MATHEMATICAL MODEL OF SUN DRYING OF SLICED TOMATO IN HAWASSA REGION – ETHIOPIA

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Abstract. This study is focused on mathematical description of the open sun drying process of sliced tomato under the conditions of Hawassa region in Ethiopia. The sliced tomatoes were open sun dried by the method of sieves drying and also by the traditional Ethiopian method of drying on canvases. For both methods the mathematical models were determined and the processes were energetically analysed. The measured data were fitted by mathematical models using the Marquardt Levenberg method for non-linear data processing and were also statistically analysed by ANOVA. The integral part of this study is also comparison of both methods in terms of usability of local farmers as well as householders in Hawassa region.

Keywords: specimen, agriculture product, curves, sun drying.

Introduction

Tomato (*Lycopersicumesculentum*) is a herb that falls within the nightshade family. It is grown in all latitudes, over an area of approx. 3,000,000 hectares, which represents almost one-third of the world's largest land used for growing vegetables [1], and constitutes one of the most important crops in the food industry. Tomato is very liable to perish in the fresh state, which leads to wastage. Current statistics indicate 20-25 % of pathogenic post-harvest losses in developed countries [2; 3], in developing countries they lose more than 35 % due to inadequate storage, processing, therefore, a correct post-harvest treatment can prolong the shelf life.

Drying is one of the oldest and most effective means of preserving food. Dry food can be successfully stored for up to several years if it is properly packed [4]. In African countries it is the traditional technique of drying fruit and vegetables from the sun. Drying in the sun is known as a food preservation process, which reduces the moisture content of agricultural products, and thereby prevents damage during storage. It is a preferable alternative for rural areas, where there is irregular power supply. This technique has the advantage of simplicity and small or no capital investment, but, on the other hand, it requires a longer drying time compared to other drying methods. It may also affect the quality of the product, which may be contaminated by dust and insects, or damaged by enzymes and mycobacterial activity [5; 6]. The most important key factors that have an influence on the drying process are humidity and ambient temperature [7; 8].

Drying is a complex process in which transient heat and moisture occur at the same time [9]. Mathematical models of drying are used for designing new or improving the existing drying systems. Many mathematical models are proposed to describe the drying process for drying of a thin film, which is widely used. Several models are used for drying in a thin layer. These models can be regarded as theoretical, semi theoretical, logarithmic and empirical [10; 11]. In recent years, various authors have conducted many studies involving mathematical modeling and kinetics of a drying process of fruits and vegetables, such as red pepper [12], eggplant [13; 14], green beans [15], okra [16; 17] and tomatoes [18; 19].

The aim of this study is to describe drying of thin sliced tomato in the conditions of Ethiopia.

Materials and methods

Freshtomatoes (*Lycopersicumesculentum*) were purchasedat a local marketinHawassain southern Ethiopia. Tomatoeswere washedwith coldwater to removesoil anddust particles.Tomatoes, forwhich theexperimenthas been conducted, havebeen storedunder temperature 4 ± 1 ºC.

The initial moisture content was determined by weighing the samples on electronic digital scales (KERN PFB 1200-2, Kern &Sohn GmbH, Balingen, Germany). Subsequently, the selected samples were oven-dried in the oven KBC G-100/250 (PREMED, Poland) at 100 ºC for 24h. Thus, three samples were tested, which were averaged. The initial moisture content of tomatoes was 95.63 ± 2.37 % DWB

Experiments were performed in Hawassa in Ethiopia, which lies on the shore of Lake Awasa Great Rift Valley located 270 km south of the capital Addis Ababa. It is given by the coordinates: Earth's latitude 7º 2.732' S and longitude 38º 27.743' W, at an altitude of 1682 m above the sea level.

For each experiment tomato slices with a thickness of 4 mm were used. The experiments were carried out in the period from October to November, a period of drought in Ethiopia. Drying was done by placing the samples in direct sunlight where the measuring place was not interfered by shadow which would affect the measurements. The dried slices of tomato were dried on a canvas which is a classical local method of drying and on a sieve (Fig. 1). The sieve was fixed in order not to impede access of the drying air to the bottom of the sample which led to drying of tomato slices over the entire surface.

Fig. 1. **Drying of tomato on sieve and canvas**

As a solid support white plates were used. The sieve had a circular shape with the diameter 240 mm. The dimensions of the sieve mesh were 1 x 1 mm, the thickness of the used wire was 0.1 mm. The test was conducted every day from 9:00 to 16:45 h, so that the samples were exposed to sunlight during the whole measurement. The weight was determined by the digital scales (KERN PFB 1200-2, Kern &Sohn GmbH, Balingen, Germany) every 30 min and it was recorded. After weight determination the temperature was deducted from the digital thermometer, which simultaneously measures the humidity of the air (Datalogger DS100, Germany). Concurrently, solar radiation (CEM DT-1307, USA) was also investigated. At night the measurement was interrupted; the dried samples were placed in a room where they were not affected by outdoor humidity. Drying was terminated when the weight loss was constant. Drying on the canvas and the sieve was carried out repeatedly three times.

