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Kinetic evaluation and optimization of the drying process of 3D printed pasta: key factors influence on the finished product quality

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Abstract

The object of study was pasta obtained as a result of 3D printing. This research was aimed to the application of the drying process as a tool to improve pasta 3D printing quality. The purpose of this study was to assess the influence of the drying process operating parameters and to find their optimal values to ensure the quality of pasta obtained by 3D printing. Hot air and infrared drying was used to heat the extruded product locally. The response surface methodology was applied for the drying process optimization. Heating power, processing time and distance from the heating source were chosen as the main variables influencing the drying process. The maximum product weight loss combined with the maximum temperature below 100 °C during the entire processing time constituted an optimization challenge. The use of infrared drying was advantageous when processing a layer of pasta dough several millimeters thick and resulted in a drier and harder surface. With a processing time of 1.5 min, the heating power was 2 units, and the distance from the support to the heating source was 1.77 cm. The noted values of the independent variables for the response function can be considered optimal.

Keywords: optimization; drying; 3D printing; post-processing.

Practical Application: The information provided in this paper will be very helpful in the production and post-processing of 3D printed flour food products. In addition, the study results can be adapted for texture-altered foods, depending on the post-processing conditions they are subjected to.

1 Introduction

Interest in the use of additive manufacturing in the food industry has grown significantly over the past 10 years. Additive technology is an important tool for creating controlled structure and texture products in this field. It has sufficient knowledge of the composition of the printed material and its rheological characteristics.

Fused Deposition Modeling is the most commonly used 3D printing technology in the food industry. Printing parameters and structural- and mechanical properties of the product to be printed play an important role in the quality of the final product in this technology (Severini et al., 2016). Wheat flour dough is one of the first food materials successfully printed in 3D. To some extent, cereal dough combines the shear flow properties required during the extrusion phase of the printing process (Jiang et al., 2019). These properties are associated with the content of wheat flour components in the dough, combined with proteins structuring effect at room temperature, obtained by kneading, and, to a lesser extent, the numerous starch granules dispersed in the dough (Bredikhin et al., 2022; Cappelli et al., 2020). The structure of gluten proteins depends mainly on the moisture content and the mixing process. It can lead to the formation of an elastic protein network in which starch granules are embedded. (Hackenberg et al., 2018; Vanin et al., 2018). Currently, wheat flour is one of the promising printing materials, due to the ability of flour to bind water, and the ability of flour proteins to interact with each other and form viscoelastic gluten networks (Bredikhin et al., 2023; Kim et al., 2019; Krishnaraj et al., 2019; Severini et al., 2018; Yang et al., 2018; Zhang et al., 2018).

Pasta was chosen as the subject of this study, as it is one of the most widespread flour food products in the world. Among print parameters, temperature control is a key one, both during extrusion and post-deposition drying (Sun et al., 2018). In its turn, the quality of pasta largely depends on the rational implementation of their stabilization after drying and moisture spread compensation in the layers of the final product. Pasta dough printing can be done hot to reduce the time required for post-print heat treatment (Mann et al., 2014). Integration of the pasta drying process directly into a 3D printer is of great interest.

Two types of drying can be distinguished. They correspond to two different developments in 3D printing. The first one involves local heating or drying of a layer of material extruded by the printer, with each layer being dried simultaneously with its application to the support. The second method involves general heating of the object being printed and is the entire object drying after printing.

Drying allows changing the grain material structure to a more rigid one. In addition, an increase in temperature also leads to an improvement in the palatability due to the Mayer reaction or sugars caramelization (Ovsyannikov et al., 2021). Physical processes are combined with physicochemical reactions

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such as starch gelatinization and flour protein denaturation in modern wheat dough baking technology. Starch gelatinization and protein denaturation occur in grain raw materials during the thermomechanical process (Allan et al., 2018; Perry & Donald, 2002). The main purpose of the heat treatment applied to the material after printing is to remove moisture from the material. Starch and gluten change from a rubbery state, in which they are deformed, to a brittle solid state upon cooling with a decrease in moisture content in the product. This transition between states directly affects the texture of flour products (Auger et al., 2008; Wang et al., 2017).

