Effect of temperature of baking chamber and process duration on rusk loaf crust color

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Abstract

Introduction. The aim of research is to determine the effect of temperature of the baking chamber and duration of the baking process on the color of rusk loaf crust.

Materials and methods. Rusk loafs were produced from wheat pastry dough, baked in an oven with radiation-convection heating in the temperature range of 120–200 °C. The baking and drying processes of rusk loafs were combined in one baking chamber. The color of the crust was determined on a universal photometer. The temperature along the thickness of the rusk was determined using a set of thermocouples.

Results and discussion. With an increase in the duration of the baking process from 20 to 140 min and an increase in the temperature of the baking chamber from 120 to 190 °C, the reflective capacity of rusks crust surface decreases from 43–53 to 12–30% according to a logarithmic dependence.

The permissible value of reflective capacity is 20–30%. With a decrease in this value, the crust surface will be excessively dark. The maximum duration of heat treatment, during which the required surface quality is ensured, decreases according to an exponential dependence from 8 h at a temperature of 120 °C to 33 minutes at 200 °C.

It is proposed to determine the defining size of a rusk loaf as the ratio of the loaf volume to its surface area, taking into account the coefficient of the ratio of product sizes. It allows to take into account the shape and dimensions of the product to determine rational modes of combined baking and drying processes.

When the air temperature increases from 120 to 190 °C and the value of the defining size decreases from 0.02 to 0.01 m, the duration of the drying process is reduced from 180 to 33 minutes.

With an increase in the defining size of the product from 0.005 to 0.03, the rational operating temperature of the baking chamber decreases from 240 to 140 °C. Exceeding the temperature leads to low crust quality.

Conclusions. The use of the obtained results will ensure high intensity of drying and proper reflectivity of the crust surface of the rusk loaf. The rational temperature of the baking chamber is 160–200 °C.

Introduction

The use of new technologies for drying food products is noted as one of the main trends of the food industry development in 2021-2030 (Ivanov et al., 2021). The present study examines the surface quality of small-sized bread rusk loafs (Figure 1) manufactured using an innovative method, namely, the baking and drying processes of rusks take place in the same baking chamber.

a b

Figure 1. Baked rusk loafs (a) and cut rusks (b)

One of the main indicators of the quality of finished rusks is the color of the crust and the absence of cracks. The main color criteria include:

(1) Uniformity of the color. The crust should have a uniform color without dark or light spots (Mior Zakuan Azmi at al., 2019; Telychkun et al., 2012).

(2) Acceptable colour. Usually it is golden-brown or dark-brown colour, depending on the formulation and type of product (Ahrner et al., 2002; Lohinova et al, 2023).

(3) Absence of the burnt areas. Burnt or overdried areas are not allowed (Therdthai et al., 2007).

(4) Matte or glossy surface. This indicator depends on the type of rusks (for example, some rusks may have a slight glossiness due to glazing).

(5) Foreign inclusions. The uneven color, carbon deposits, or traces of flour are not allowed (Telychkun et al., 2013).

The color and thickness of the crust depend on the temperature (Ahrner et al., 2002), the duration of the heat treatment process (Purlis et al., 2009), and the recipe composition (Purlis et al., 2009). From the point of view of the drying process of the rusk slices, which occurs after the rusk loaves are cut, it is desirable that the crust be less intensely coloured and have a thickness of more than 3 mm (Telychkun et al., 2013). Therefore, when baking rusk loaves with a high sugar content, the temperature of the baking chamber in the second drying period should not exceed 180–200 °C (Mior Zakuan Azmi et al., 2019).

When small-sized crackers produce, it is advisable to combine the baking and drying processes in one baking chamber (Telychkun et al., 2013).

However, in this case, the heat treatment process is longer, so at the end of the process the crust temperature approaches the coolant temperature. In addition, the significant duration of the process contributes to the thickening of the crust and its burning (Dessev et al., 2020).

The aim of the research was to determine the effect of the temperature of the baking chamber and the duration of the baking process on the color of rusk loaf crust.

Materials and methods

Recipe for rusk loaves

The rusks loaves for baking and drying were prepared according to the following recipe, kg: Premium grade wheat flour, 100; pressed yeast, 3; salt, 1; margarine with fat content 82%, 7; sugar, 15; water, 42 l.