Results and discussion

The measured weights were evaluated with the aid of Excel. In Fig. 2 the evaluated values of normalized weight during the day are displayed, and during the night the weight was not determined.

For determination of a mathematical model it is needed to display the curve, without a time when there is no reading of the weight measurement (Fig. 3), i.e. at night. Despite the very high altitude at the place, where experiment was conducted, at night drop weight of the measured samples occurred. On the curves this change of the weight by jumping weight is seen. This is the last measured value on the first day and the first day of the following value of measurements. Thus, the filtrated data were evaluated in the program Mathcad 14 and the equation of the drying curves with coefficients was determined (Tab. 1).

Fig. 2 shows drying during the first, second and third day. The third day was only for checking whether there is a change of the drying mass. As apparent from Fig. 3, stabilization of the mass occurs on the second day. A similar conclusion was reached by the authors of [10; 19]. The solid supports 1 and 2 are characterized by the classical drying on a full plate; the sieve support is characterized by drying on the sieve, which allows access of air from all sides of the dried sample. On each support the measurement was repeated three times, where Fig. 2 and 3 show the average values. From the curves it is apparent that drying on the sieves is faster than on a solid support. The author [16] indicates that the drying time of 5 days in the open sun, compared with drying in a tunnel oven, was reduced by one day. In this region of Ethiopia the drying time to a constant weight takes only two days. Fig. 4 presents the process weight changes without measuring time, when the samples were stored in a room. Overnight in the measured region increasing of humidity up to 80 % occurs, thereby affecting the samples. The graph shows that weight loss occurs during the night, which is evident by the weight jump.

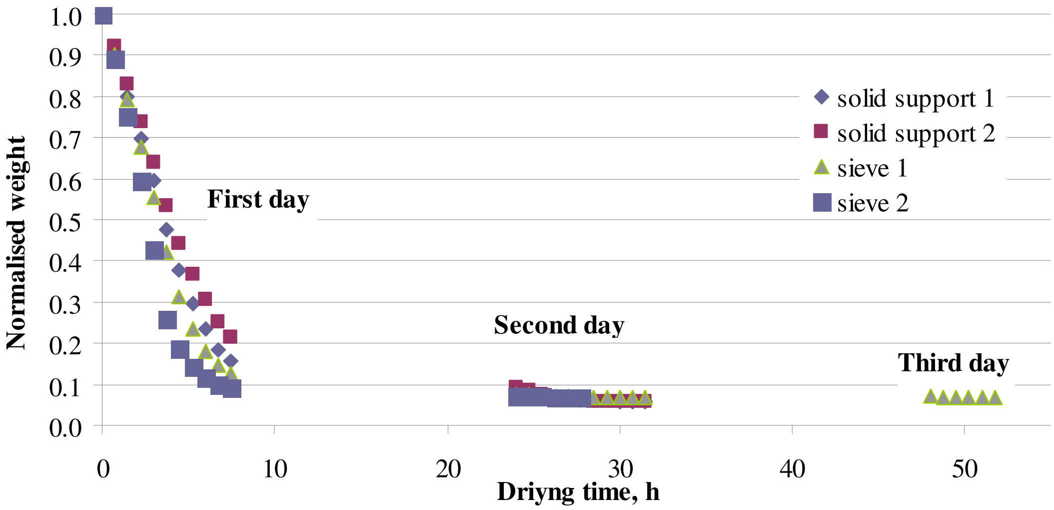

Fig. 2. **Dependency between normalised weight and drying time**

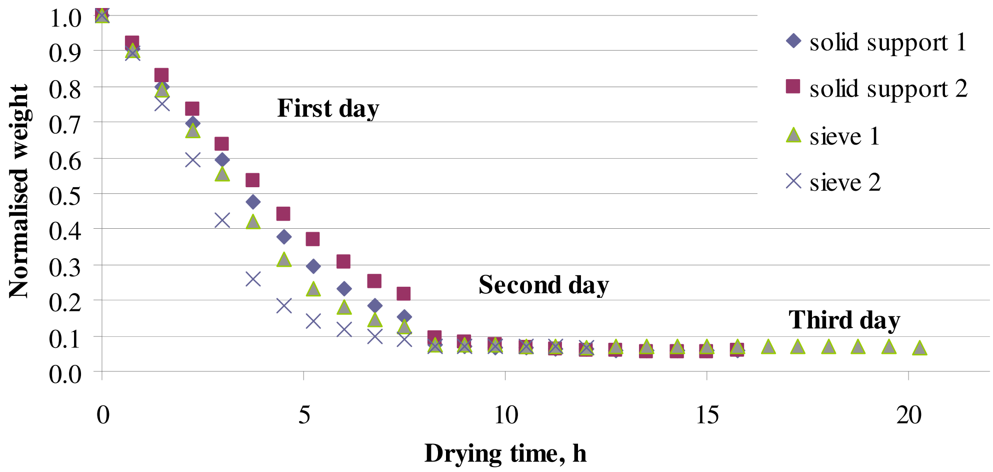

Fig. 3. **Dependency between normalised weight and drying time without night time**

Theoretical drying curve for the area:

$$K_{(t)} = U_0 \cdot e^{U_1 \cdot x} + U_2 \cdot e^{U_3 \cdot x} + U_4, \tag{1}$$

where U_0 – first partial normalized weight;
U_1 – first ratio of normalized weight, h^{-1};
U_2 – second partial normalized weight;
U_1 – second ratio of normalized weight; h^{-1}
U_4 – normalized weight in ∞, constant normalized weight;
x – drying time, h.

