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A NEW APPROACH TO THE KINETICS OF CONVECTIVE PLUM DRYING USING SENSORS

Marko Petković[1], Alexander Lukyanov[2], Nemanja Miletić[1], Danila Donskoy[2], Aleksandr Zhuravlev[3]

Abstract: This study investigates the dehydration kinetics of halved plums under controlled conditions, focusing on the drying rate (Water Loss Speed, WLS) over time. Conducted at an average temperature of 55.4 ± 6.7 °C and air velocity of 3 m s^{-1}, the experiment involved 823 g of plums in a mono-layer tray. The maximum WLS reached 7.83 g min^{-1} within the first 6 – 7 minutes, followed by a slower diffusion-controlled phase. Over a drying period of approximately 20 hours, 562 g of water was removed, reducing moisture content from 85% to 52.7%, with energy consumption measured at 8.81 kWh kg^{-1}. Sensor technology played a critical role in ensuring uniform drying and quality retention.

Keywords: plum, convective drying, sensors

Introduction

Drying is one of the oldest and most commonly used food preservation techniques, effectively extending the shelf life of perishable products by reducing their moisture content. Among various drying methods, convective drying is favored for its simplicity, energy efficiency, and the ability to retain the nutritional and sensory qualities of dried products (da Silva Ferreira et al., 2024). However, optimizing the drying conditions for fruits like plums remains challenging, as it requires balancing effective moisture removal with maintaining product quality (Sacilik et al., 2006; Hedayatizadeh and Chaji, 2016). Recent advancements in sensor technology have enhanced the precision of drying process control and monitoring, improving both drying efficiency and final product quality. The integration of sensors into drying systems enables real-time data collection on key parameters such as temperature, humidity, and moisture content, allowing for better optimization of drying conditions (Ingeaua et al., 2015).

[1]University of Kragujevac, Faculty of Agronomy, Cara Dušana 34, Čačak, Serbia (marko.petkovic@kg.ac.rs)

[2]Don State Technical University, Gagarin sq. 1, 344002 Rostov-on-Don, Russia

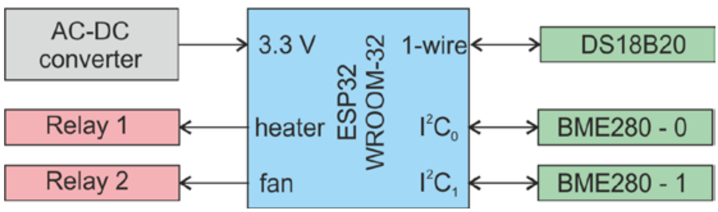
[3]JSC Gruvior, Šolohova, 298,

This research focuses on examining the impact of convective drying halved, pitted plums by utilizing advanced sensor technology to track and enhance the drying process.

Materials and methods

The convective drying process of plums (*Prunus Domestica* L. "Stanley" species) occurred in a laboratory-scale drying chamber (Colossus CSS 5330, 250 W, PRC) with advanced sensor technology. The plum fruits were pitted and dried as halves. The moisture content of the plum samples was regularly monitored throughout the drying process.

The laboratory drying chamber was equipped with multiple MEMS sensors, incorporating a BME280 sensor (Bosch Sensortec, 2022) that measured temperature and relative humidity while enabling real-time moisture content calculations. These sensors were linked to a data acquisition system (Graph 1) powered by an IoT microcontroller (ESP32 WROOM 32), which recorded measurements every minute and transmitted the data via WiFi to Telegram cloud storage. This setup allowed for continuous monitoring and control of the drying conditions, optimizing both energy efficiency and product quality.



