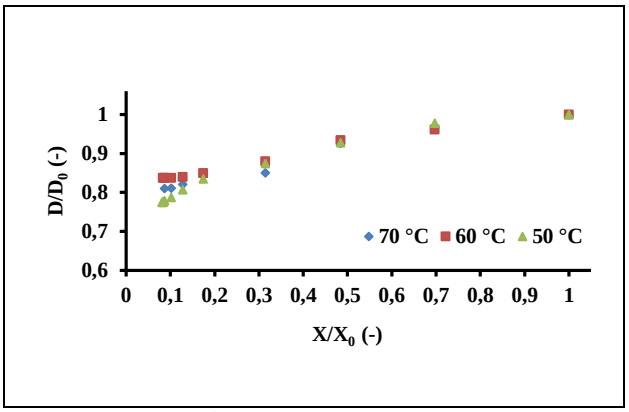

Figure 1. Variation of the apple slices diameter during static drying.

Figure 2 shows the variation of the thickness ratio (e/e_0) of the fruit slices during static drying versus water content ratio (X/X_0) at the same three air temperatures. The curves also present the same linear trend and consequently no influence of the drying temperature on the thickness shrinkage was found. The thickness of each slice decreased by 70%, approximately, thus in a more important way compared with the diameter case.

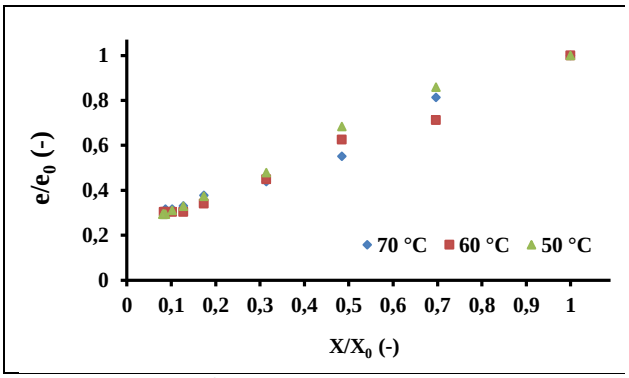

Figure 2. Variation of the apple slices thickness during static drying.

Figure 3 shows the variation of the volume ratio (V/V_0) of the fruit during static drying (in the regulated oven) versus water content ratio (X/X_0) at 50, 60 and 70 °C. The curves show the same linear trend and, as in the diameter and thickness cases, no influence of the temperature on the volume shrinkage was observed; but, an important reduction of about 80% in volume was obtained.

Since the shrinkage phenomenon of the apple slices during static drying was independent of temperature, in the (50 - 70 °C) range, then a unique equation can be used (Eq. (6)).

$$V/V_0 = 0.8149\ X/X_0 + 0.1642 \qquad (6)$$

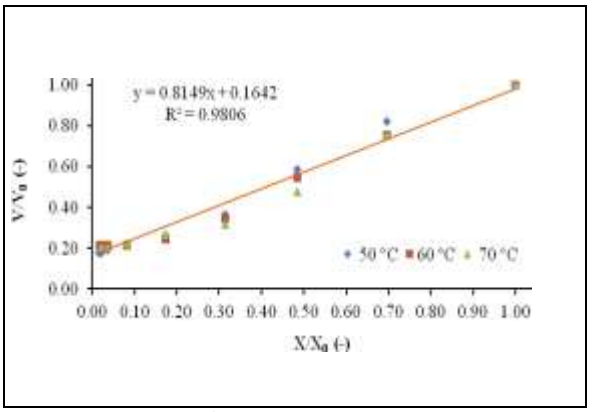

Figure 3. Variation of the apple slices volume during static drying.