Pasta obtained by mechanical processing shows good extrusion properties. But the extruded layer deforms due to its weight and the weight of the layers subsequently applied. Therefore, this "raw" paste is incompatible with 3D printing layer by layer. The structuring step during printing is necessary to use the dough as a food material (Dessev et al., 2011). The research objective is to improve the printability of pasta dough by increasing its viscosity through starch gelatinization and protein denaturation during printing. To do this, it is necessary to control the texture of the printed material layer by changing its structure during the drying phase after printing.

Finally, combining different heat- and mass transfer processes in one printer will be relevant for printing foods with different textures by combining food printing and drying. We also suppose that printing material above room temperature will shorten post-print drying time and overall foods printing time.

According to the above mentioned, this study was aimed to the use of the drying process as a tool to improve the 3D printing quality of pasta. The purpose of this study was to assess the influence of the operating parameters of the drying process and to find their optimal values to ensure the quality of pasta obtained by 3D printing.

2 Materials and methods

2.1 Dough-making

Wheat flour (moisture content 14.6% and protein 11.3%) and distilled water were mixed to form a dough with a heated planetary mixer (Thermomix TM6, Vorwek, Germany) equipped with a sheet beater. The heating temperature of the mixer bowl was maintained at the level of 85-90 °C. A portion of the water was added to the flour and stirred in a mixer at 125 rpm for 4 minutes to obtain a dough with 50% moisture content. Then the second part of water was added to this dough and mixed for another 11 minutes to obtain a dough with a moisture content of 56%. This process was used to improve the stability of the dough over time and to prevent the dough phase separation. The heat treatment processes described below were carried out on a single cylindrical layer of extruded material. We will refer to it as dough filament hereinafter.

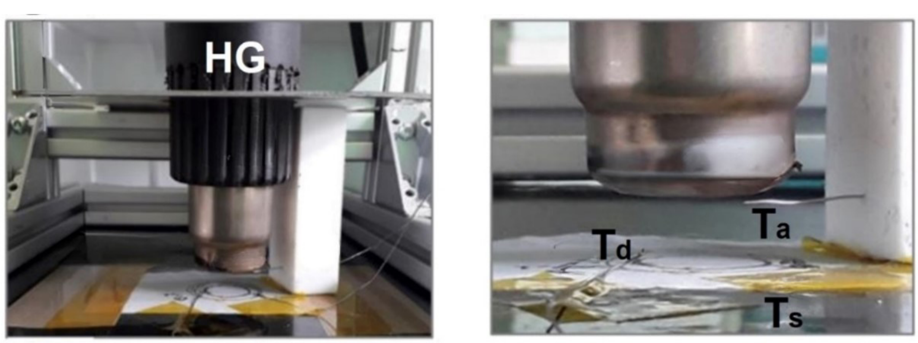
2.2 Experimental devices for local drying

Hot air and infrared drying are used to locally heat the extruded dough filament. The heat gun (GHG 600 CE Bosch Professional, Germany) with 6 levels of temperature control is placed on a jib crane (Figure 1A) mounted on a ceramic coated support. The distance between the support and the heat gun nozzle can be adjusted. The infrared lamp (infrared quartz heater FQE 200, Ireland) provides radiation (wave range: 1.5-8 μm, with a maximum wave length of 5 μm) with a power of 200 W. The lamp is mounted on stainless steel reflectors to concentrate the waves below the radiation source.

HG is the heat gun; IR is the infrared lamp, T_d is the thermocouple for dough filament temperature measuring; T_s is the thermocouple for support temperature measuring; T_a is the thermocouple for air temperature measuring.

Teflon surface is used as a support for the IR heated test. Ceramic support is chosen for hot air drying. Its temperature is measured during the experiment. Ceramic support was given preference due to its ease of use and thermal properties (faster cooling than Teflon support).

A dough filament with a diameter of 4 mm (nozzle tip size) is placed under the heat sources. Type K thermocouples (Thermoelement, Russia) are designed to measure the dough filament temperature, the support temperature and the air temperature under the heating zone (Figure 1B). Thermocouples are fixed at the measurement points with hot-melt adhesive tape or on a Teflon block. A thermocouple for air temperature measuring is located



A B

Figure 1. Placement of heating devices for local drying. (A) with heat gun and ceramic support, (B) thermocouples placing under the heat gun. HG is the heat gun; T_d is the thermocouple for dough filament temperature measuring; T_s is the thermocouple for support temperature measuring; T_a is the thermocouple for air temperature measuring.

at a distance of 0.8 cm from the support under the heat gun and 1.6 cm from the support under the infrared lamp. The thermocouple for dough filament temperature detecting is raised relative to the support to facilitate its penetration during the product layer deposition. Temperature measurement over time is performed by a thermocouple reader (Fluke 8845A, Fluke Corporation, USA) at a measurement speed of 1 point/2 s. Measurements are recorded with software Fluke 884x (Firmware, USA).

