

COMPARATIVE DRYING KINETICS AND MOISTURE DIFFUSION OF ALBANIAN AND ITALIAN ORANGE PEELS: A MATLAB – BASED ANALYSIS

Abstract:

The study carries out a mathematical comparison of the drying behaviour of orange peels from Albania and Italy under various thermal conditions and for different sample sizes. Peel samples having characteristic dimensions of 5, 10, and 15 mm were dried at 50, 100, and 150 °C in a thermostat and at 95 °C in a convective dryer. The experimental mass data were processed in MATLAB in order to determine the moisture content, the moisture ratio (MR), the drying rate (DR), and the apparent effective moisture diffusivity (D_{eff}). The moisture transport was interpreted by means of the linearised solution of Fick's second law for slab geometry. In both cases, drying took place mainly during the falling-rate period, which indicates that internal moisture diffusion was the main controlling factor. Higher temperatures had a marked effect in speeding up the removal of moisture, and the 5 mm samples generally attained equilibrium sooner than the 10- and 15-mm samples. Differences associated with the origin of the peels were also found. At 50 °C the Italian peel dried more quickly and matched the Fick diffusion model representation more closely. At 100 °C the Italian samples showed more variable behaviour depending on their thickness, while the Albanian ones displayed a more consistent response with respect to dimension. When dried convectively at 95 °C, the Italian peel lost moisture more rapidly, especially in the case of the 5- and 10-mm samples. The findings show that the drying behaviour is determined by the combined influence of temperature, characteristic dimension, drying method, and the origin of the material. The MATLAB–Fick approach offers a practical way of comparing moisture-transport behaviour, while the deviations observed at high temperature point to the necessity of taking into account shrinkage and structural changes in future modelling.

Key words:-

Orange peel, drying kinetics, MATLAB, Fick's second law, effective moisture diffusivity, moisture ratio, convective drying

Introduction:-

Drying involves both heat and mass transfer and is commonly used to decrease moisture content and enhance material stability. It occurs through the transfer of thermal energy to the wet solid and the movement of moisture from within the material to the surface. Hence, drying temperature, air movement, material shape, initial moisture distribution, and internal structure can all strongly affect the rate at which moisture is removed [1–3].

When it comes to food and plant materials, drying usually takes place mainly in the falling-rate period, it being at this stage that the internal resistance to the movement of moisture becomes more and more significant. In such cases, diffusion-based methods offer a useful engineering basis for understanding the transfer of moisture. Frequently, Fick's second law is used to calculate an apparent effective moisture diffusivity (D_{eff}), a quantity summarising the overall response of internal moisture transport under certain assumptions regarding geometry and boundary conditions [2,3].

Temperature is one of the key operating variables in the drying process. While higher temperatures usually increase the driving force for heat transfer and speed up the movement of moisture, they can also lead to shrinkage, surface hardening, changes in porosity, and non-uniform distributions of moisture. Such structural effects can cause a departure from ideal diffusion behaviour, especially in the later stages of drying [1,4]. As a result, D_{eff} must be regarded as an apparent transport parameter which depends on the model rather than as an invariant material constant.

Sample dimension is equally important because it sets the characteristic distance moisture must diffuse before it reaches the surface; thin samples tend to dry more quickly because of their shorter diffusion path, whereas thicker samples can retain moisture longer [4–6]. However, it can interact with material heterogeneity and thermal treatments, so simple thickness-based trends may not hold at higher temperatures.

Orange peel is a biological material which is made up of two structurally different outer and inner tissues. Variations in fruit type, cultivar, maturity stage, growing conditions, and post-harvest history can affect tissue structure and the initial distribution of moisture. Because of this, comparing orange peels from different places of origin can reveal whether a single mathematical drying model remains valid for materials subjected to the same drying conditions. However, such a comparison should be interpreted as indicating an origin-associated response rather than as proof that origin alone causes the observed differences, unless compositional and microstructural measurements are also available.

Computational processing allows simultaneous analysis of the experimental drying curves and the diffusion parameters. Because MATLAB provides a reproducible environment, it is possible to calculate moisture content, moisture ratio, drying rate, regression slopes, and apparent diffusivity from mass measurements over time. When these calculations are combined with Linearized Fick diffusion model, it becomes possible to directly compare temperature, dimension, drying configuration, and material source.

The aim of the current study was to compare drying kinetics and apparent moisture diffusion in orange peels from Albanian and Italian origin. We examined 5, 10, and 15 mm samples using thermostat drying at 50, 100, and 150 °C and convective drying at 95 °C. Moisture content, MR, DR, and Deffwere calculated in MATLAB, and the linearised version of Fick's second law was applied to examine internal moisture transport. We paid special attention to the combined effects of temperature, sample dimension, drying method, and material differences associated with origin.

Materials and Methods:-

Raw material and experimental design

We examined orange peels of Albanian and Italian origin. According to the experimental dataset, we bought fruit of both origins from the same supermarket in Tirana, Albania. We cut the peels into three sample sizes: M1 = 5 mm, M2 = 10 mm, and M3 = 15 mm. The experimental setup included thermostat drying at 50, 100, and 150 °C and convective drying at 95 °C.

Drying experiments

We measured sample mass over time as they dried, continuing until the mass reached a stable level. Measurement times differed across experiments; for a given condition, we took measurements at various intervals and over different total drying times. For this reason, reach temperature and source was processed in MATLAB, with the data being forced into one matrix with missing values.