The variation of the surface ratio of the fruit samples versus volume ratio is represented in Figure 4, and like the volume ratio, a linear relation can be proposed connecting the surface ratio to the volume ratio (Eq. (7)):

$$S/S_0 = 0.4542\ V/V_0 + 0.5339 \qquad (7)$$

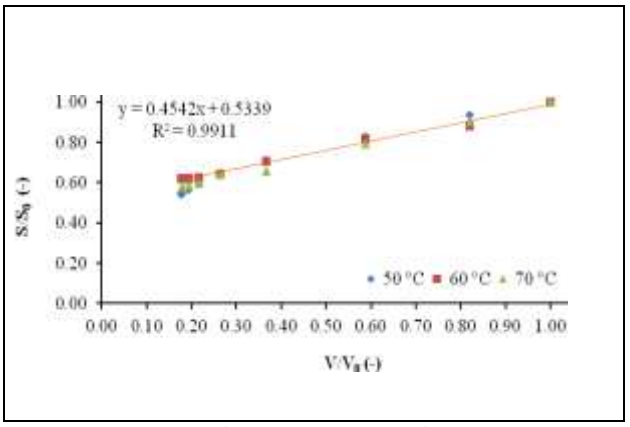

Figure 4. Variation of the apple slices surface during static drying.

➢ *Shrinkage during open sun drying*

The evolutions of the external parameters during three typical days of sun drying are shown on Figure 5. The solar radiation reached maximal values of 1000 W/m^2 with daily average exceeding 700 W/m^2. The maximal and average temperatures of the ambient air were close to 45 and 36°C, respectively. Regarding the relative humidity, the values were low during the typical drying days; exceptionally, the values exceeded 24% during the third day.

In addition, Figure 5 shows that the ambient temperature was low at the beginning and the end of the day, but significant at noon; it increased and decreased with the solar radiation. The relative humidity had a reverse trend to that of the ambient temperature and to that of the solar radiation.

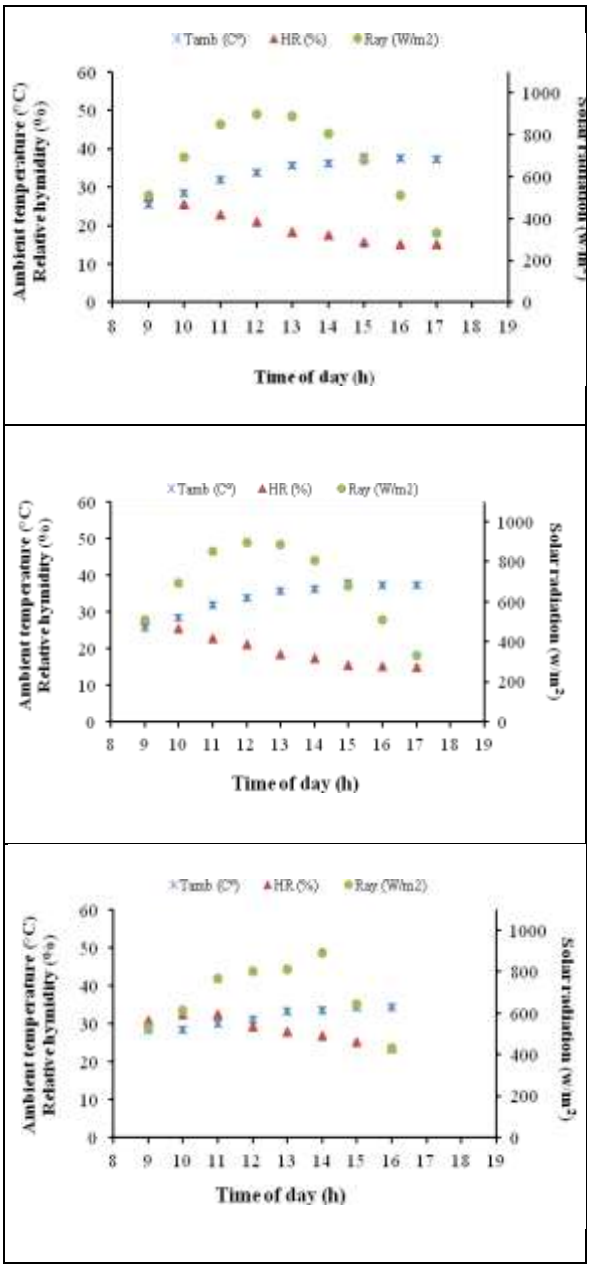

Figure 5. Evolutions of the external parameters during three typical days of open sun drying

Figure 6 shows the variations of the diameter ratio and the thickness ratio of the apple slices versus relative moisture content ratio during open sun drying in Ouargla city, Algeria. Both variations were different then the shrinkage of the apple was anisotropic i.e. the diameter and the thickness do not decreased in the same way. In the same figure, diameter shrinkage of 25% and thickness shrinkage of 76% could be read.

