



TRANSFORMING FOOD ANALYSIS AND CONTROL:

NON-DESTRUCTIVE TECHNOLOGIES AND INNOVATIONS

K. Prasad, S. Shekhar, M. K. Paswan and R. Ahuja



Advancing Food Quality, Safety and Sustainability with
Smart, Innovative and Non-Destructive Technologies



SLIET
LONGOWAL



Sant Longowal Institute of Engineering
and Technology, Longowal

Transforming Food Analysis and Control: Non-Destructive Technologies and Innovations

Edited by

**Kamlesh Prasad, PhD
Shubhra Shekhar, M. Tech.
Mani Kant Paswan, PhD
Rajeev Ahuja, PhD**



**Sant Longowal Institute of Engineering and Technology,
Longowal – 148106, Sangrur, Punjab, INDIA**

Editors

Prof. Kamlesh Prasad, SLIET, Longowal
Mr. Shubhra Shekhar, UNSW, Sydney
Prof. Manikant Paswan, Director, SLIET, Longowal
Prof. Rajeev Ahuja, Director, IIT, Ropar

Copyright© SLIET Longowal

The data and views expressed in the book are those of the contributors and not of the editorial board. Though every care has been taken to reproduce the book accurately, the publisher is not responsible for any damage caused by misinterpretation of information expressed or implied within its pages.

Published By

Publication Division
Sant Longowal Institute of Engineering and Technology,
Longowal - 148106 (Punjab) INDIA

Transforming Food Analysis and Control: Non-Destructive Technologies
and Innovations

Sant Longowal Institute of Engineering and Technology, Longowal,
(Punjab) INDIA

SLIET Communication No. 4401/18112025

ISBN: 978-81-990304-0-4 (Hardback)

ISBN: 978-81-990304-1-1 (e-Book)

Finite Element Modeling for Bi-Directional Transport Phenomena During Atmospheric Deep Fat Frying of Kofta: Simulation and Experimental Validations

Rahul Das  and Kamlesh Prasad 

Abstract. The growing demand for convenient, nutritionally improved, and lower-oil traditional foods has encouraged the development of optimized ready-to-use (RTU) mixes to deliver consistent quality. In this context, the present study focuses on optimizing banana and chickpea flour for the development of an RTU kofta dry composite mix using a statistical optimization technique. A 2D axisymmetric finite element method (FEM) was applied to model atmospheric deep-fat frying at 170°C for 180 s, with a 30 s time interval, for a kofta ball using COMSOL Multiphysics 6.0. Simulated results showed that the surface temperature quickly reached the bulk temperature of frying oil, while the center temperature gradually increased to 113°C after 180 s as expected. The dry-basis moisture content at the surface decreased by 52.60% during frying, while the oil content increased by 11.17%. However, the crumb portion exhibited minimal change in both moisture and oil content. The optimized kofta had a 42.68% reduction in surface oil compared to the control, with comparable texture and flavor. Experimental data were used to validate the FEM predictions using statistical parameters such as mean absolute error, mean square error, root mean square error, chi-square, and coefficient of multiple determination, highlighting the accuracy of the FEM in tracking HMT phenomena. Future research should focus on refining the HMT model for different-shaped and sized food products, improving oil absorption mechanisms, exploring alternative frying methods, such as air frying and vacuum frying, to further reduce oil content at the pilot plant or industrial scale to maintain the product quality.

Keywords: Atmospheric deep fat frying, Composite mix, COMSOL Multiphysics, Heat and mass transfer, Microstructure

R. Das (✉) and K. Prasad (✉)

Department of Food Engineering and Technology, SLIET, Longowal-148106, Punjab, India

email: dasrahul111111@gmail.com, profkprasad@gmail.com

© The Author(s), under exclusive license to SLIET, Longowal. 2026 K. Prasad et al. (eds.), Transforming Food Analysis and Control: Non-Destructive Technologies and Innovations, SLIET, Longowal, Punjab, INDIA.

