JSAES
Journal of Sustainable Agricultural and Environmental Sciences

Print ISSN : 2735-4377
Online ISSN : 2785-9878
Homepage: https://jsaes.journals.ekb.eg/

Research Article

Engineering Studies on Drying Tomatoes (*Essolanum Lycopercum*) Leathers Using Infrared and Hot Air

Eman Elbadawy[1], Mohamed Darwesh[2], Magda Abdelrahman[1] and Mohamed Ghoname[3]

1Agricultural Engineering Research Institute, Egypt-Dokki,Egypt ,e-mail : eng.monam38@yahoo.com and mmagda212@yahoo.com

[2] Tanta University, Faculty of Agriculture, Agricultural Engineering Department, and Faculty of technology of Industry and Energy Samannoud Technological University, Egypt; e-mail : mohamed.darwish@agr.tanta.edu.eg

[3] Tanta University, Faculty of Agriculture, Agricultural Engineering Department,Emails: mohamed.ghonaim@agr.tanta.edu.eg.
[1] Correspondence: eng.monam38@yahoo.com

Article info: -
-**Received:** 23 September 2023
- **Revised:** 23 October 2023
- **Accepted:** 2 November 2023
-**Published:**15 November 2023

Keywords:
drying; tomato leather; moisture content, infrared

Abstract:
This study was carried out at Rice Mechanization Center (RMC) in Meet Eldeebah village, Agricultural Research center,Dokki,Giza,,Egypt, during 2021 to study the possibility of utilization the infrared radiation and hot air for drying tomato leathers at two different levels of infra-red radiation intensity (1000 and 900 W/m^2), two different levels of drying air temperature (55 and 60°C), drying air velocity (0.5m/sec) and thickness of (0.8 cm). The experimental work included the use of the simple exponential Lewis model for describing the drying behavior and predicting the changes in moisture content of tomato leathers during the drying process. The obtained results showed that the drying rate increases with increasing temperature and infrared radiation. The highest value recorded at 60 °C and 1000W/m^2 and reached 0.620155 (gw/gd.hr). The optimum treatment that achieved the highest quality of tomato leathers at radiation intensity of 1000W/m^2, air temperature of 60°C, also the same treatment recorded the Less drying time (9 hours).

1. Introduction

Egypt is the fifth largest producer of tomatoes in the world, with a total production of about 6.245 million tons annually, which is harvested from 150.109 thousand feddans according to (FAO, 2021).

Purkayastha et al, (2011) pointed out that tomato is one of the world's largest vegetable which is available round the year. The demand of tomato is increasing day-by day however, tomato is highly perishable in the fresh state leading to wastage and losses during the peak harvesting period. The prevention of these losses and wastage is of major interest especially when there is subsequent imbalance in supply and demand at the harvesting off-season. These growing market opportunities have necessitated that tomatoes be accessible in a more convenient form and thus led to the development of technologies for the preservation and sale of the product especially in a dry form.

Fruit leather is one product which will be made employing a drying process. Fruit leathers are dried sheets of fruit pulp that have a soft, rubbery texture & a sweet taste. Fruit leathers are often dried using various drying techniques including sun drying, oven drying, cabinet drying &dehydrator drying. The edible portion of fruit (one or more types) is pureed, mixed with other ingredients to enhance its physic-chemical & sensory characteristics (Damodaran and Parkin, 2010).

As 17 fruit leather is formed of fruit, it's generally nutritious and is usually targeted at food markets, using marketing images like 'pure', 'sun-dried' and 'rich in vitamins' (Vatthanakul et al., 2010). Fruit leather that's made without sugar may be a healthy choice of snacks for diabetic adults or children. The most advantage of creating fruit leathers is to preserve food by drying and, hence, controlling postharvest spoilage. Making fruit leather from ripe or slightly over-ripe fruit that's not suitable for fresh consumption will enable producers to satisfy market demand during off season periods. for instance, strawberries have a high post-harvest physiological activity with short ripening and senescence periods which makes marketing of this high-quality product a challenge. (Bharambhe et al., 2009).