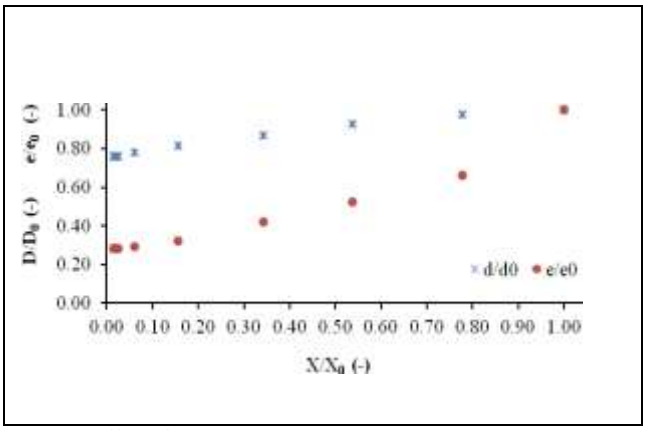

Figure 6. Effect of the open sun drying on the apple slices dimensions.

Figure 7 shows the variation of the volume ratio of the fruit slices during open sun drying versus water content ratio. The curves trend is linear (Eq. (8)) and the diameter decreases by 86 %, approximately of its initial value.

$$V/V_0 = 0.766\ X/X_0 + 0.1303 \quad (8)$$

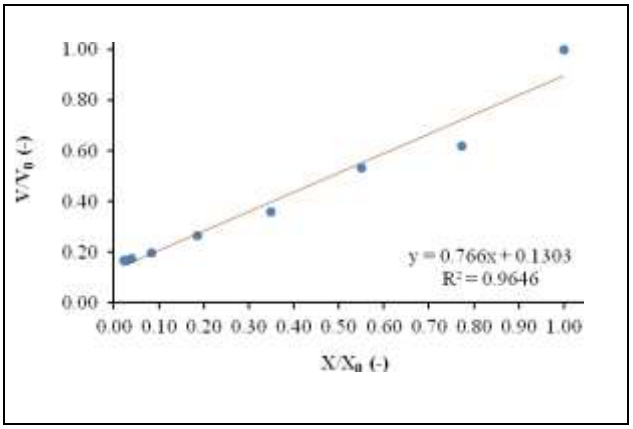

Figure 7. Variation of the apple slices volume during open sun drying

The surface ratio variation of apple slices dried naturally versus its volume ratio is shown in Figure 8. The evolution was almost linear and consequently the following Equation (Eq. (9)) can be proposed:

$$S/S_0 = 0.578\ V/V_0 + 0.463 \quad (9)$$

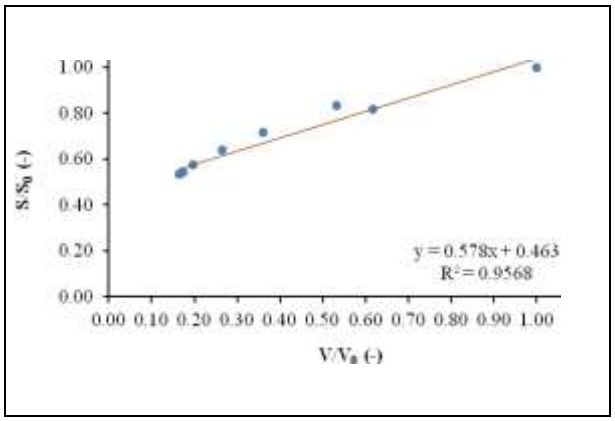

Figure 8. Variation of the apple slices surface during open sun drying.

III.2 Drying kinetics

- ***Static drying case***

The curves obtained experimentally (X/X_0 = f (t)) in Figure 9 show the evolution of the moisture content ratio versus drying time at temperatures of 50, 60 and 70 °C. The moisture content decreased constantly in time to reach a final value: it was the drying process. The drying time decreased when the temperature increased, especially when exceeding 50 °C.