ISBN: 978-81-990304-0-4 (Hardback), 978-81-990304-1-1 (e-Book)

1. Introduction

Indian food differs from that of the rest of the world due to its unique taste. Local and homemade snacks have always been a part of Indian culture. In India, fried foods are in high demand at every festival and social gathering, as they are considered essential to a complete meal. This love for fried foods extends beyond India, as consumers worldwide are captivated by their distinctive golden color, crispy texture, and enticing aroma (Wang et al., 2023). Banana kofta is a delicious fried food made from a mixture of pre-boiled mashed banana, chickpea flour (CF), and other suitable ingredients. It is characterized by a golden-brown crust and a soft, flavorful interior, often enhanced with various spices and seasonings. However, in today's fast-paced society, busy lifestyles and the search for easier alternatives are driving consumers towards convenient, ready-to-use (RTU) composite food products, particularly those that offer low-fat fried options.

Considering these factors, the development of a popular Indian RTU kofta composite mix product with banana as the primary ingredient is of great concern to food technologists and researchers for the production of fried banana kofta. In this innovative approach, the pregelatinized banana flour is substituted with the required proportion of CF, and the careful selection and homogeneous dry mixing of other ingredients, such as bell peppers, including green, red, and yellow, NaHCO_3 , salt, and spices, are equally important for the successful development of the composite flour blends. To prepare smooth, spherical dough balls before frying, a required quantity of mild warm water is added to the developed dry composite flour. This step ensures that the dough achieves the right consistency, facilitating the formation of uniform kofta that can be fried to perfection.

Furthermore, to enhance the quality of fried products and reduce oil absorption during frying, it is essential to optimize key process parameters and frying conditions (Dehghannya and Ngadi, 2021). The color of dried food items is an important parameter that directly affects the final quality of fried foods. It is influenced by pretreatments and the adaptation of appropriate dehydration methods. Besides, pretreatment methods also reduce the oil uptake of fried foods (Dehghannya and Ngadi, 2023). Various pretreatment methods, including coating potato strips with different concentrations of alginate (Naghavi et al., 2018a) and blanching (Moyano and Pedreschi, 2006), are used before deep-fat frying to reduce oil absorption. In addition, blanching can be used to inactivate enzymes, which subsequently cause the leaching of carbohydrates and starch gelatinization, and induce cell disintegration. It helps produce samples with reduced moisture content,

MSE: 7.68×10^{-6} -21.45; RMSE: 0.003-1.520; χ^2 : 0.001-1.207; R^2 : 0.937-0.999) confirmed the model accuracy, offering valuable insights for improving product quality and frying efficiency in food engineering.

Acknowledgments

The authors are highly thankful to the Director, Sant Longowal Institute of Engineering and Technology, Longowal, Punjab, and the Indian Institute of Technology, Kharagpur, West Bengal, India, for providing resources and extending support in completing this work. The authors would like to express their gratitude to the All-India Council for Technical Education (AICTE), New Delhi, India, for providing the necessary support as an AICTE Doctoral Fellowship (ADF).

References

- Abera, G., (2019). Review on high-pressure processing of foods. *Cogent Food & Agriculture* 5 (1), 1568725. <https://doi.org/10.1080/23311932.2019.1568725>
- Acevedo C, D., Montero, P.M., Meza, J.R., Sandrith Sampayo, R., Martelo, R.J., (2022). Evaluation of the Thermophysical, Sensory, and Microstructural Properties of Colombian Coastal Carimañola Obtained by Atmospheric and Vacuum Frying. *International Journal of Food Science* 2022, 1-10. <https://doi.org/10.1155/2022/7251584>
- Ahromrit, A., Nema, P.K., (2010). Heat and mass transfer in deep-frying of pumpkin, sweet potato and taro. *Journal of Food Science and Technology* 47 (6), 632-637. <https://doi.org/10.1007/s13197-010-0100-7>
- Asokapandian, S., Swamy, G.J., Hajjul, H., (2020). Deep fat frying of foods: A critical review on process and product parameters. *Critical Reviews in Food Science and Nutrition* 60 (20), 3400-3413. <https://doi.org/10.1080/10408398.2019.1688761>
- Basava, S., Menon Rekha, R., Praveen Kumar, Y.S., Anand, S., Mahesh Kumar, G., Kumar, A., (2018). Measurement of Physico-Thermal Properties of Gulabjamun during Sub-Baric Frying. *International Journal of Current Microbiology and Applied Sciences* 7 (1), 239-246. <https://doi.org/10.20546/ijcmas.2018.701.026>
- Botero-Uribe, M., Fitzgerald, M., Gilbert, R.G., Midgley, J., (2017). Effect of pulsed electrical fields on the structural properties that affect french fry texture during processing. *Trends in Food Science & Technology* 67, 1-11. <https://doi.org/10.1016/j.tifs.2017.05.016>