Drying may be a simple process of excess water (moisture) removal from a natural or industrial product so as to succeed in the quality specification moisture content (Belessiotis and Delyannis, 2011).

Recently, novel thermal hybrid drying has been identified as a viable substitute to convective drying of agricultural products (Zhang et al., 2017). Specifically, the utilization of infrared (IR) energy together with hot-air drying (HAD) has gain significant interest within the drying of agricultural crops due to the synergistic effect of infrared including the heated drying air. This method involves the distribution of hot air throughout a chamber with the help of a fan/blower and an electrical heater. However, this drying method is found to consume too much energy and time, and affects the standard of the ultimate products (Onwude et al., 2016).

Convective hot air drying is that the commonest method for the economic and commercial drying of agricultural crops (An et al., 2016).

Hot air drying has two primary advantages: effective surface water removal and minimal operating costs. It is commonly employed in food dehydration, involves blowing heated air over food ingredients to eliminate moisture (Okunola et al., 2021).

Nuthong et al. (2011) showed that Infrared radiation (IR) is a part of the electromagnetic spectrum that is predominantly responsible for the heating effect of the sun. IR is an electromagnetic wave that has three categories based on its wavelength: the near-infrared (NIR; 0.78–1.4 mm), middle-infrared (MIR; 1.4–3 mm) and far-infrared (FIR; 3–1,000 mm) (Fig. 1).The transition of infrared radiation through water is at the NIR, which has a short wavelength, whereas at the FIR (longer wavelength) it is absorbed at the surface. IR drying has several advantages over conventional drying system. These advantages include short process time, improved energy efficiency, uniform or even product temperature, superior quality of final products, high degree of process control parameters, high heat transfer coefficient, space saving, and eco-friendliness (Rastogi, 2012). Infrared radiation and hot air are mixed to reduce drying time and thus increase the efficiency of the final product. Kocabiyik et al. (2015) stated that infrared drying of tomato provided good nutrient retention and low cost of energy. Therefore, infrared radiation can be suggested in both nutritional and operational aspects in terms of drying tomato slices. At present, it was applied in different driers using infrared radiators. The mechanism of these radiators, as an energetic advance that can give high drying efficiency, clean environment, space saves.

Sadin et al. (2014) investigated thin layer drying of tomato slices using infrared dryer and hot air. The drying tests were conducted using 3, 5, 7 mm thickness tomato slices weighing 60 ± 2 g. Drying temperature was programmed as 60, 70 and 80 °C for each experiment. Drying rate increased with increasing temperature and reduction thickness and thus reduced the drying time. The effective diffusivity increased with increasing temperature samples thickness. The effective diffusivity values changed from 1.094 × 10−9 to 4.468 × 10−9 m^2/s. The objectives of this study were to investigate the effect of radiation intensity and drying air temperature on drying characteristics of tomato leathers and assess the effects of the studied drying method on final quality of the dried tomato leathers.

2. Materials and Methods

The experimental work of this study was mainly carried out to determine the effect of radiation intensity, drying air temperature, air velocity by the heating method infrared radiation and convection heating on the drying behavior of tomato leathers. The present research work was carried out at Rice Mechanization Center (RMC), Meet Eldeebah village, Agricultural Research Center, Dokki, Giza, Egypt, during 2021.

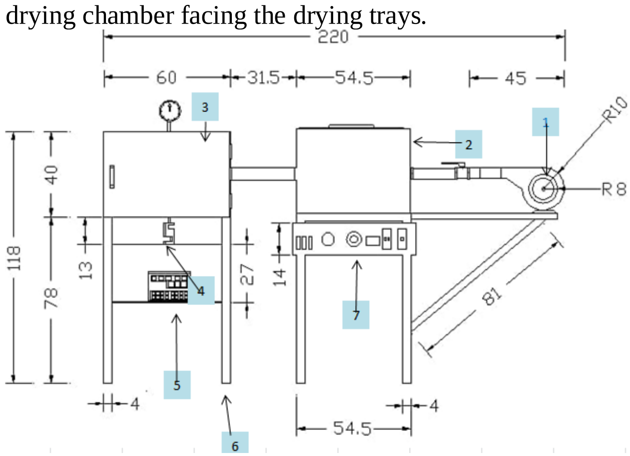
2.1. Raw material

Tomatoes used in the present study were obtained at moisture content of 95% (w.b) which harvested and transported to Kafr El-Sheikh Governorate.