2.3 Determination of heating temperatures

The kinetics of weight loss and internal temperature of a pasta dough filament under the infrared lamp are measured at different distances from the dough filament. The temperature stabilization of the support depends on the distance to the lamp. The stabilization time of the support temperature is 22 min at a distance to the lamp of 8 cm, 20 min at 5 cm and 15 min at 2 cm. Changes in the temperatures of the air, support and dough filament are recorded within 5 minutes after deposition.

The study of hot air drying efficiency is carried out by the response surface calculating method (Moloto et al., 2021). The experiment planning has been carried out. It allows us to vary all variables and obtain quantitative assessment of their interaction effects. Heating power (P), processing time (t) and distance from the heating source (D) were chosen as the main variables influencing the drying process. The studied variables, as well as their levels, are shown in Table 1.

The lower and higher boundaries of the plan for the heating power ranged from 1 to 3 units (1 unit - 55 (± 16) °C; 2 units - 130 (± 14) °C; 3 units - 212 (± 18) °C), for a distance from the support to the heat gun from 1 to 3 cm and processing time from 0.5 to 2.5 minutes. The choice of the intervals for changing the variables is due to the technological conditions of the drying process and the technical characteristics of the experimental device. Dough filament weight loss (WL), %; maximum temperature at the dough filament center (T_{max}), °C; support temperature (T_s), °C were chosen as the criteria for evaluating of various variables influence on the drying process. Thus, the maximum dough filament weight loss with a maximum dough filament center temperature below 100 °C during the entire processing time is the optimization task.

2.4 Statistical analysis

Statistical analysis software Statistica (StatSoft, USA) is used for experimental studies planning and analyzing, as well as for response surface data visualizing. Regression coefficients are calculated for each model. Analysis of variance (ANOVA) is made to assess model (test F for the significance, test of lack of adjustment and coefficient of determination R^2) performance at a 5% significance level.

Table 1. Range of different variables studied in the design.

Variables	Low level	Medium level	High level
Heating power (units)	1	2	3
Processing time (min)	0.5	1.5	2.5
Distance (cm)	1	2	3

3 Results and discussion

3.1 IR-drying

Temperature kinetics, as well as weight loss after drying, depending on the distance from the IR lamp to the support are shown in Figure 2.

The distance to the lamp affects the temperature of the support, the dough filament and its weight loss (Abdelbasset et al., 2022). The closer the lamp is to the dough filament, the higher the support temperature: about 87 °C (± 4 °C), 120 °C (± 1 °C) and 290 °C (± 4 °C) for 2, 5 and 8 cm, respectively. At the distance of 5-8 cm, the air temperature is about 40 °C (± 2 °C) and it rises to 80 °C (± 6 °C) when the lamp is 2 cm from the support. Air heating occurs mainly due to a sharp increase in the support temperature. Likewise, the dough filament temperature increases as the lamp is put closer to the support. At the distance of 8 cm, the dough filament temperature does not exceed 70 °C for 5 min 30 sec of heating. For the distances of 5 and 2 cm, the dough filament temperature reaches 90 °C in 4 min 30 s and 5 min, respectively. The initial slope of the dough filament temperature, as a function of time, increases as the distance from the lamp to the support decreases. A decrease in the distance from the support to the lamp from 5 to 2 cm causes a significant change in the kinetics of increase in the dough filament temperature, which is inversely proportional to the distance between the sample and the lamp, which is consistent with the literature data (Nowak & Lewicki, 2004). Over time, the dough filament temperature approaches the air temperature. The formation of a crust on the dough filament surface slows down the temperature rise in the dough filament center. However, the crust forms very quickly, and the dough filament temperature reaches 100 °C in 1 min 36 s and is maintained at this level due to the large amount of moisture evaporation at the 2 cm distance to the lamp (Wagner et al., 2007).