MATLAB data processing

We imported the experimental mass data into MATLAB and sorted it by sample and drying time. To calculate moisture content on a dry basis, we used the dry mass (m_d). The MATLAB workflow produced moisture-content curves, drying-rate curves, moisture-ratio values, and Linearized Fick diffusion models for each experimental condition.

$$X_t = \frac{m_t - m_d}{m_d} \cdot 100 \quad (1)$$

where m_t represents the sample mass at t_i .

Drying rate and moisture ratio

The drying rate was obtained by dividing the difference in moisture content between successive measurements by the corresponding time interval. We calculated the moisture ratio using the initial and equilibrium moisture contents;

$$MR = \frac{(X_t - X_e)}{(X_0 - X_e)} \quad (2)$$

where X_0 , X_t , and X_e represent the initial, instantaneous, and equilibrium moisture contents, respectively.

Effective moisture diffusivity and Fick diffusion analysis

Internal moisture transport was evaluated using the linearized form of Fick's second law for a slab-type geometry. The natural logarithm of MR was regressed against drying time in seconds. The slope obtained by linear regression was used to calculate apparent effective moisture diffusivity according to the MATLAB implementation:

$$D_{eff} = \frac{-(slope \cdot L^2)}{\pi^2} \quad (3)$$

where L is the characteristic sample dimension used in the experimental MATLAB calculation. Because shrinkage and time-dependent geometry were not included in the model, the resulting D_{eff} values are interpreted as apparent effective diffusivities.

Comparative analysis

The data were examined descriptively for four factors: the material's origin (Albanian or Italian), temperature, sample size, and drying method. The study examined differences in moisture-loss behaviour, drying rate, time to reach stabilisation, the linearised Fick diffusion model, and apparent D_{eff} . Because the provided dataset does not include replicate-level statistical information needed for ANOVA or hypothesis testing, we do not report inferential statistical significance. We interpreted the origin differences descriptively because the two origins cited were based on the available market samples, not on independent orchards or cultivars, and were not treated as causal geographical effects.

Results and Discussion:-

General drying behaviour

The moisture content of both the Albanian and Italian orange peels decreased gradually as drying continued. The experimental curves were mainly characterised by the falling-rate phase and did not show a clearly maintained constant-rate phase. This shows that the movement of moisture within the material was the main resistance throughout most of the drying process. The MATLAB linearizations of $\ln(MR)$ plotted against time generally agreed with the Fick diffusion model, although deviations appeared under certain conditions, in particular during late-stage drying and at high temperature.

Effect of temperature

Temperature strongly influenced the drying rate; at 50 °C, the drying process was slow and took the longest to reach equilibrium. At 95–100 °C, moisture removal became much faster, and at 150 °C the initial drop in moisture content was the fastest. The data also show that the apparent D_{eff} increases as the temperature rises. This behaviour agrees with greater thermal activation of the moisture transport process, but the curves at high temperatures should not be interpreted solely in terms of ideal diffusion, since structural changes might modify the effective transport path.

The effect of sample dimension

The 5 mm sample (M1) usually dried more quickly than M2 (10 mm) or M3 (15 mm). This was especially noticeable with the Albanian peel at 50 and 100 °C and when convectively drying at 95 °C. Because M1 has a shorter characteristic transport distance, moisture needs to migrate less. M2 generally exhibited behaviour between the other two, while M3 retained moisture for a longer period. Nevertheless,

at 150 °C the dimensional trend became less regular, showing that thickness alone was not enough to account for all observations under severe thermal conditions.

Albanian orange peel

For the Albanian material, the dimensional effect was relatively regular. At 50 °C, M1 displayed the quickest reduction in moisture and attained equilibrium before the thicker samples. The same pattern was seen at 100 °C, where M1 once again dried more rapidly, and M3 had the slowest overall response. At 95 °C under convective conditions, M1 showed faster moisture transfer, M2 showed intermediate behaviour, and M3 retained moisture the longest. The data thus indicate a strong interaction between temperature and transport distance in the Albanian peel.