2.1.1. Experimental setup

Fig 1 illustrates a general view of the schematic diagram of the dryer prototype used for the experimental work. It was used for drying tomato leathers of 0.8 cm thickness The experimental parameters of combined Infrared radiation and convection heating method included two different levels of infra-red radiation intensity (900 and 1000 W/m^2), and two different levels of drying air temperature (55 and 60°C).

The drying bed shown in Fig 1. constructed of an iron frame of 60 x 60 x 40cm (W*H*L) and the base of tray was made of stainless-steel mesh. The size of sample holding tray was 40x30x2cm. It was placed facing the infrared lamps in vertical consequence with a distance of 15cm between the trays and the heating sources. For heating and temperature control of the dryer, two (1kW) ceramic Infra-red heaters (German-750°C) were fixed over two iron blades and assembled into the sealing of drying chamber facing the drying trays.



No.	Part name	No.	Part name
1	Blower	5	Digital balance
2	Electric heaters box	6	Infrared drying system
3	Drying chamber	7	Dimmer
4	Load cell		

Fig1. Pictorial view of the experimental setup.

For controlling the distance between the ceramic heaters and the tomato leathers, two screw rods are welded to the iron blades to allow movement of the heaters up and down. To control the radiation intensity of the infra-red heaters a digital dimmer was used. An electric heater was used for air heating of drying chamber. The heating circuit of chamber consists of two 1.5 kW-Italian German heaters were connected to a thermocouple type (T) to control and measure air temperature, where a thermocouple was placed on tomato leathers to measure the fruit temperature during the drying process.

2.2. Experimental Procedure

Several steps have been taken for tomato leathers preparation as follow: selecting, washing of ripened tomatoes, Squeezing and preparing tomato puree, addition sugar to puree (30%), addition of citric acid to puree (0.3 %), addition of calcium carbonate to puree, pouring puree on the trays, drying at 50 – 70 °C for 8-10 h, removing trays from dryers and cutting, packaging and storage.

2.2.1. Moisture content

Initial and Final moisture content of tomato leathers were determined according to A.O.AC. (1990) using a German electric oven 1.5 KW (Rumo -10878) at 105°C for 24hour.

$$M.C = \frac{wi - wd}{wd} \quad \text{Eq 1}$$

Where:

wi: weight before drying

w_d: weight after drying

2.2.2. Drying rate

The drying rate was calculated according to the following equation:

$$DR = \frac{Mct}{t} \quad \text{Eq 2}$$

Where:

DR: drying rate ($MC_t = MC_1 - MC_2$).

T: time (min) (t=t2-t1).

2.2.3. Moisture ratio

$$MR = \frac{M - Mf}{Mo - Mf} \quad \text{Eq 3}$$

Where:

MR: Moisture ratio, dimensionless

M: Instantaneous moisture content during the drying process, %(db).

M_o: Initial moisture content of tomato samples, % (db).

M_e: Final moisture content of tomato samples, % (db).

2.2.4. Lewis model

This model is used to evaluate the drying process. The model is presented in equation 4:

$$MR = \exp(-kt) \quad \text{Eq 4}$$

k_l: Drying constant, min^{-1}

t: Drying time, min

2.3. Measurements and Instruments

Air temperature inside the dryer was measured by a digital temperature and humidity meter (Model Chino HNK). The measurements were done at hourly base intervals. A digital fan anemometer (model TFA) was used to determine hot air drying velocities in Hybered drying system. The anemometer had a range of 0.1 to 30 m s^{-1} and an accuracy of ± 2%. Energy meter type of CA4 N678T 40r (50-100 A) with an accuracy class 2 and voltage ratings 220 and 380 V was used to measure electric energy consumption.