- Chan, D.-S., (2020). Computer Simulation with a Temperature-Step Frying Approach to Mitigate Acrylamide Formation in French Fries. *Foods* 9 (2), 200. <https://doi.org/10.3390/foods9020200>
- Choi, Y., Okos, M.R., (1986). Effects of temperature and composition on the thermal properties of foods, in: Maguer, M.L., Jelen, P. (Eds.), *Food Engineering and Process Applications Volume 1, Transport Phenomena*. Elsevier Applied Science Publishers, New York.
- Costa, E., Almeida, M.F., Alvim-Ferraz, M.C., Dias, J.M., (2022). Exploiting the Complementary Potential of Rice Bran Oil as a Low-Cost Raw Material for Bioenergy Production. *Processes* 10 (11), 2460. <https://doi.org/10.3390/pr10112460>
- Dadmohammadi, Y., Datta, A.K., (2022). Food as porous media: a review of the dynamics of porous properties during processing. *Food Reviews International* 38 (5), 953-985. <https://doi.org/10.1080/87559129.2020.1761376>
- Das, R., Kumar, Y., Kaur, R., Shekhar, S., Prasad, K., (2023). Concentration-dependent rheological characteristics of chickpea (*Cicer arietinum* L.) flour dispersion in steady and dynamic shear. *International Food Research Journal* 30 (5), 1243-1260. <https://doi.org/10.47836/ifrj.30.5.13>
- Das, R., Prasad, K., (2023). Finite Element Modeling of Bell Pepper Slice Dehydration and Product Characterization on Opto-Physico-Chemical, Nutritional, and Functional Properties. *Journal of Food Chemistry & Nanotechnology* 9 (2), 63-77. <https://doi.org/10.17756/jfcn.2023-152>
- Das, R., Thota, N., Prakash, P., Sudharshan Reddy, R., Datta, A., (2022). Optimization of Different Process Variables on Structural and Quality Attributes for the Development of Vacuum Fried Gulab Jamun. *Asian Journal of Dairy and Food Research* 43 (1), 130-135. <https://doi.org/10.18805/ajdfr.DR-1908>
- Dash, K.K., Sharma, M., Tiwari, A., (2022). Heat and mass transfer modeling and quality changes during deep fat frying: A comprehensive review. *Journal of Food Process Engineering* 45 (4), e13999. <https://doi.org/10.1111/jfpe.13999>
- Datta, A.K., (2007). Porous media approaches to studying simultaneous heat and mass transfer in food processes. II: Property data and representative results. *Journal of Food Engineering* 80 (1), 96-110. <https://doi.org/10.1016/j.jfoodeng.2006.05.012>