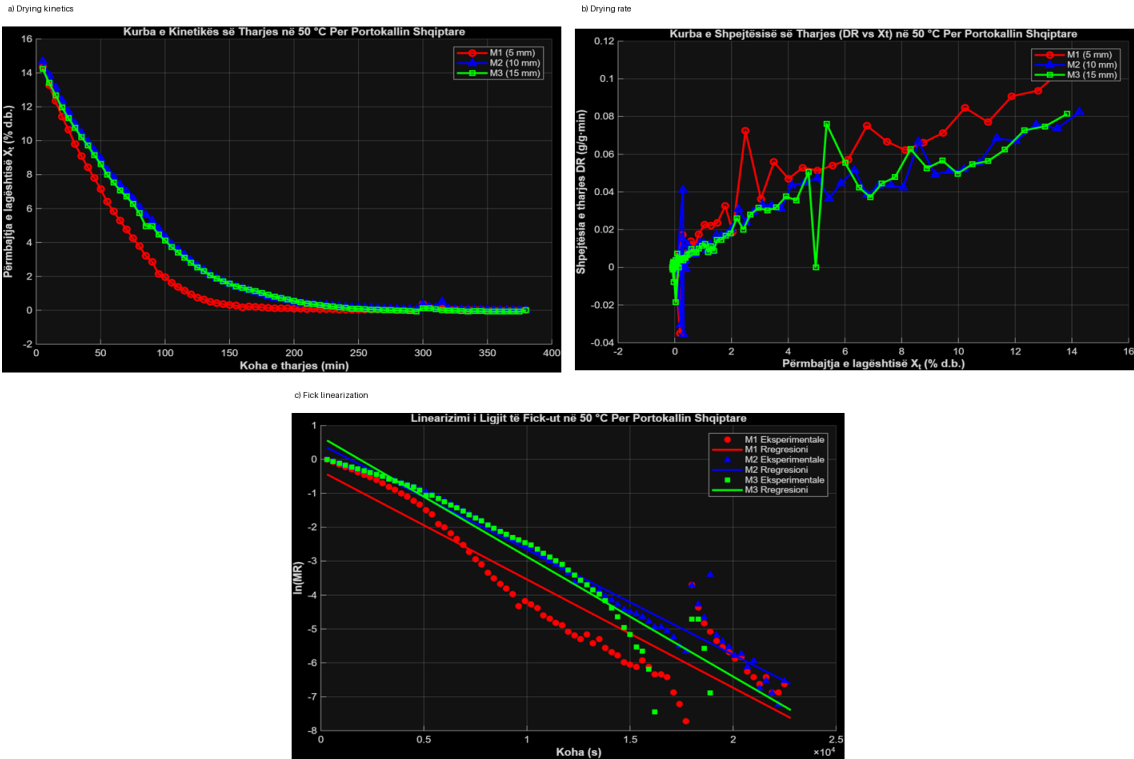


Figure 1. The MATLAB drying kinetics curve, drying rate, and Linearized Fick diffusion model for Albanian orange peel at 50 °C.

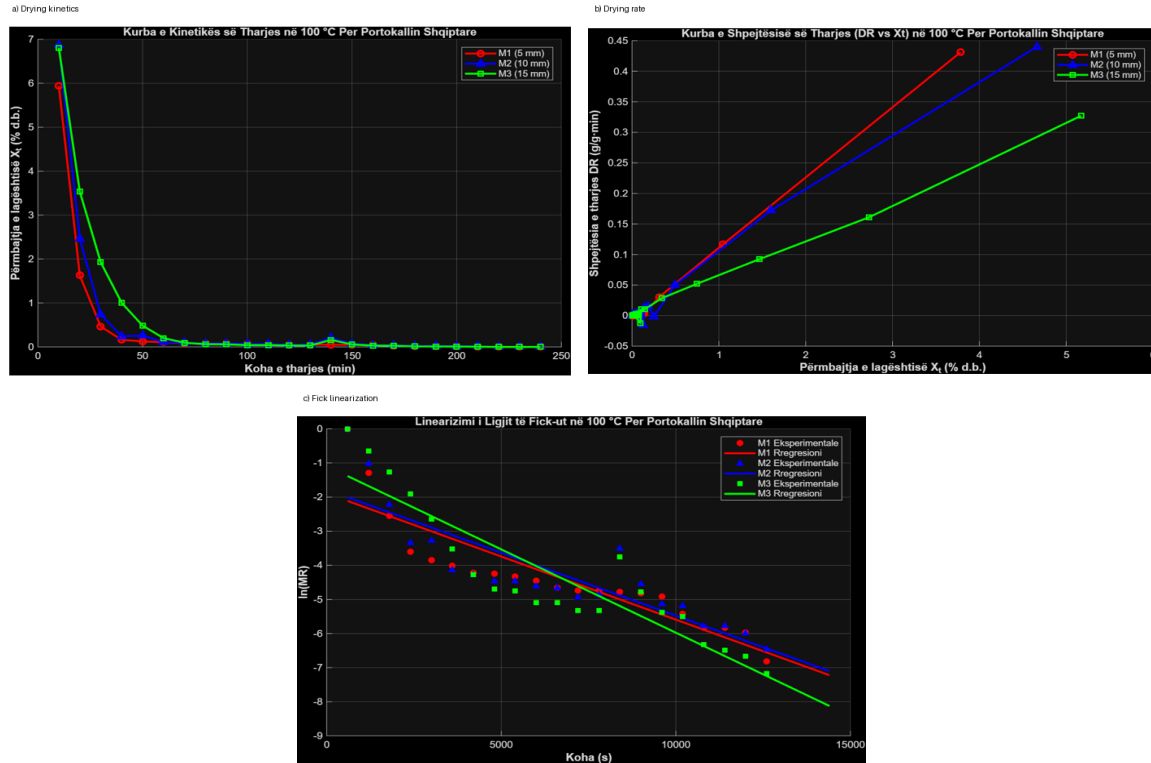


Figure 2. The MATLAB drying kinetics, drying-rate curve, and Linearized Fick diffusion model for Albanian orange peel at 100 °C.