2.4. Physio-Chemical analyses of dried tomato leathers.

Dried tomato leathers quality was measured in terms of Ascorbic acid (Vitamin c) and Carotenoids (Vitamin A) at different levels of infrared radiation intensity, drying air temperature and slice thickness according to the method reported in (Demiray et al. 2013).

Dried tomato leathers quality was measured in terms of total protein , total calcium and total solids according to the method reported in (Sarkar et al. 2018) also total ash was measured according to the method reported in (Sarkar et al. 2018).

3. Results

3.1 The effect of drying air temperature and infra-red radiation levels on tomato leathers drying curve

Tomato leathers were dried from 95% (w.b) to a safe final moisture content of 10±2% (w.b) by combining infrared drying and hot-air convection system under different treatments. Fig. 2 represents the variation of the MC in tomato leathers with drying time at drying air velocity of 0.5m/s, drying air temperature 60 and 55 °C respectively, tomato leathers thickness of 0.8 cm and two different levels of infrared radiation 1000 and 900 W/m^2 respectively. The drying runs were stopped when the final moisture content reached about 10±2 % (w.b.).

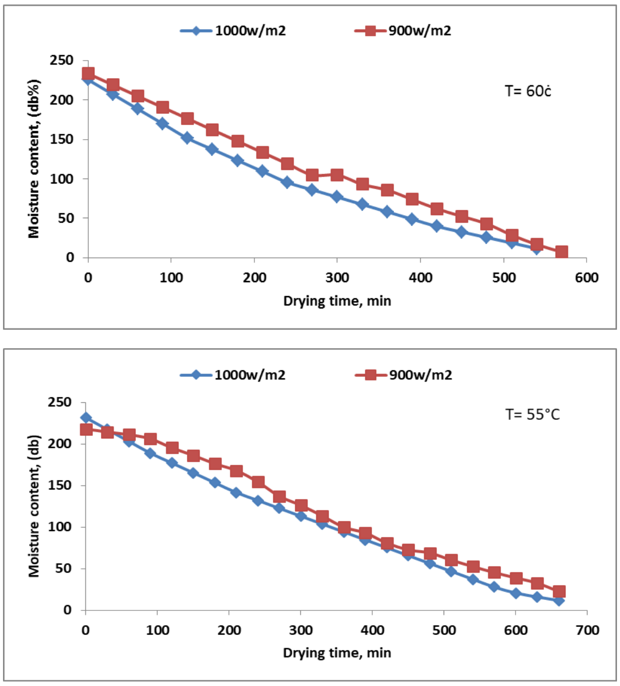
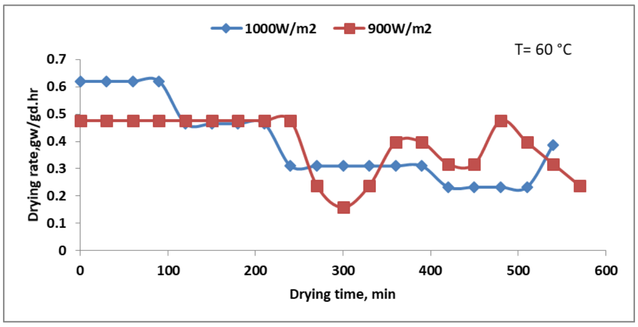


Fig2. The influence of infra-red radiation intensity and drying air temperature on tomato leathers moisture content at drying air velocity 0.5 m/s and thickness of samples 0.8 cm.

3.2 The effect of drying air temperature and infra-red radiation levels on tomato leathers drying rate

Fig 3 shows that the changes in drying rate ($g_w/g_d.h_r$) as a function of drying time at drying air velocity of 0.5m/s , drying air temperature of 60 and 55 , toma°C to leathers thickness 0.8 cm and two different levels of infrared radiation 1000 and 900 W/m^2 respectively. The highest value recorded at 60°C and 1000W/m^2 and reached 0.620155 ($g_w/g_d.h_r$).