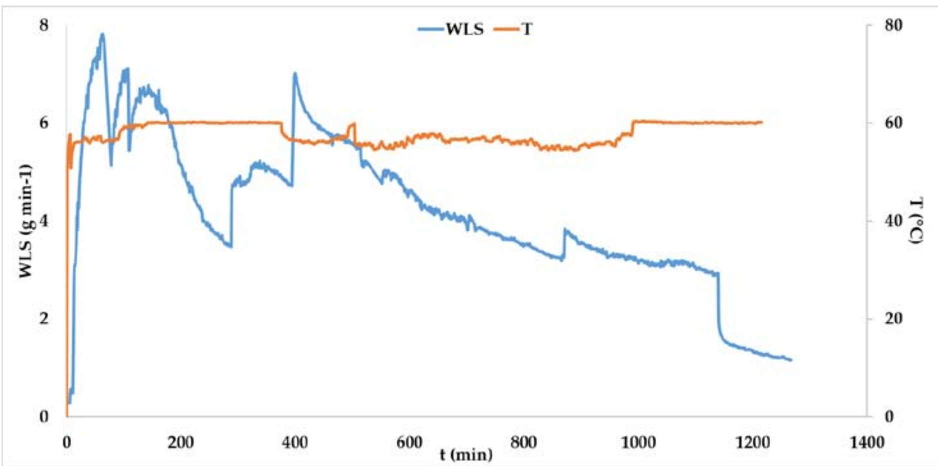
Graph 1. The structure of dehydrator control system

A digital PID controller, implemented as a subroutine within the microcontroller program, regulated the hot air temperature. The DS18B20 digital thermometer served as the temperature sensor for hot air control. Relay 1 and Relay 2 operated the heater and fan, respectively, with the fan functioning in an on off[-1] mode. To maintain the desired hot air temperature, the heater's solid-state relay was controlled using a quasi-PWM regime with a one-second control period, which was sufficient due to the heating element's high thermal inertia.

To monitor the dehydration process, a Telegram bot was utilized, displaying the dataset in the Telegram mobile or desktop application. This interface allowed users to input commands for adjusting dehydration parameters. Each data string included the following information in sequence: elapsed time since system activation, air temperature after the heater (DS18B20), input air temperature, relative humidity, and pressure (BME280-0), output air parameters (BME280-2), reserved space for another BME280-3 sensor, differential air moisture values between sensors, water loss rate, cumulative energy consumption, and average heater duty cycle.

Results and discussion

Dehydration was carried out at atmospheric pressure and the drying rate (Water Loss Speed, WLS) was monitored as a function of drying time (g min^{-1}). Drying chamber maintained an average temperature of 55.4 ± 6.7 °C (Graph 2) and an air velocity of 3 m s^{-1}. An amount of 823 g of plum (pitted and cut in half) was placed in a 0.32 m diameter tray with a mass load of 10.24 kgm^{-2} (1 tray, mono-layer model). The maximum WLS was 7.83 g min^{-1} in 6 – 7 minutes of drying process.



Graph 2. WLS and temperature range during the drying process

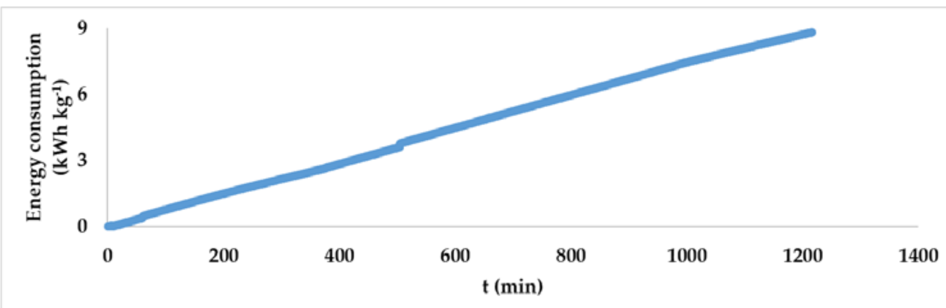
The drying kinetics of halved plum samples are characterized by an initial rapid moisture loss, followed by a slower drying phase controlled by diffusion. Sensor data revealed that moisture content dropped sharply during the first 400 minutes of drying, corresponding to the removal of free water from the plum surface, which has no barrier or obstruction to water evaporation (the plums were placed on tray with the skin side facing down). After this initial phase, the rate of moisture loss slowed as the drying process became controlled by the diffusion of water from the inner tissue of the plum to the surface.