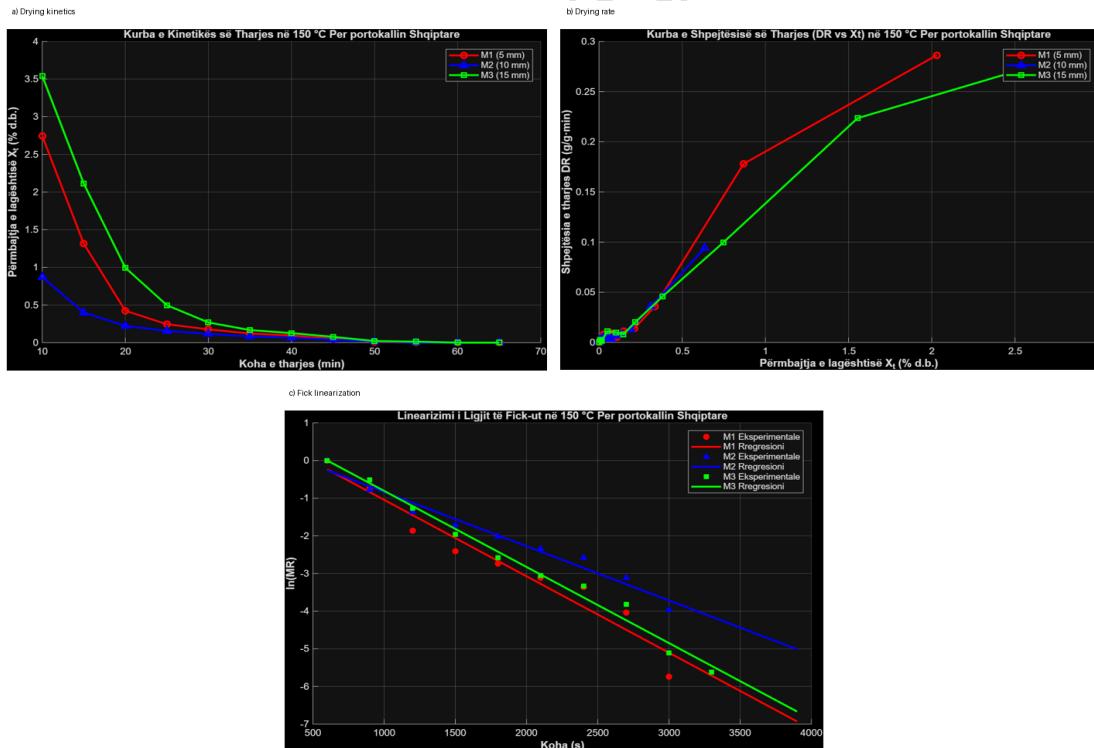


Figure 3. The MATLAB drying kinetics, drying-rate curve, and Linearized Fick diffusion model for Albanian orange peel at 150 °C.

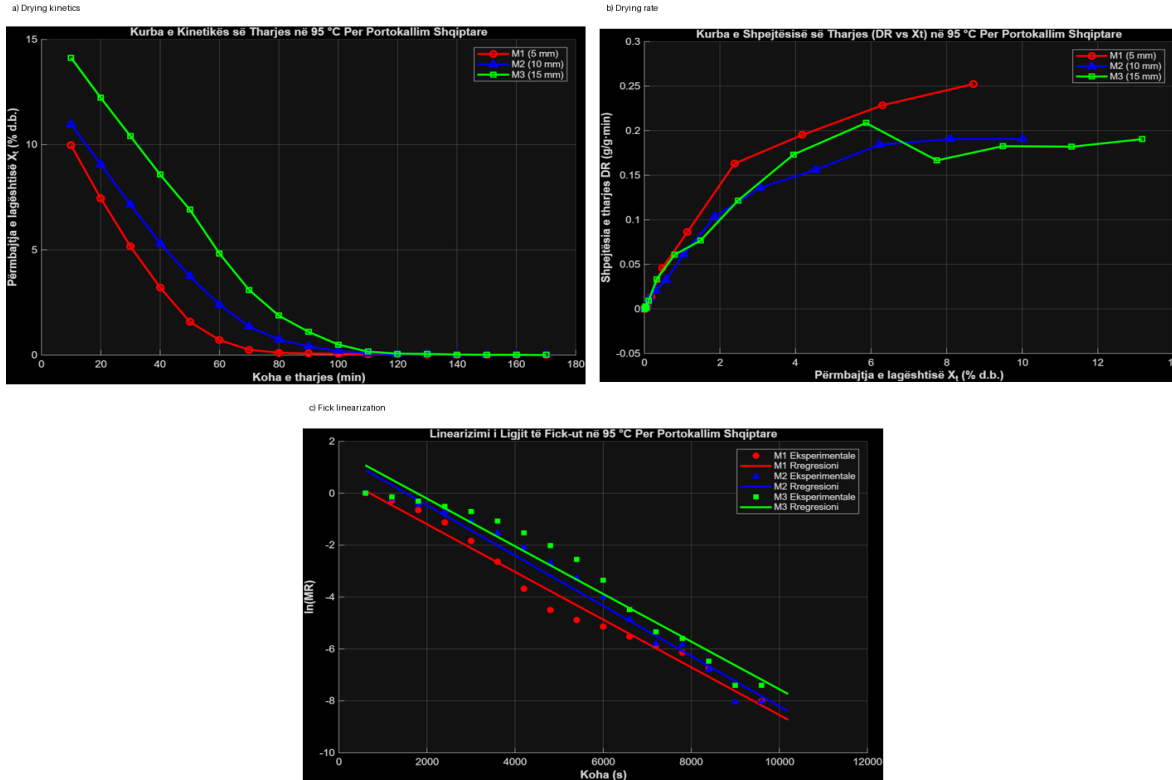
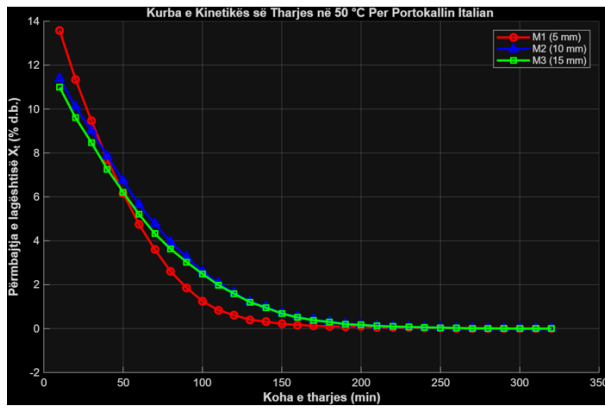