- Deb, M., Dash, K.K., (2022). Rheological and mass transport characteristics of hydrocolloid incorporated multilayered wheat flour dough sheet (Khaja) during frying. *Journal of Food Processing and Preservation* 46 (2), e16227. <https://doi.org/10.1111/jfpp.16227>
- Dehghannya, J., Ngadi, M., (2021). Recent advances in microstructure characterization of fried foods: Different frying techniques and process modeling. *Trends in Food Science & Technology* 116, 786-801. <https://doi.org/10.1016/j.tifs.2021.03.033>
- Dehghannya, J., Ngadi, M., (2023). The application of pretreatments for producing low-fat fried foods: A review. *Trends in Food Science & Technology* 140, 104150. <https://doi.org/10.1016/j.tifs.2023.104150>
- Farinu, A., Baik, O.-D., (2008). Convective mass transfer coefficients in finite element simulations of deep fat frying of sweetpotato. *Journal of Food Engineering* 89 (2), 187-194. <https://doi.org/10.1016/j.jfoodeng.2008.04.024>
- Franklin, M.E.E., Pushpadass, H.A., Ravindra Menon, R., Rao, K.J., Nath, B.S., (2014). Modeling the Heat and Mass Transfer during Frying of *Gulab Jamun*. *Journal of Food Processing and Preservation* 38 (4), 1939-1947. <https://doi.org/10.1111/jfpp.12168>
- Gargari, A.N., Asefi, N., Roufegarinejad, L., (2022). Simulation of Heat Transfer in Deep Fat Frying of Foods: an Appropriate Method for Predicting the Temperature Distribution in a Potato Model. *Potato Research* 65 (4), 933-957. <https://doi.org/10.1007/s11540-022-09552-1>
- Goel, C., Semwal, A.D., Ananthan, P., Sharma, G.K., (2018). Development and storage stability of buckwheat chips using response surface methodology (RSM). *Journal of Food Science and Technology* 55 (12), 5064-5074. <https://doi.org/10.1007/s13197-018-3445-y>
- Halder, A., Dhall, A., Datta, A.K., (2011). Modeling Transport in Porous Media With Phase Change: Applications to Food Processing. *Journal of Heat Transfer* 133 (3). <https://doi.org/10.1115/1.4002463>
- Joglekar, A.M., May, A.T., (1991). *Product Excellence through Experimental Design*. The AVI Pub. New York.
- Krokida, M.K., Oreopoulou, V., Maroulis, Z.B., (2000). Water loss and oil uptake as a function of frying time. *Journal of Food Engineering* 44 (1), 39-46. [https://doi.org/10.1016/s0260-8774\(99\)00163-6](https://doi.org/10.1016/s0260-8774(99)00163-6)

- Kumar, S., Chandra, A., Nema, P.K., Sharanagat, V.S., Kumar, S., Gaibimei, P., (2022). Optimization of the frying process in relation to quality characteristics of Khaja (A traditional sweet). *Journal of Food Science and Technology* 59 (11), 4352-4361. <https://doi.org/10.1007/s13197-022-05509-x>
- Lalam, S., Sandhu, J.S., Takhar, P.S., Thompson, L.D., Alvarado, C., (2013). Experimental study on transport mechanisms during deep fat frying of chicken nuggets. *LWT - Food Science and Technology* 50 (1), 110-119. <https://doi.org/10.1016/j.lwt.2012.06.014>
- Li, Y., Guo, Q., Wang, K., Nverjiang, M., Wu, K., Wang, X., Xia, X., (2022). Monitoring the Changes in Heat Transfer and Water Evaporation of French Fries during Frying to Analyze Its Oil Uptake and Quality. *Foods* 11 (21), 3473. <https://doi.org/10.3390/foods11213473>
- Liu, Y., Tian, J., Zhang, T., Fan, L., (2021). Effects of frying temperature and pore profile on the oil absorption behavior of fried potato chips. *Food Chemistry* 345, 128832. <https://doi.org/10.1016/j.foodchem.2020.128832>
- Mondal, I.H., Dash, K.K., (2017). Textural, Color Kinetics, and Heat and Mass Transfer Modeling During Deep Fat Frying of Chhena Jhili. *Journal of Food Processing and Preservation* 41 (2), e12828. <https://doi.org/10.1111/jfpp.12828>
- Moyano, P.C., Pedreschi, F., (2006). Kinetics of oil uptake during frying of potato slices:: Effect of pre-treatments. *LWT - Food Science and Technology* 39 (3), 285-291. <https://doi.org/10.1016/j.lwt.2005.01.010>
- Naghavi, E.-A., Dehghannya, J., Ghanbarzadeh, B., (2018a). 3D computational simulation for the prediction of coupled momentum, heat and mass transfer during deep-fat frying of potato strips coated with different concentrations of alginate. *Journal of Food Engineering* 235, 64-78. <https://doi.org/10.1016/j.jfoodeng.2018.04.026>
- Naghavi, E.-A., Dehghannya, J., Ghanbarzadeh, B., (2018b). Effect of hydrocolloid type on transfer phenomena during deep-fat frying of coated potato strips: Numerical modeling and experimental analysis. *Computers and Electronics in Agriculture* 154, 382-399. <https://doi.org/10.1016/j.compag.2018.09.024>
- Ran, X., Lin, D., Zheng, L., Li, Y., Yang, H., (2023). Kinetic modelling of the mass and heat transfer of a plant-based fishball alternative during deep-fat frying and air frying and the changes in physicochemical properties.