The coefficients for the different methods of measurement are shown in Table1. Individual measured amounts of normalised weight (Fig. 3) were fitted using Marquardt Levenbergalgoritm [20] by exponential curve described by Eq. 1, and its coefficients are presented in Table 1.

An ANOVA (Analysis of variance) statistical analysis using the MathCAD software of the measured and fitted data shows that the measured data could be mathematically described by Eq. 1. The significance of the ANOVA analysis results was based on the values of F_{crit} being higher than Frat values as well as P_{value} greater than 0.05 with high coefficients of determination R^2 (Table 1).

Table 1

Coefficients for the different methods of measurement

Method	U_0	U_1	U_2	U_3	U_4	F_{rat}	F_{crit}	P_{value}	R^2
Solid canvas 1	-5210	-0.0081	5211	-0.00810	0.038	$2.287 \cdot 10^{-14}$	4.07	0.99	0.997
Solid canvas 2	-5372	-0.0070	5373	-0.00702	0.025	0	4.07	0.99	0.995
Sieve 1	5632	-0.0097	-5631	-0.00967	0.061	$5.547 \cdot 10^{-15}$	4.02	0.99	0.997
Sieve 2	5365	-0.0130	-5364	-0.01300	0.060	$8.774 \cdot 10^{-15}$	4.15	0.99	0.997

Note: F_{rat} – value of the F test; F_{crit} – critical value that compares a pair of models; P_{value} – hypothesis of the study outcomes significant level; R^2 – coefficient of determination.

Figure 4 shows the average values of solar radiation and humidity during the measurement. A similar waveforms of sunlight and moisture are achieved by the authors [12; 13; 20]. Simultaneously with sunlight, the temperature was measured; its course is similar to the solar radiation in Fig. 4. The temperature at the start of the measurement was 29.9 ± 2.3 ºC, after13 h it reached a maximum of 50 ± 1.6 ºC and subsequently decreased, when at the end of the measurement it was 32.4 ± 2.8 ºC. The coefficient of variation was determined by CV = 8 %, which is consistent with the behavior of biological materials.

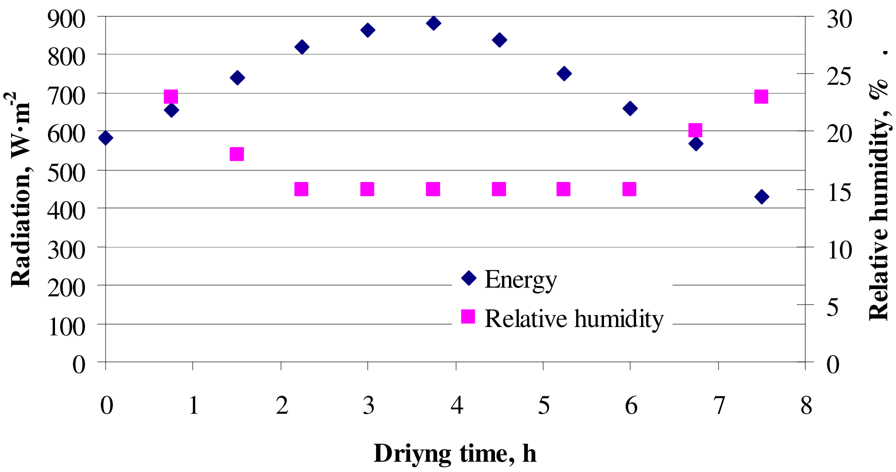

Fig. 4. **Dependency between solar radiation and humidity drying time**

The total amount of solar energy incident on the unit area of the entire drying process was calculated as 14.165 Wh·m^{-2} and it was determined as the area under the curve of the measured data (Fig. 4) of solar radiation.

The area of tomato slices was detected with the aid of the software Engauge Digitize. The average area of one slice of tomato was 16.59 x 10^{-4} ± 3.8 x 10^{-4} m^2. The amount of solar energy required for drying one slice of tomato 23.51 ± 5.39 Wh was determined as a product of the total amount of solar energy and average area of one slice of tomato. This determined amount can be used as background for further design of a drying oven specified for a given region.

Conclusions

1. Determination of a mathematical model for drying sliced tomatoes in condition of Hawassa region.
2. Drying on the sieve was faster in comparison with the traditional method on a solid support.
3. The solar energy needed for drying of one slice of tomato was determined as 23.51 ± 5.39 Wh.

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