Figure 4. The MATLAB results showing the drying kinetics, drying-rate curve, and Linearized Fick diffusion model for Albanian orange peel when subjected to convective drying at 95 °C.

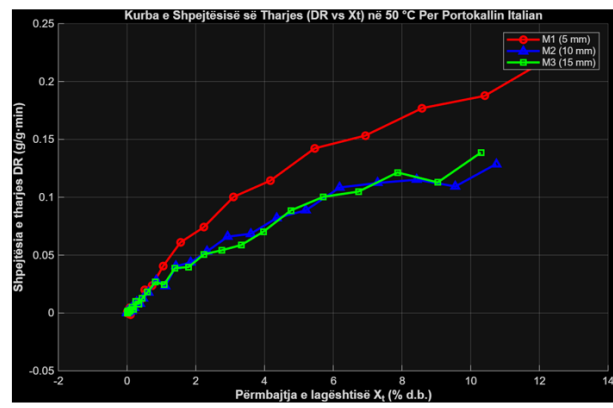
Italian orange peel

The Italian peel also showed a faster drying rate as the temperature rose, but its behaviour varied more from one dimension to another. At 50 °C, the process took several hours to reach complete stabilisation, with M1 achieving this earlier than the thicker samples. At 100 °C, M1 attained a nearly constant mass much earlier, although the $\ln(MR)$ versus time plots, in the absence of direct measurements of shrinkage and porosity, showed some deviations in the later stages. At 150 °C, moisture loss was very rapid, and the order of the samples by drying rate became less consistent. This behaviour is consistent with greater contributions from shrinkage, surface hardening, changes in porosity, or a non-uniform initial moisture distribution; however, because these mechanisms were not measured directly, they remain hypotheses rather than experimentally confirmed causes.

a) Drying kinetics



b) Drying rate



c) Fick linearization

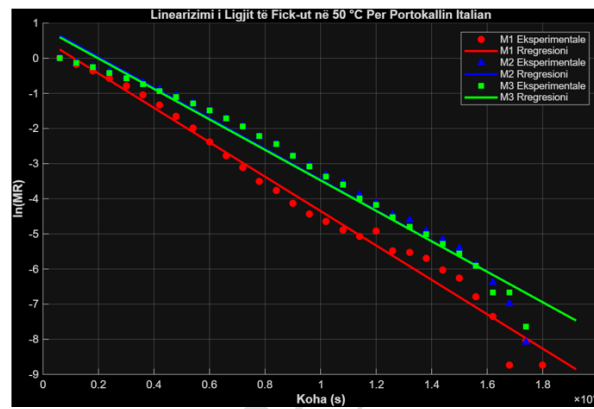


Figure 5. The drying kinetics, drying-rate curve, and Linearized Fick diffusion model for Italian orange peel at 50 °C.