- Journal of Food Engineering 350, 111457.
<https://doi.org/10.1016/j.jfoodeng.2023.111457>
- Rani, L., Kumar, M., Kaushik, D., Kaur, J., Kumar, A., Oz, F., Proestos, C., Oz, E., (2023). A review on the frying process: Methods, models and their mechanism and application in the food industry. Food Research International 172, 113176. <https://doi.org/10.1016/j.foodres.2023.113176>
- Safari, A., Salamat, R., Baik, O.-D., (2018). A review on heat and mass transfer coefficients during deep-fat frying: Determination methods and influencing factors. Journal of Food Engineering 230, 114-123. <https://doi.org/10.1016/j.jfoodeng.2018.01.022>
- Salehi, F., (2018). Color changes kinetics during deep fat frying of carrot slice. Heat and Mass Transfer 54 (11), 3421-3426. <https://doi.org/10.1007/s00231-018-2382-7>
- Santos, J.C.O., Santos, M.G.O., Dantas, J.P., Conceição, M.M., Athaide-Filho, P.F., Souza, A.G., (2005). Comparative study of specific heat capacities of some vegetable oils obtained by DSC and microwave oven. Journal of Thermal Analysis and Calorimetry 79 (2), 283-287. <https://doi.org/10.1007/s10973-005-0050-x>
- Siddiqua, T., Uddin, I., Hasan, M.R., Begum, R., (2024). Effect of heating and Re-heating on physico-chemical properties of rice bran oil and soybean oil. Journal of Agriculture and Food Research 15, 100979. <https://doi.org/10.1016/j.jafr.2024.100979>
- van Koerten, K.N., Somsen, D., Boom, R.M., Schutyser, M.A.I., (2017). Modelling water evaporation during frying with an evaporation dependent heat transfer coefficient. Journal of Food Engineering 197, 60-67. <https://doi.org/10.1016/j.jfoodeng.2016.11.007>
- Wang, X., McClements, D.J., Xu, Z., Meng, M., Qiu, C., Long, J., Jin, Z., Chen, L., (2023). Recent advances in the optimization of the sensory attributes of fried foods: Appearance, flavor, and texture. Trends in Food Science & Technology 138, 297-309. <https://doi.org/10.1016/j.tifs.2023.06.012>
- Warning, A., Dhall, A., Mitrea, D., Datta, A.K., (2012). Porous media based model for deep-fat vacuum frying potato chips. Journal of Food Engineering 110 (3), 428-440. <https://doi.org/10.1016/j.jfoodeng.2011.12.024>
- Wu, B., Wang, J., Guo, Y., Pan, Z., Ma, H., (2018). Effects of infrared blanching and dehydrating pretreatment on oil content of fried potato

chips. Journal of Food Processing and Preservation 42 (3), e13531.
<https://doi.org/10.1111/jfpp.13531>

Yang, D., Zhu, L., Wu, G., Li, X., Li, P., Zhang, H., Liu, T., (2022). Whether the degradation of frying oil affects oil absorption: Tracking fresh and degraded oil in fried potato strips during frying and cooling and microstructure characterization. Food and Bioproducts Processing 133, 87-99. <https://doi.org/10.1016/j.fbp.2022.03.001>

Zhang, W., Chen, J., Yue, Y., Zhu, Z., Liao, E., Xia, W., (2020). Modelling the Mass Transfer Kinetics of Battered and Breaded Fish Nuggets during Deep-Fat Frying at Different Frying Temperatures. Journal of Food Quality 2020, 1-8. <https://doi.org/10.1155/2020/8874163>