The fragility of the dough filament is assessed by its cutting with a scalpel. Drying at the distance of 8 cm and holding for 5 min 30 sec allows the formation of a fine crust on the dough filament exposed to infrared heating. In this case, the part of the dough filament facing the support has a soft structure. When

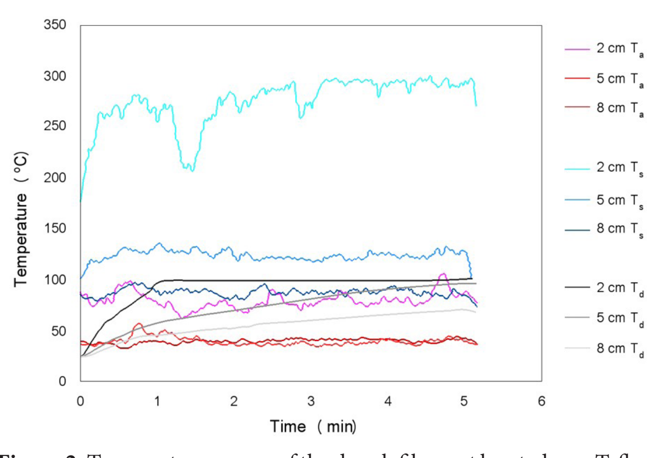


Figure 2. Temperature curves of the dough filament located on a Teflon support when drying with the infrared lamp at the distance of 2, 5 and 8 cm from the radiation source.

being cut, the dough filament has a tendency to deform, which decreases when the lamp is put at the distance of 5 cm from the support. When putting the lamp at the distance of 2 cm from the support, the dough filament becomes stiff, brittle and loose.

An increase in temperature leads to a gradual transfer of moisture from the center to the surface with the crust formation at the distances of 8 and 5 cm. Under these conditions, it can be assumed that the weight loss mainly reflects the moisture loss, which is 16.5% and 28.6% at the distances from the lamp of 8 cm and 5 cm respectively. The dough filament moisture content is 54.5% when the lamp is located at the distance of 8 cm from the support, and 47.3% at the distance of 5 cm from the support with a processing time of 5 min 30 s.

Thus, the distance from the IR source to the dough filament allows you to control the drying intensity. The dough filament texture and color can be changed depending on the distance from the source and the processing time. Infrared waves penetration causes a significant increase in the temperature of the surface facing the source compared to the sample central part.

Infrared heating, as a type of local drying, can be recommended when it is necessary to obtain a product with a crust on the surface and a soft texture on the inside. Optimization of lamp power, infrared behavior, distance and time needs to be done to use infrared heating in the context of 3D printing drying.

3.2 Hot air drying

Regression equations that adequately describe this process under the influence of the studied variables were obtained as a result of statistical processing of experimental data. The weight loss equation is as follows:

$$WL = 17.98 + 15.02(P-2) + 1.05(D-2) + 7.96(t-1.5) - 3.54(P-2)\times(D-2) + 7.11\cdot(P-2)\times(t-1.5) + 4.81(P-2)^2 \quad (1)$$

The heating power has a significant effect on all measured characteristics. This is the factor on which all results depend strongly. Time is the second factor that has the largest impact on the drying process, in particular on weight loss. The influence of the distance from the heating zone to the product is the least significant. This analysis allows us to conclude that the dough filament and support temperatures mainly depend on the heating power, and the mass loss depends on the three variables studied. The nature of the output parameters change from the changeable variables is represented by the response surfaces in Figures 3-6.

Figure 3 shows that the effect of distance on the weight loss depends on the heating power supplied. With the heating power of 1 unit the weight loss increases with distance increasing to the support, and at the heating power of 3 units the weight loss increases with distance decreasing.

The effect of the processing time on the dough filament weight loss depends on the heating power as well (Figure 4). With the heating power of 1 unit the weight loss does not increase dramatically over time. For the heating power of 3 units the weight loss increases rapidly over time. With a short-term

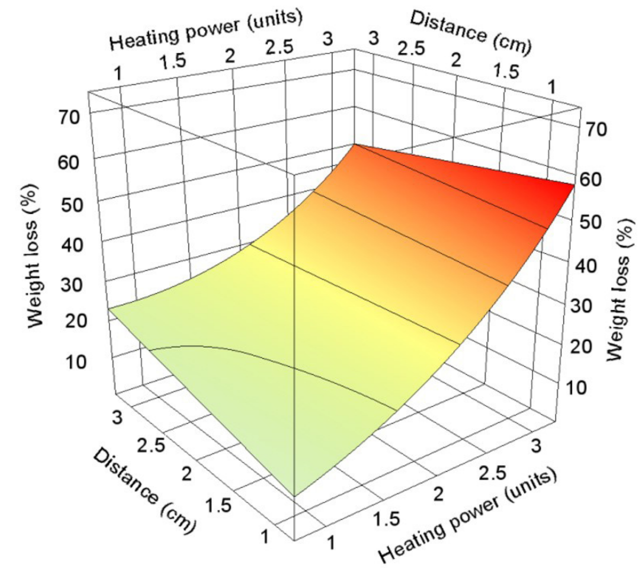


Figure 3. Dependence of weight loss on the distance and heating power.