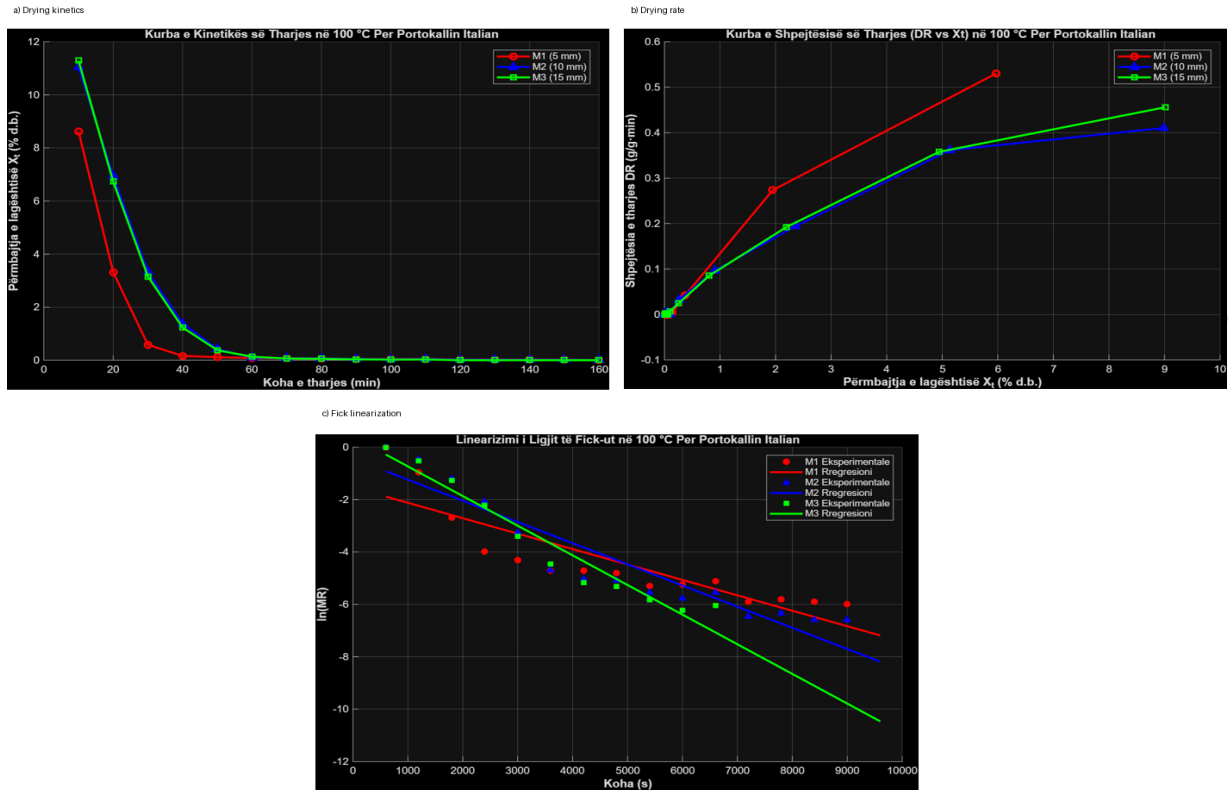


Figure 6. The drying kinetics, drying-rate curve, and Linearized Fick diffusion model for Italian orange peel at 100 °C.

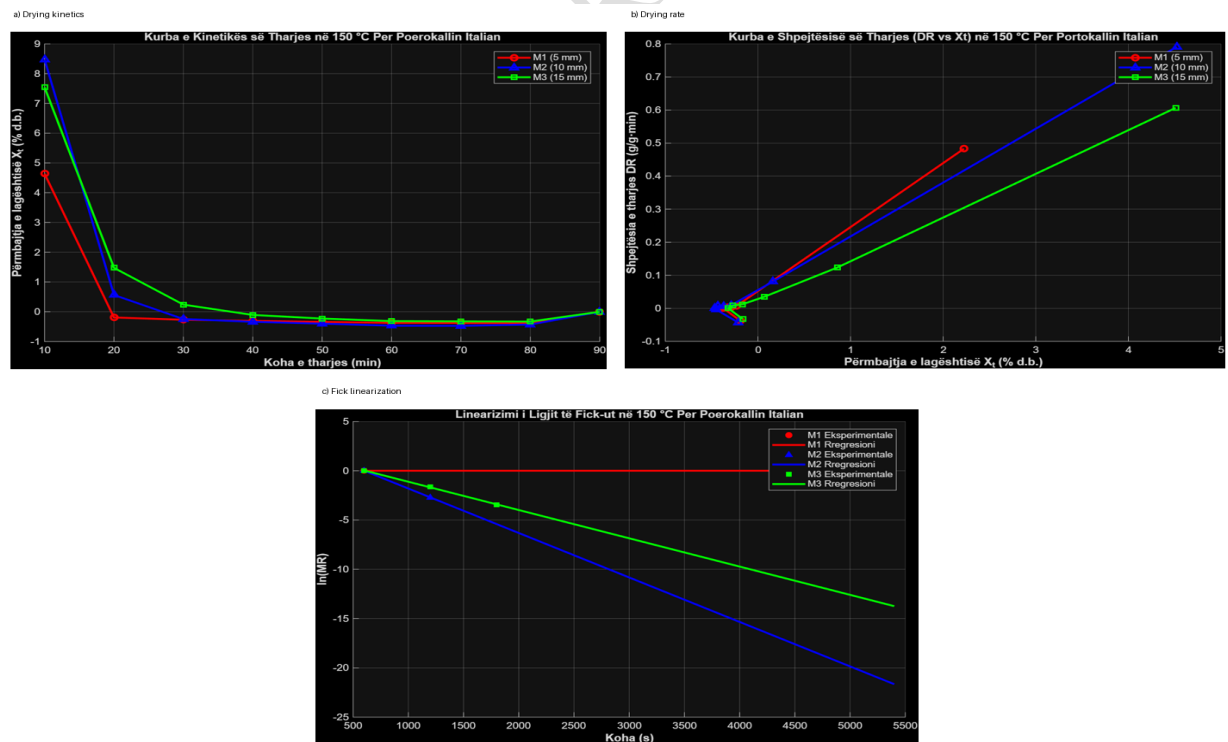


Figure 7. The drying kinetics, drying-rate curve, and Linearized Fick diffusion model for Italian orange peel at 150 °C.