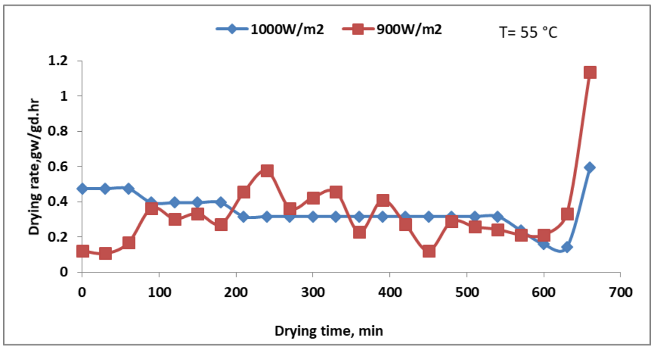
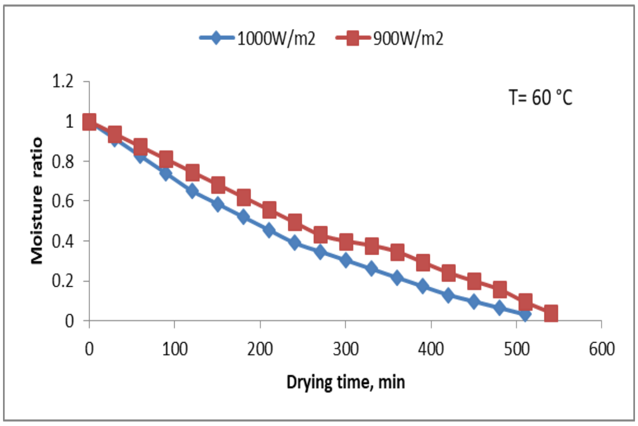


Fig3. The influence of infra-red radiation intensity and drying air temperature on tomato leathers drying rate at drying air velocity 0.5 m/s and thickness of samples 0.8 cm. on tomato leathers drying rate.

3.3 Influence of drying parameters on the change in tomatoes leather moisture ratio

Fig 4 illustrates the change in tomato leathers moisture ratio as related to drying time at different levels of drying air temperature and infrared radiation.



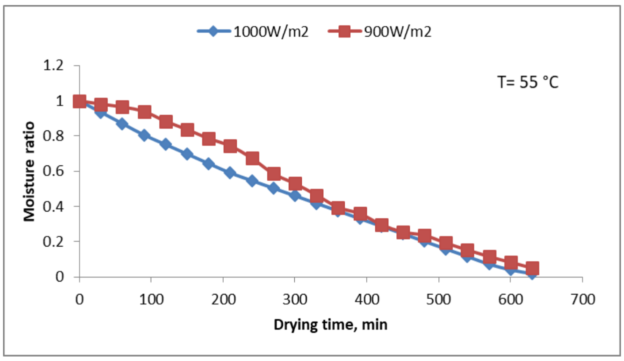


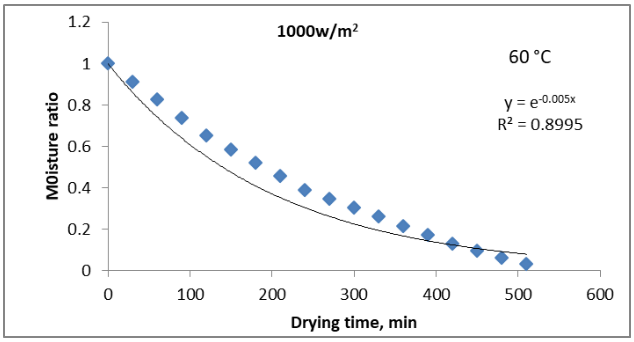
Fig4. Tomatoes leathers moisture ratio as related to drying time at different levels of infrared radiation and different drying air temperature.