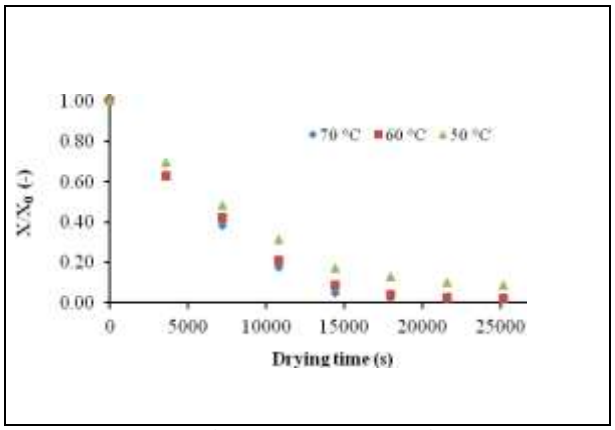

Figure 9. Variation of the moisture content of the apple slices during static drying.

The curves (DR = f (t)) in Figure 10 represent the drying rate in the static method: the constant drying phase was absent and the falling rate period was the most dominant during all the process.

Figure 11 shows the variation of the static drying rate ratio versus moisture ratio of apple slices without taking into account the change of the external surface during the process. So this surface was taken as constant, i.e. shrinkage phenomenon of the fruit was neglected. Figure 11 also shows a short adaptation phase followed by a dominant falling drying rate phase.

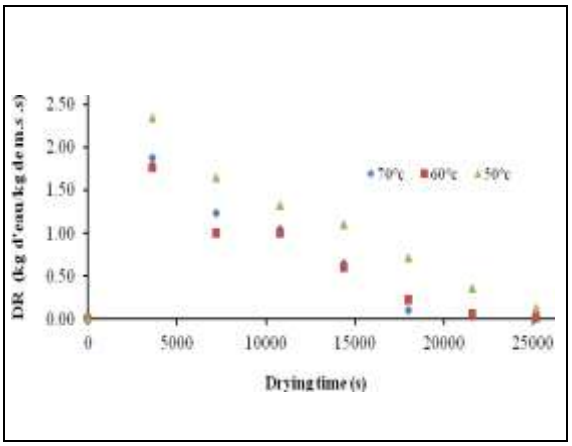

Figure 10. Variation of the drying rate of the apple slices during static drying.

Really, the three classic phases of drying existed and were very well readable in the Krischer curve (Figure 12): Variation of the static drying rate ratio versus moisture content by taking into account the variation of the evolution of the external surface. The importance of considering such phenomenon was very clear.

The four Figures (9-12) also show that the drying was influenced by the temperature indeed the drying rate increased with this parameter when the drying time decreased.

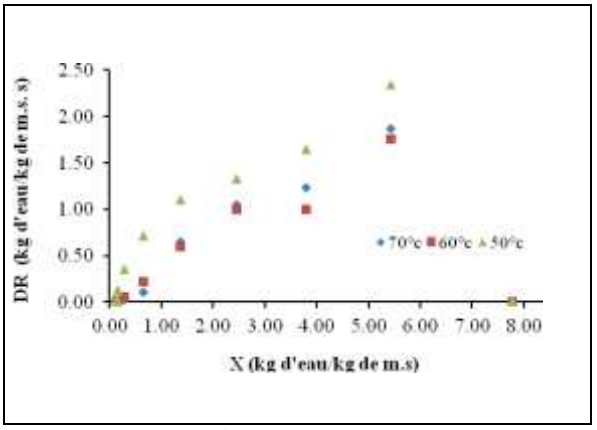

Figure 11. Variation of the drying rate v.s. moisture content during static drying of the apple slices.