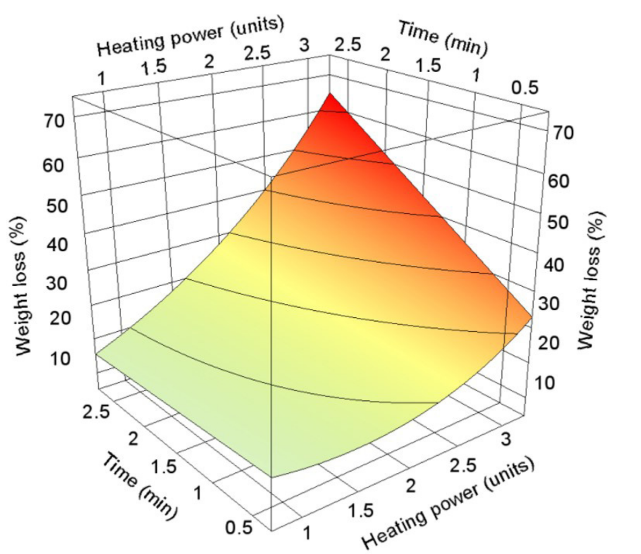


Figure 4. Dependence of weight loss on the processing time and heating power.

exposure (0.5 min), an increase in the weight loss begins with an increase in the heating power to 2 units. With the prolonged heating time (2.5 min), an increase in the weight loss is observed at the heating power of above 1 unit.

According to the Equation 1, the weight loss is 11.5% for the least intensive drying (P = 1, D = 3 cm, t = 0.5 min), 18% for the average intensity (P = 2, D = 2 cm, t = 1.5 min) and 50.4% for the most intensive drying (P = 3, D = 3 cm, t = 2.5 min). At low heating power, the processing time does not affect the weight loss, and the greater distance from the heating source allows the dough filament to dry more efficiently. On the other hand, when using the maximum heating power, the moisture

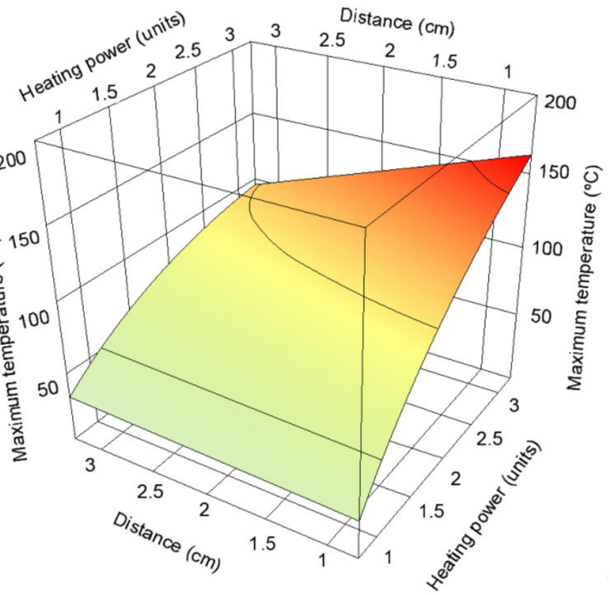


Figure 5. Dependence of the maximum dough filament temperature on the distance and heating power.