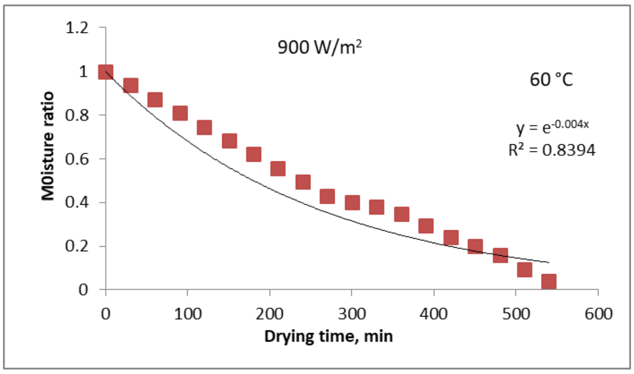
3.4. Thin layer drying equations

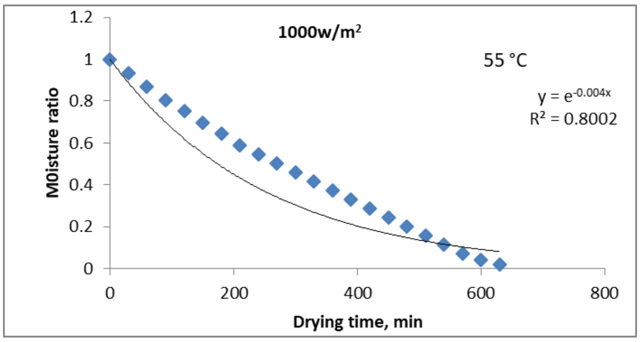
The obtained data was employed to examine and analyses the applicability of thin layer drying models (Lewis's equations) on describing and simulating the drying data. In this part of study, an analysis of thin layer drying of tomatoes leathers under different combination of drying air temperature (55 and 60°C) and infra-red radiation intensity (1000 and 900 W/m^2) was carried out.

3.4.1. Calculation of drying constant (k) for Lewis's equation

The values of drying constant (k) for the Lewis's model could be obtained from the exponential relationship between the moisture ratio (MR) of the tested sample versus drying time (t). Fig 6 presents this exponential relationship at the maximum radiation intensity of 1000 and 900 W/m^2 and drying air temperatures of 55°C and 60 °C.







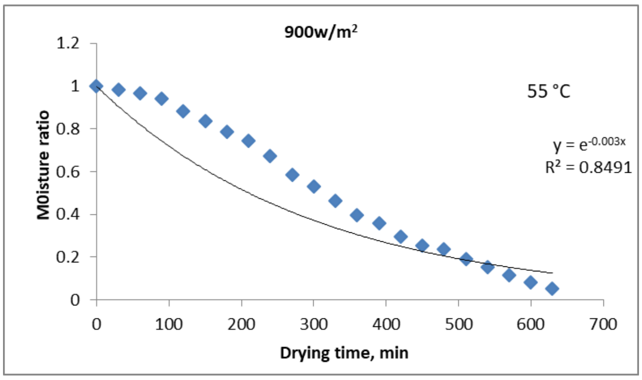


Fig5. Determination of the drying constant; (k) of Lewis's equation at the maximum radiation intensity of 1000 and 900 W/m2 and different drying air temperature levels.

Table1. : Drying constant (k) for Lewis equation at different levels of infrared radiation and drying air temperature.

Infrared radiation (W/m^2)	Drying constant (k)	
	Drying air temperature (°C)	
	55	60
1000	0.004	0.005
900	0.003	0.004

3.5. Chemical analysis of tomatoes leathers

3.5.1. Ascorbic acid (Vitamin c)

The range of ascorbic acid of tomato leathers was from 205 to 218 mg/100g. The tomato leathers dried at radiation intensity of $1000W/m^2$, air temperature of 60°C, drying air velocity 0.5 m/s and slices thickness of 0.8 cm recorded the highest ascorbic acid content of 213 mg/100g.