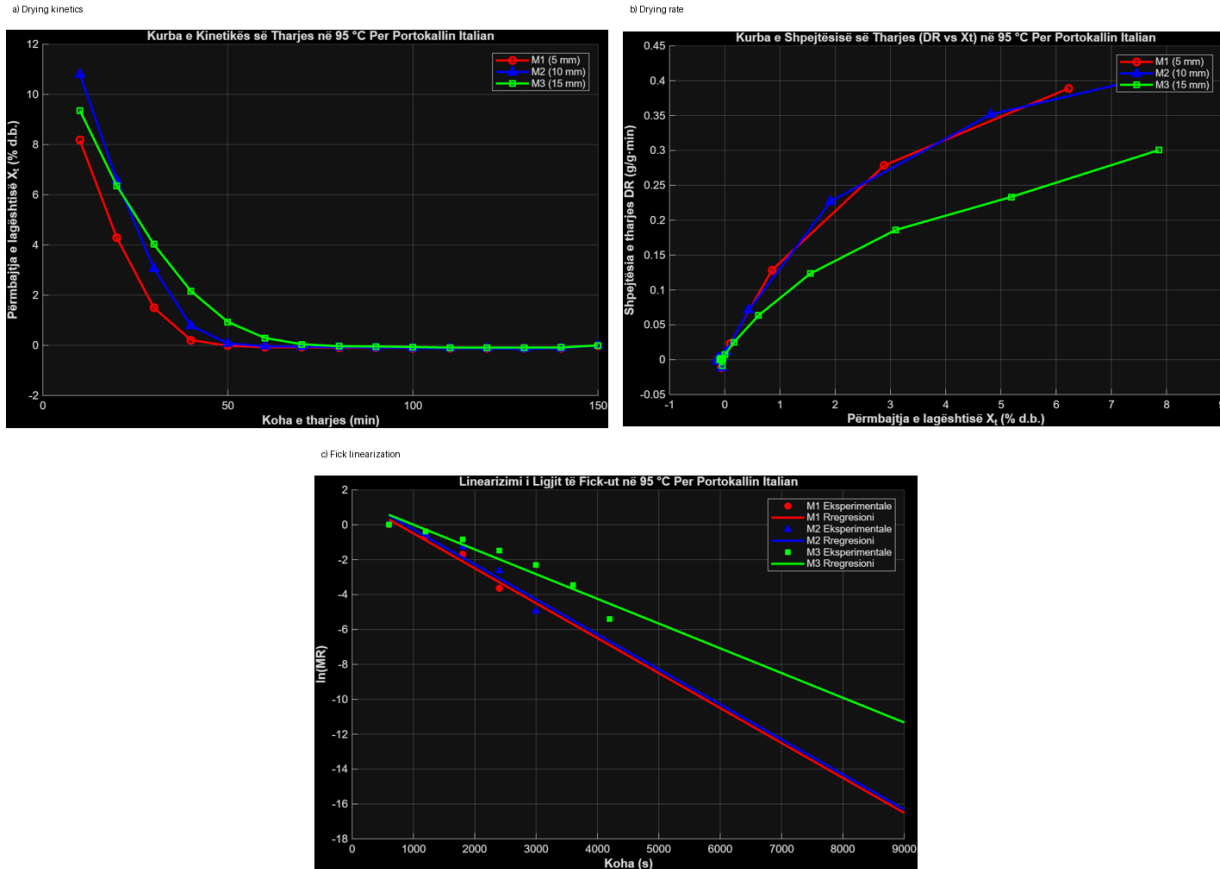


Figure 8. The MATLAB results showing the drying kinetics, drying-rate curve, and Linearized Fick diffusion model for Italian orange peel when subjected to convective drying at 95 °C.

Origin-associated differences

The evidence shows that both materials exhibited the same general diffusion-governed drying behaviour, but differed in the intensity and regularity of their response. At 50 °C., the Italian peel showed faster drying kinetics and more closely matched the Diffusion behaviour described by Fick's second law described in the dataset. At 100 °C., the Albanian peel showed a more distinct sequence that depended on thickness, whereas the Italian peel showed greater variation with sample dimensions. Moreover, the experimental summary notes that, during thermostat drying at 100 °C, the Italian peel stabilised after about 140 to 150 minutes, while the Albanian peel needed about 240 minutes to complete drying. These differences are best explained by the origin of the materials, since the study did not separately measure tissue density, porosity, wax content, composition, or the effects of cultivar.

Convective drying at 95 degrees Celsius

Convective drying at 95 °C resulted in strong moisture removal for both materials. For the Albanian peel, the 5 mm piece dried fastest, whereas larger dimensions required more time to reach equilibrium. The Italian peel also dried rapidly, with the data indicating especially high drying rates for M1 and M2. The Linearized Fick diffusion models showed steeper negative slopes for these Italian samples, indicating higher apparent $Deff$. Altogether, the findings indicate that forced convection enhanced both external heat and mass transfer, even though internal diffusion was still important.

Fick diffusion modelling and MATLAB implementation

The MATLAB procedure offered a reliable method for converting mass measurements into values for moisture content, DR, MR, $\ln(\text{MR})$, and apparent Deff . The approximately linear sections of the $\ln(\text{MR})$ versus time plot justify applying Fick's second law for comparison. However, the model assumes simplified geometry and does not account for time-dependent shrinkage or structural changes. As a result, the discrepancies between the experimental data points and the regression line, especially at 150 °C and during the later stages of drying, should be regarded as significant indications of the model's limitations rather than merely experimental noise.