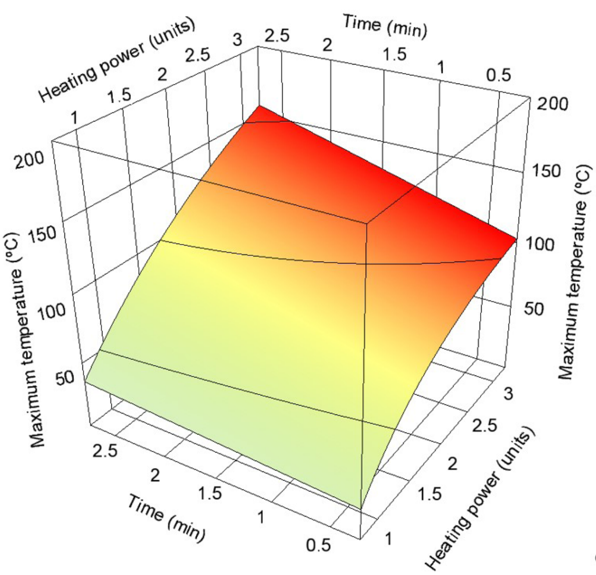


Figure 6. Dependence of the dough filament maximum temperature on the processing time and heating power.

loss will have a maximum value for the shortest distance and long processing time.

The maximum temperature at the dough filament center mainly depends on the heating power (Figures 5, 6).

If the heating source is located at the distance of 1 cm from the support, then the maximum dough filament temperature is reached with increasing power. Likewise, the maximum dough filament temperature is reached at a processing time of 2.5 minutes with increasing power.

With a constant heating power, a decrease in the distance and an increase in the processing time lead to an increase in the maximum temperature at the dough filament center. The equation for the maximum temperature at the dough filament center as a function of three variables is given below.

$$T_{max} = 95.15 + 40.79(P-2) - 12.13(D-2) + 13.33(t-1.5) - 11.62(P-2)\times(D-2) + 6.53\bullet(P-2)\times(t-1.5) + 10.04(P-2)^2 \quad (2)$$

From the Equation 2, it can be concluded that the distance to the heating source and the processing time have a significant effect on the maximum temperature in the dough filament center only when the heating power is 3 units. According to the response surface as a function of distance and heating power, the support temperature increases almost linearly with the heating power increasing.

The regression equation for determining the support temperature as a function of three variables is presented below.

$$T_s = 140.06 + 85.17(P-2) - 2.16(D-2) + 2.47(t-1.5) - 0.72(P-2)\times(D-2) + 0.65\bullet(P-2)\times(t-1.5) + 6.72(P-2)^2 \quad (3)$$

Equation 3 shows that when adjusting the heating power from 1 to 3 units and the distance of 2 cm from the heating source, the support temperature values are 61.61 °C; 140.06 °C and 231.9 °C respectively. The support temperature does not depend on the exposure time and the distance from the heating source.

The optimal parameters have been determined according to the optimization problem and regression models obtained for each response. The support temperature is fixed at 100, 140, 160 and 180 °C with the exposure time of 1, 1.5, 2.3 and 2.5 min, respectively, and the maximum temperature in the dough filament center is close to 100 °C for all models.

With a processing time of 1.5 min, the heating power is 2 units, and the distance from the support to the heating source is 1.77 cm. The noted values of the independent variables for the response function can be considered optimal. T_s = 140.6 °C, T_{max} = 97.9 °C and WL = 17,7% are provided with these parameters.

The device studied in this work ensures flexibility in drying parameters, allowing better control of pasta color change and crust formation, depending on air temperature, distance from the heating source and processing time. However, using this drying method, it is not possible to obtain a solid structure of the object within the time provided for the experimental plan. It is proposed to increase the time of exposure to the object by performing several rounds of the deposited layer, for example, using a device for drying with pulsed air. The device has the ability to track the movement of the print nozzle. This will remove moisture during and between hot air pulses. Diffusion of moisture from the center of the layer to the surface between two air pulsations helps to limit the crust rapid formation on the layer surface.

Hot air drying allows to reduce the initial mass by 15-35%, depending on the support temperature and processing time, which varies from 0.5 to 2.5 minutes (Li et al., 2022). Local hot air drying combines the rapid impact of microwaves and the possibility of forming a thin crust on the layer surface which cannot be achieved with drying with microwaves alone or in combination with infrared radiation (Chhanwal et al., 2019). It should be noted that we observed the formation of thin layer (crust) with low permeability in case of harsh drying conditions. The internal temperature of the dough filament continues to rise simultaneously with the crust formation. This leads to the moisture evaporation due to the boiling point achieving. The combination of these two phenomena (the formation of the impermeable layer on the surface and the formation of gases) causes deformation of the dough filament during drying.

4 Conclusion

Two methods of local drying in combination with hot printing have been studied in the work.

Infrared drying has the advantage of drying of pasta dough layer several millimeters thick and results in a drier and harder surface. The formation of a thin crust on the surface of the printed material can contribute to a variety of textures in printed food products as well as reduce the tackiness between the layers of the applied material.