Description of experimental installation

Baking was conducted in the baking chamber of the experimental installation (Figure 2). The baking chamber has upper and lower heating surfaces, which corresponds to the principle of operation of most industrial tunnel ovens.

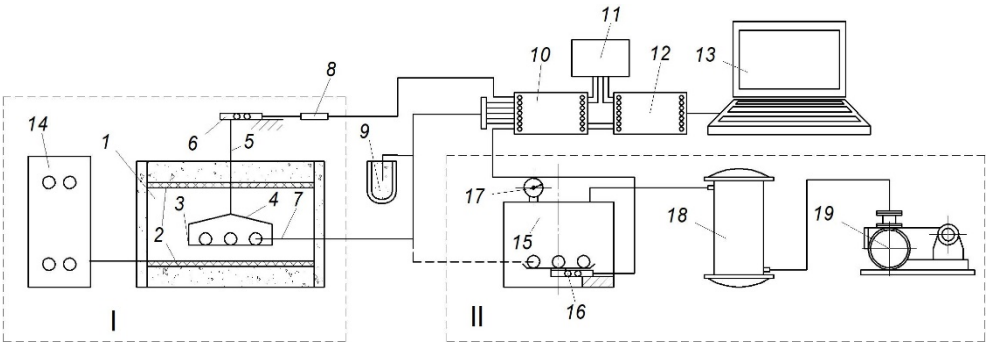

Figure 2. Experimental installation for baking and drying of rusk loaves:
I – installation for baking-drying rusk loaves;
II – installation for cooling of rusk loaves under vacuum conditions
1 – baking chamber, 2 – upper and lower heating surfaces, 3 – sheet, 4 – pendant, 5 – rod, 6 – weight strain gauge sensor, 7 – thermocouple block, 8 – signal amplifier, 9 – Dewar vessel, 10 – analog module, 11 – power supply, 12 – conversion module, 13 – computer, 14 – control panel, 15 – vacuum chamber, 16 – weight strain gauge sensor, 17 – pressure gauge, 18 – condenser, 19 – vacuum pump.

The installation consists of a baking chamber 1 with upper and lower 2 heating surfaces. On the sheet 3, which is held on the pendant 4, there are dough loaves. The pendant is attached to the rod 5, which is connected to the weight strain gauge sensor 6. The dough weight values are recorded via the analog module 10 and the conversion module 11.

The oven has an autonomous automatic temperature control of the upper and lower heating surfaces, which is carried out from the control panel 14. The panel also displays the temperature of the baking chamber.

The temperature in the layers of dough loaves is measured by thermocouples, the potential of which is supplied to the analog module ICP CON I-7018 10, which is powered by the power supply 11. Using the conversion module ICP CON I-7520 12, the signal is converted and transmitted to the computer 13. Appropriate software is used to record data in the computer.

After baking and drying, the rusk loaves are loaded into a vacuum chamber and cooled under vacuum conditions.

Determining of color of rusk crust

To determine the intensity of crust glossiness, a universal photometer FM-56 was used. The principle of operation of the device is based on comparing two light fluxes by changing the area of one of them using a diaphragm with a hole (CIE, 2023).

Due to the fact that the surface of the bread and rusk is not white, but has a certain color, measurements are complicated by the multi-color comparison fields. Therefore, the whiteness of the sample is determined as the average value of the reflectance coefficients measured through red, blue and green light filters.

Reflection coefficient R_0 of the rusks crust:

$$R_0 = r \cdot R,$$

where r is a ratio of the average brightness coefficient of the sample to the brightness coefficient of the barite plate;

R is a reflection coefficient of the barite plate.

Almost all light-scattering surfaces exhibit a sheen at the illuminated directional light, which is manifested in the fact that the brightness of the surface in the direction of specular reflection is greater than in other directions.

Using a universal photometer, the sheen (glossiness) of the crust can be examined at a constant angle between the beam of light incident on it and the beam of light in which the observation is made.