Process interpretation and limitations

Based on the drying time and qualitative behaviour described in the dataset, 100 °C proved a useful intermediate thermostat temperature: drying was much faster than at 50 °C, but the curves did not show the same clear high-temperature behaviour as at 150 °C. However, this temperature is not considered optimised because product quality, chemical composition, energy consumption, shrinkage, and microstructure were not measured directly. The main limitations include the use of a simplified constant-rate Fick diffusion model, the lack of direct measurements of shrinkage and porosity, the absence of direct measurements of shrinkage and porosity, and the absence of statistical analysis at the replicate level in the dataset.

Conclusions:-

This study showed that the drying behaviour of Albanian and Italian orange peels was influenced by the combined effect of temperature, the size of the sample, the drying configuration, and the material characteristics associated with the origin. In all the conditions examined, moisture removal took place mainly during the falling-rate phase, which shows that internal moisture transport was the main mechanism responsible for the drying process. Raising the drying temperature from 50 °C to 150 °C greatly increased the rate of moisture removal, and the 5 mm samples generally attained a steady moisture level sooner than the 10 mm and 15 mm samples since they had a shorter path for moisture transport.

Even though both materials had the same general drying mechanism, there were clear differences in their kinetic behaviour. The orange peel from Albania displayed a more regular relationship with the size of the sample, while that from Italy generally dried more quickly but with greater variation as the dimensions were changed. The most obvious practical difference was seen when thermostat drying at 100 °C was carried out, the Italian peel reaching stabilisation after about 140 to 150 minutes whereas the Albanian peel took about 240 minutes. During convective drying at 95 °C, both materials showed rapid removal of moisture, with the Italian peel showing a particularly strong response for the 5 and 10 mm samples.

The use of MATLAB to analyse the experimental data allowed for the systematic calculation and visualisation of the moisture content, the moisture ratio, the drying rate, and the apparent effective moisture diffusivity. The fact that there is approximately a linear relationship between $\ln(\text{MR})$ and drying time over large sections of the drying curves means that Fick's second law can be used as a practical comparative model for the orange peels under investigation. Yet the deviations seen at the later stages of drying, especially at 150 °C, indicate that the constant-geometry Fick-based diffusion approximation does not fully capture the physical changes taking place in the material; it therefore follows that the calculated Deff values must be regarded as apparent effective diffusivities and not as intrinsic material constants.

From a process perspective, 100 °C represented a useful intermediate thermostat condition in the present dataset, providing substantially shorter drying times than 50 °C without the pronounced high-temperature behaviour observed at 150 °C. However, this condition should not be considered a fully optimised drying temperature because energy consumption, chemical composition, antioxidant retention, essential-oil preservation, colour, and other product-quality parameters were not measured.

Overall, the study shows that material origin should be considered together with temperature and characteristic dimension when comparing orange-peel drying performance. The combined experimental

and MATLAB–Fick approach provides a useful framework for screening and comparing drying conditions. Future studies should include replicate-based statistical analysis, direct measurements of shrinkage and microstructure, and quality and energy assessments to determine whether the origin-associated kinetic differences observed here persist under controlled and industrially relevant conditions.

References:-

- [1] V. P. Chandramohan, “Convective drying of food materials: An overview with fundamental aspects, recent developments, and summary,” *Heat Transfer*, vol. 49, no. 3, pp. 1281–1313, 2020, doi: 10.1002/htj.21662.
- [2] A. S. Mujumdar, *Handbook of Industrial Drying*, 4th ed. Boca Raton, FL, USA: CRC Press, 2014.
- [3] C. J. Geankoplis, *Transport Processes and Separation Process Principles*, 4th ed. Upper Saddle River, NJ, USA: Prentice Hall, 2003.
- [4] E. K. Akpınar, “Mathematical modelling of thin layer drying process under open sun of some aromatic plants,” *Journal of Food Engineering*, vol. 77, no. 4, pp. 864–870, 2006, doi: 10.1016/j.jfoodeng.2005.08.014.
- [5] S. Erbay and F. İcier, “A review of thin layer drying of foods: Theory, modeling, and experimental results,” *Critical Reviews in Food Science and Nutrition*, vol. 50, no. 5, pp. 441–464, 2010.
- [6] I. Doymaz, “Convective air drying characteristics of thin layer carrots,” *Journal of Food Engineering*, vol. 61, pp. 359–364, 2004.
- [7] A. Midilli, H. Kucuk, and Z. Yapar, “A new model for single-layer drying,” *Drying Technology*, vol. 20, no. 7, pp. 1503–1513, 2002.
- [8] M. O. Camilo, R. F. Carvalho, A. B. S. Costa, E. F. C. Junior, A. O. S. Costa, and R. C. Souza, “Drying kinetics for moisture content prediction of Tahiti lemon peel: Approach by machine learning and optimization—genetic algorithms and nonlinear programming,” *South African Journal of Chemical Engineering*, vol. 51, pp. 136–152, 2025, doi: 10.1016/j.sajce.2024.10.005.
- [9] M. Garau, S. Simal, C. Rosselló, and A. Femenia, “Effect of air-drying temperature on physico-chemical properties of dietary fibre and antioxidant capacity of orange by-products,” *Food Chemistry*, vol. 104, no. 3, pp. 1014–1024, 2007.
- [10] E. K. Akpınar, Y. Bicer, and C. Yildiz, “Thin layer drying of red pepper,” *Journal of Food Engineering*, vol. 59, pp. 99–104, 2003.