Local hot air drying opens up a number of possibilities for controlling the physical- and mechanical properties of printed food. We have shown that this method can quickly reduce the moisture content in the material, limiting the crust development. However, high initial moisture content is a limiting factor for a hard and brittle material obtaining. Drying can be done during 3D printing by adapting the printing so that multiple passes of hot air can be made in a single layer.

The weight loss rate for the above drying methods is high compared to the results reported in the literature. However, the final moisture content after heat treatment remains high. On the one hand, an increase in the moisture evaporation rate can shorten the processing time. This opens up the possibility of quick heating of pasta dough layer. On the other hand, shortening the processing time does not reduce the moisture content required for the dough to harden. The drying time of the printed pasta dough layers should be optimized to obtain a hard and brittle texture according to these criteria.

References

Abdelbasset, W. K., Alrawaili, S. M., Elkholi, S. M., Eid, M. M., Abd-Elghany, A. A., & Mahmoud, M. Z. (2022). The role of infrared waves in increasing the quality of food products. *Food Science and Technology (Campinas)*, 42, e118421. http://dx.doi.org/10.1590/fst.118421.

Allan, M. C., Rajwa, B., & Mauer, L. J. (2018). Effects of sugars and sugar alcohols on the gelatinization temperature of wheat starch. *Food Hydrocolloids*, 84, 593-607. http://dx.doi.org/10.1016/j.foodhyd.2018.06.035.

Auger, F., Morel, M.-H., Lefebvre, J., Dewilde, M., & Redl, A. A. (2008). Parametric and microstructural study of the formation of gluten network in mixed flour–water batter. *Journal of Cereal Science*, 48(2), 349-358. http://dx.doi.org/10.1016/j.jcs.2007.10.006.

Bredikhin, S. A., Martekha, A. N., & Andreev, V. N. (2023). Research of the rheological properties of mayonnaise with adding pumpkin and rice oils to replace sunflower oil. *Food Science and Technology (Campinas)*, 43, e67722.

Bredikhin, S. A., Martekha, A. N., Andreev, V. N., Kaverina, Yu. E., & Korotkiy, I. A. (2022). Rheological properties of mayonnaise with non-traditional ingredients. *Food Processing: Techniques and Technology*, 52(4), 739-749. http://dx.doi.org/10.21603/2074-9414-2022-4-2402.

Cappelli, A., Bettaccini, L., & Cini, E. (2020). The kneading process: a systematic review of the effects on dough rheology and resulting bread characteristics, including improvement strategies. *Trends in Food Science & Technology*, 104, 91-101. http://dx.doi.org/10.1016/j.tifs.2020.08.008.

Chhanwal, N., Bhushette, P. R., & Anandharamakrishnan, C. (2019). Current perspectives on nonconventional heating ovens for baking process: a review. *Food and Bioprocess Technology*, 12(1), 1-15. http://dx.doi.org/10.1007/s11947-018-2198-y.

Dessev, T., Jury, V., & Le-Bail, A. (2011). The effect of moisture content on short infrared absorptivity of bread dough. *Journal of Food Engineering*, 104(4), 571-576. http://dx.doi.org/10.1016/j.jfoodeng.2011.01.019.

Hackenberg, S., Jekle, M., & Becker, T. (2018). Mechanical wheat flour modification and its effect on protein network structure and dough rheology. *Food Chemistry*, 248, 296-303. http://dx.doi.org/10.1016/j.foodchem.2017.12.054. PMid:29329858.

Jiang, H., Zheng, L., Zou, Y., Tong, Z., Han, S., & Wang, S. (2019). 3D food printing: main components selection by considering rheological properties. *Critical Reviews in Food Science and Nutrition*, 59(14), 2335-2347. http://dx.doi.org/10.1080/10408398.2018.1514363. PMid:30285472.

Kim, H. W., Lee, I. J., Park, S. M., Lee, J. H., Nguyen, M. H., & Park, H. J. (2019). Effect of hydrocolloid addition on dimensional stability in post-processing of 3D printable cookie dough. *Lebensmittel-Wissenschaft + Technologie*, 101, 69-75. http://dx.doi.org/10.1016/j.lwt.2018.11.019.