2.4.2. Carotenoids (Vitamin A)

The range of Carotenoids of tomato leathers was from 0.25 to 0.38 mg/100g. The tomato leathers dried at radiation intensity of 1000W/m2, air temperature of 60°C, drying air velocity 0.5 m/s and slices thickness of 0.8 cm recorded the highest Carotenoids content of 0.30 mg/100g.

2.4.3. Physio-Chemical analyses

The tomato leathers dried at radiation intensity of $1000W/m^2$, air temperature of 60°C, drying air velocity of 0.5 m/s and slices thickness of 0.8 cm recorded the highest total calcium content of 0.8%. The highest mean of total solid of 75.2% was recorded at radiation intensity of $1000W/m^2$. The tomato leathers dried at radiation intensity of $900W/m^2$, air temperature of 55°C, drying air velocity of 0.5 m/s and slices thickness of 0.8 cm recorded the highest total Protein of 4.31%, also total ash recorded the highest value at the same treatment by 5.35%.

4. Discussion

Fig 2 shows that with increasing temperature and infrared radiation drying time decreases. it was observed that for tomatoes leathers of 0.8 cm and drying air temperature of 60 °C its moisture content reaches the safe level of moisture content for storage after 9 to 9.5 hours respectively at infrared radiation level of 1000 and 900 W/m^2 respectively, for tomatoes leathers 0.8 cm and drying air temperature 55 °C after 11 and 11 hours respectively at infrared radiation level 1000 and 900 W/m^2 respectively. These results agree with those published by (E. E et al. 2011) Fig3 indicated to in the beginning the drying rate was high as a result of the beginning high moisture content. But with the time drying rate was decrease due to the decrease in tomato leather thickness moisture content. The drying rate increases with increasing temperature and infrared radiation. These results agree with those published by (Cesar et al. 2012) As shown in the fig 4, the reduction in moisture ratio of tomatoes leathers varied with the experimental treatments and it increased with the increase of radiation intensity, and the drying air temperature. It was observed that with increasing drying air temperature, drying time decreased. These results agree with those published by (Sadin et al. 2017).

5. Conclusions

The current research focused on the variation of the MC and DR by combined of infrared drying and hot-air convection system. Under different operating conditions of air velocities of 0.5 m/s and air temperatures 55 and 60 °C, The following conclusions were reached:

1-Increasing the air velocity and temperature caused a significant decrease in the drying period.

2-Increasing the infrared radiation caused a significant decrease in the drying period.

Author Contributions:
Eman Elbadawy, Mohamed Darwesh., Magda Abdelrahman., and Mohamed GHONAME., methodology and investigation, Eman Elbadawy., Magda Abdelrahman. and Mohamed GHONAME.; writing-original draft preparation, Eman Elbadawy and Magda Abdelrahman..; primitive and final field experiments, Eman Elbadawy., Mohamed Darwesh. and Magda Abdelrahman., Mohamed GHONAME; writing-review and editing, Eman Elbadawy, Mohamed Darwesh., Magda Abdelrahman., and Mohamed Ghoname.,Authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding

Institutional Review Board Statement: In this section,

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

Abano, E. E.; Ma, H,; and Qu,W. (2011). "Influence of Air Temperature on the Drying Kinetics and Quality of Tomato Slices." Journal of Food Processing and amp;amp; Technology 02, no. 05. https://doi.org/10.4172/2157-7110.1000123

An, K.; Zhao, D.; Wang, Z.; Wu, J.; Xu, Y.; and Xiao, G. (2016). Comparison of different dryingmethods on Chinese ginger (Zingiberofficinale Roscoe): changes in volatiles, chemicalprofile, antioxidant properties, and microstructure. Food Chem. 197,1292–1300 ttps://doi.org/10.1016/j.foodchem.2015.11.033.