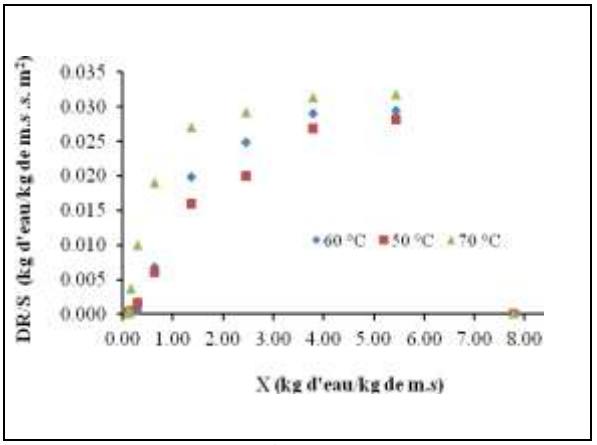

Figure 12. Krischer curve of the apple slices during static drying

➢ ***Open sun drying case***

The experimental study of open sun drying and the analysis of drying kinetics (Figures 13-15) also showed the importance of the shrinkage considering. The three classical drying phases were present.

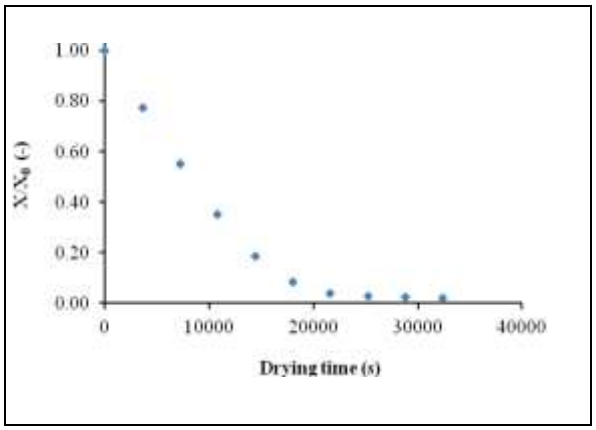

Figure 13. Variation of the moisture content of the apple slices during open sun drying.

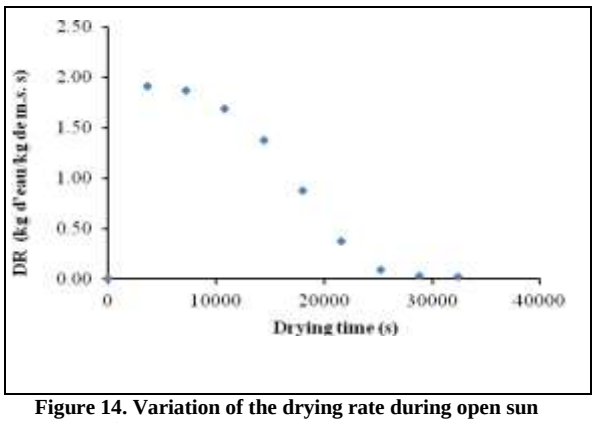

Figure 14. Variation of the drying rate during open sun drying of the apple slices.

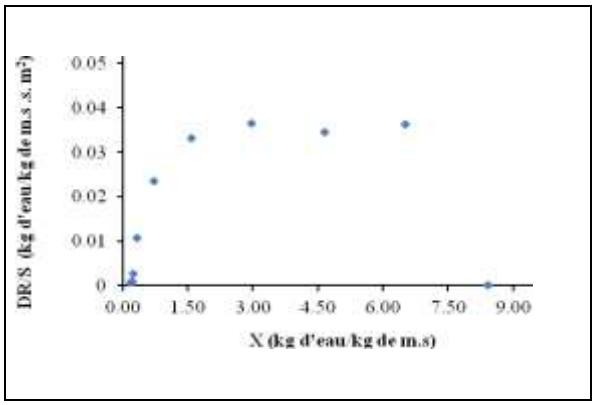

Figure 15. Krischer curve of the apple slices during open sun drying.

IV. Conclusions

During an experimental investigation of the static and sun drying of apple, it was proved that the shrinkage phenomenon of a fruit took place in a remarkable way. The effect of the process on the fruit dimensions was important and the main conclusions of this study can be recapitulated as follows:

- During the static drying of apple slices, the diameter decreased by 20%, the thickness by 70 % and the volume by about 80%, of the initial values.
- During the sun drying of apple slices, the diameter decreased by 25%, the thickness by 76% and the volume by 86%, of the initial values.
- At the temperature range of this study, the drying showed an anisotropic shrinkage independently of the temperature.
- A unique shrinkage equation was proposed for each of both drying methods.
- The drying rate increased with temperature, however the drying time decreased.

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