Krishnaraj, P., Anukiruthika, T., Choudhary, P., Moses, J. A., & Anandharamakrishnan, C. (2019). 3D extrusion printing and post-processing of fibre-rich snack from indigenous composite flour. *Food and Bioprocess Technology*, 12(10), 1776-1786. http://dx.doi.org/10.1007/s11947-019-02336-5.

Li, Y., Liu, Y., & Guo, S. (2022). Reveal the internal moisture changes of white gourd during hot air-drying process using low-field NMR. *Food Science and Technology (Campinas)*, 42, e40422. http://dx.doi.org/10.1590/fst.40422.

Mann, J., Schiedt, B., Baumann, A., Conde-Petit, B., & Vilgis, T. A. (2014). Effect of heat treatment on wheat dough rheology and wheat protein solubility. *Food Science & Technology International*, 20(5), 341-351. http://dx.doi.org/10.1177/1082013213488381. PMid:23751547.

Moloto, P. I., Mosala, M., Omolola, A. O., Jideani, A. I. O., & Laurie, S. M. (2021). Optimization of hot-air drying conditions on functional properties of flour from dried South African sweet potato cultivars (Impilo and Bophelo) using the response surface methodology. *Food Science and Technology (Campinas)*, 41(1), 39-46. http://dx.doi.org/10.1590/fst.28019.

Nowak, D., & Lewicki, P. P. (2004). Infrared drying of apple slices. *Innovative Food Science & Emerging Technologies*, 5(3), 353-360. http://dx.doi.org/10.1016/j.ifset.2004.03.003.

Ovsyannikov, V. Yu., Toroptsev, V. V., Berestovoy, A. A., Lobacheva, N. N., Lobacheva, M. A., & Martekha, A. N. (2021). Development and research of new method for juice extracting from sugar beet with preliminary pressing. *IOP Conference Series. Earth and Environmental Science*, 640(5), 052011. http://dx.doi.org/10.1088/1755-1315/640/5/052011.

Perry, P., & Donald, A. (2002). The effect of sugars on the gelatinisation of starch. *Carbohydrate Polymers*, 49(2), 155-165. http://dx.doi.org/10.1016/S0144-8617(01)00324-1.

Severini, C., Azzollini, D., Albenzio, M., & Derossi, A. (2018). On printability, quality and nutritional properties of 3D printed cereal based snacks enriched with edible insects. *Food Research International*, 106, 666-676. http://dx.doi.org/10.1016/j.foodres.2018.01.034. PMid:29579973.

Severini, C., Derossi, A., & Azzollini, D. (2016). Variables affecting the printability of foods: preliminary tests on cereal-based products. *Innovative Food Science & Emerging Technologies*, 38, 281-291. http://dx.doi.org/10.1016/j.ifset.2016.10.001.

Sun, J., Zhou, W., Yan, L., Huang, D., & Lin, L. (2018). Extrusion-based food printing for digitalized food design and nutrition control. *Journal of Food Engineering*, 220, 1-11. http://dx.doi.org/10.1016/j.jfoodeng.2017.02.028.

Vanin, F. M., Lucas, T., Trystram, G., & Michon, C. (2018). Biaxial extensional viscosity in wheat flour dough during baking. *Journal of Food Engineering*, 236, 29-35. http://dx.doi.org/10.1016/j.jfoodeng.2018.05.007.

Wagner, M. J., Lucas, T., Le Ray, D., & Trystram, G. (2007). Water transport in bread during baking. *Journal of Food Engineering*, 78(4), 1167-1173. http://dx.doi.org/10.1016/j.jfoodeng.2005.12.029.

Wang, K.-Q., Luo, S.-Z., Zhong, X. Y., Cai, J., Jiang, S. T., & Zheng, Z. (2017). Changes in chemical interactions and protein conformation during heat-induced wheat gluten gel formation. *Food Chemistry*, 214, 393-399. http://dx.doi.org/10.1016/j.foodchem.2016.07.037. PMid:27507490.

Yang, F., Zhang, M., Prakash, S., & Liu, Y. (2018). Physical properties of 3D printed baking dough as affected by different compositions. *Innovative Food Science & Emerging Technologies*, 49, 202-210. http://dx.doi.org/10.1016/j.ifset.2018.01.001.

Zhang, L., Lou, Y., & Schutyser, M. A. I. (2018). 3D printing of cereal-based food structures containing probiotics. *Food Structure*, 18, 14-22. http://dx.doi.org/10.1016/j.foostr.2018.10.002.