Table 1 shows the quantitative parameter of evaporated water. During the observed drying period of about 20 hours (1,270 minutes), 562 g of water was removed, reducing the initial moisture content from 85% to 52.7%. The mass of evaporated water is obtained by integrating the polynomial equation $WLS = -2{\cdot}10^{-6}{\cdot}t^2 - 0.0003{\cdot}t + 5.6891$ ($R^2 = 0.7235$) over the observed drying period and applying the conversion factor for calculation with the given sensor. The analyzed drying period of 20 hours was also studied in the research by Živković et al. (2011).

Table 1.

	Fresh plums					Dried plums	
Sample	Weight (g)	Moisture content (%)	Moisture content (g)	Dry matter (g)	Evaporated water (g)	Weight (g)	Moisture content (%)
plums	823.0	85.0	699.6	123.5	562.0	261.0	52.7

To remove 562 grams of water from halved plums, 8.81 kWh kg^{-1} was consumed (Graph 3). For example, the energy consumption for the hybrid solar dryer was 8.73 kWh kg^{-1}, sun drying 5.42 kWh kg^{-1}, or a hot air dryer 9.51 kWh kg^{-1} (Hadi Samimi et al., 2017).



Graph 3. Energy consumption during the drying process

Incorporating sensor technology into the drying process was essential for achieving uniform drying of the plums and maintaining their quality throughout the procedure. The amount of evaporated water measured by sensors during drying was also confirmed using the "gravimetric method" by measuring the mass of halved plums before and after drying.

Additionally, drying fresh plums can produce a delicious treat; however, this technological process is inevitably accompanied by certain chemical changes, such as variations in antioxidant activity (Miletić et al., 2019).

Conclusion

This study examines the dehydration of halved plums in a mono-layer tray at atmospheric pressure, with drying at 55.4 ± 6.7 °C and air velocity of 3 m s^{-1}. After 1270 minutes, 562 g of water was removed, reducing moisture from 85% to 52.7%, with an energy consumption of 8.81 kWh kg^{-1}. The drying process exhibited rapid initial moisture loss, followed by a diffusion-controlled phase. Sensor data confirmed uniform drying, validated by the gravimetric method. The findings contribute to optimizing plum drying processes using sensor technology.

Acknowledgement

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References

Bosch Sensortec (2022). BME280 Datasheet. Rev. 1.23, p. 60.

da Silva Ferreira, M.V., Ahmed, M.W., Oliveira, M., Sarang, S., Ramsay, S., Liu, X., Malvandi, A., Lee, Y., Kamruzzaman, M. (2024). AI-Enabled Optical Sensing for Smart and Precision Food Drying: Techniques, Applications and Future Directions. Food Engineering Reviews. https://doi.org/10.1007/s12393-024-09388-0

Hadi Samimi, A., Akbar, A., Mohammad Hossein, K. (2017). Comparative quality assessment of different drying procedures for plum fruits (Prunus domestica L.). Czech Journal of Food Sciences, 355), 449–455. http://doi.org/10.17221/440/2016-cjfs

Hedayatizadeh, M., Chaji, H. (2016). A review on plum drying. Renewable and Sustainable Energy Reviews, 56, 362–367. http://doi.org./10.1016/j.rser.2015.11.087

Ingeaua, M., Prisecaru, Pirna, I., T., Sorica, C. (2015). Analysis of a convective drying process of plums. INMATEH – Agricultural Engineering, 46(2), p.115.

Miletić, N., Mitrović, O., Popović, B., Mašković, P., Mitić, M., Petković, M. (2019). Chemical changes caused by air drying of fresh plum fruits. International Food Research Journal Universiti Putra Malaysia., 26(4), 1191–1200.

Sacilik, K., Elicin, A. K., Unal, G. (2006). Drying kinetics of Üryani plum in a convective hot-air dryer. Journal of Food Engineering, 76(3), 362–368. http://doi.org./10.1016/j.jfoodeng.2005.05.031

Živković, M., Rakić, S., Maletić, R., Povrenović, D., Nikolić, M., Kosanović, N. (2011). Effect of temperature on the physical changes and drying kinetics in plum (*Prunus domestica* L.) Pozegaca variety. Chemical Industry and Chemical Engineering Quarterly, 17(3), 283–289. http://doi.org/10.2298/ciceq101109013z