Belessiotis, V.; and Delyannis, E. (2011). Solar drying. Sol. Energy 85, 1665–1691. http://dx.doi.org/10.1016/j.solener.2009.10.001

Bharambhe, K..; Girish, J.; and Gayatri, K. (2009). Preparation of sapota mix fruit leather. Paper presented at the Proceedings of the 10th International Agricultural Engineering Conference, Bangkok, Thailand, 7-10 December, 2009. Role of agricultural engineering in advent of changing global landscape.

Cesar Corrêa, P.; Horta de Oliveira, G. H.; Machado Baptestini, F.; Martins Silva Diniz, M. D.; and amp Almeida da Paixão, A. (2012). Tomato infrared drying: Modeling and some coefficients of the dehydration process. Chilean Journal of Agricultural Research, 72(2),262–267.https://doi.org/10.4067/s0718-58392012000200015

Damodaran, S.; Parkin, K. L.; and Fenemma, O. R. (2010) Química de alimentos de Fennema. Porto Alegre, 2010, 900p.

Das Purkayastha, M.; Nath, A.; Deka, B.C.; and Mahanta, C.L. (2011). Thin layer drying of tomato slices. Journal of Food Science and Technology 50:642–653. doi: 10.1007/s13197-011-0397-x

Demiray, E.; Tulek, Y.; and Yilmaz, Y. (2013) 'Degradation kinetics of lycopene, β-carotene and ascorbic acid in tomatoes during hot air drying', LWT - Food Science and Technology, 50(1), pp. 172–176. doi:10.1016/j.lwt.2012.06.001.

FAO, (2021). FAOSTAT. FAO. Food and Agriculture Organization of the United Nations, Rome, Italy.

Kocabiyik, H.; Yilmaz, N.; Tuncel, N.B.; Sumer, S.K.; and Buyukcan, M.B. (2014). Drying, energy, and some physical and nutritional quality properties of tomatoes dried with short-infrared radiation. Food and Bioprocess Technol., 8 (3): 516-525.

Nuthong, P.; Achariyaviriya, A.; Namsanguan, K.; Achariyaviriya, S. (2011) Kinetics and modeling of whole longan with combined infrared and hot air. Journal of Food Engineering 2011, 102(3), 233–239.

Okunola, A.; Adekanye,T.; and Idahosa, E. (2021). Energy and exergy analyses of okra drying process in a forced convection cabinet dryer, Res. Agric. Eng. 67 8–16.

Onwude, D.I.; Hashim, N.; and Chen, G. (2016). Recent advances of novel thermal combinedhot air drying of agricultural crops. Trends Food Sci. Technol. 57, 132–145. https://doi.org/10.1016/j.tifs.2016.09.012.

Rastogi, N.K. (2012) recent trends and developments in infrared heating in food processing. Crit Rev Food Sci Nutr 52:737–760

Sadin, R.; Chegini, G.; and Khodadadi, M. (2017) Drying Characteristics and Modeling of Tomato Thin Layer Drying in Combined Infrared-Hot Air Dryer Agric. Eng. Int. CIGR J.,19, 150–157.

Sadin, R.; Chegini, G.R.; and Sadin, H. (2014). The effect of temperature and slice thickness on drying kinetics tomato in the infrared dryer. Heat and Mass Transfer, 50 (4): 501-507.

Sarkar, T.; and Chakraborty, R. (2018). Formulation, physicochemical analysis, sustainable packaging-storage provision, environment friendly drying techniques and energy consumption characteristics of Mango Leather Production: A Review. Asian Journal of Water, Environment and Pollution, 15(3), 79–92. https://doi.org/10.3233/ajw-180046.

Vatthanakul, S.; Jangchud, A.; Jangchud, K.; Therdthai, N.; and Wilkinson, B. (2010). Gold kiwifruit leather product development using a quality function deployment approach. Food Quality and Preference, 21(3), 339-345.

Zhang, M.; Chen, H.; Mujumdar, A.S.; Tang, J.; Miao, S.; and Wang, Y. (2017). Recent developmentsin high-quality drying of vegetables, fruits, and aquatic products. Crit. Rev.Food Sci. Nutr. https://doi.org/10.1080/10408398.2014.979280