The value $\gamma_{(\delta)}$, which characterizes the glossiness of the surface at an angle δ, is determined by the formula (Telychkun et al., 2012):

$$\gamma_{(\delta)} = \frac{100P}{m(\delta)},$$

where P is the refinement coefficient of the device, P=1.305;

m is the value on photometer scale, which corresponds to the average position of photometric equilibrium;

δ is the angle at which the glossiness of the surface has the greatest value.

Results and discussion

Effect of temperature of baking chamber and duration of heat treatment on reflection coefficient of rusk crust

It was found that with an increase in the baking chamber temperature *t*, the reflectivity of the surface of the rusks R_0 decreases (Figure 3).

Increasing the duration of the drying process leads to a decrease in the reflectivity of the crust surface R_0 (Figure 4) at all temperatures in the baking chamber t.

The decrease in the reflection coefficient R_0 (Figure 4) with increasing baking chamber temperature t and the duration of heat treatment process τ occurs due to the accumulation of coloring products – Maillard reaction (Lohinova et al., 2023; Mandiuk et al., 2024).

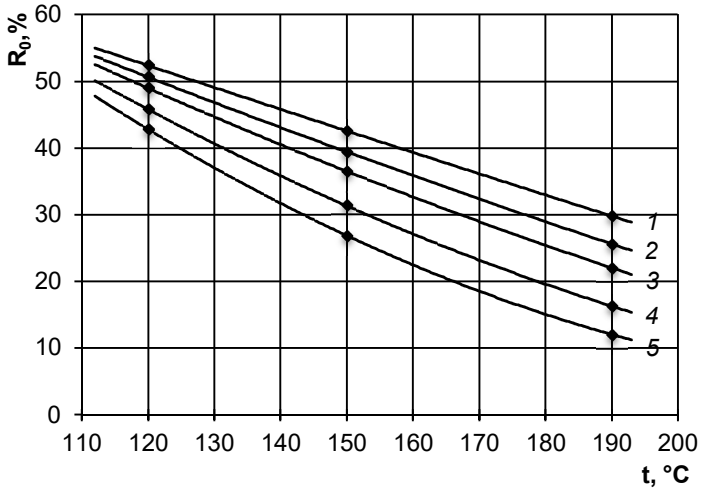

Figure 3. Effect of temperature in baking chamber on reflection coefficient of surface of rusk loaves
Process duration, min: 1 – 20; 2 – 40; 3 – 60; 4 – 100; 5 – 140.

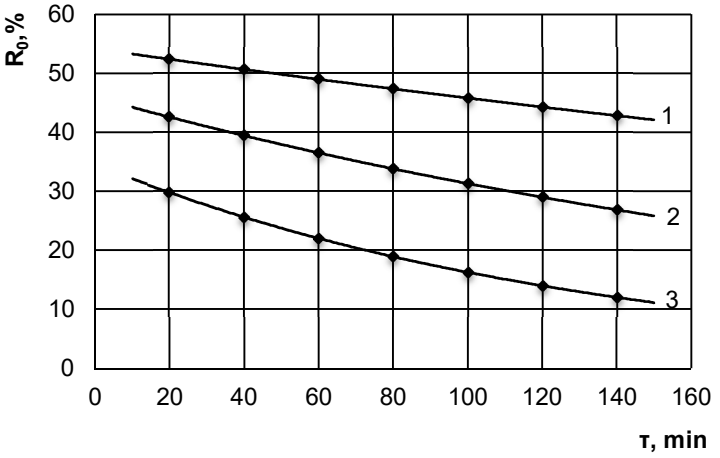

Figure 4. Effect of duration of heat treatment process on reflectance coefficient of rusk loaves surface.
Baking chamber temperature t, °C: 1 – 120, 2 – 150, 3 – 190.

The dependence of the reflectivity coefficient of rusk loaves surface on the temperature of baking chamber and the duration of heat treatment was obtained:

$$R_0 = (-9.33 \cdot \ln(\tau) - 20.74) \cdot \ln(t) + 39,58 \cdot \ln(\tau) + 168.3 .$$

The rational value of the reflection coefficient R_0 of rusk loaves surface is 20–30%, which corresponds to 3–4 units of the reference color scale.

Influence of product shape and size on duration of heat treatment

According to the results obtained, it was determined the geometric dimensions of the loaves for which it is advisable to combine the baking and drying processes.

Figure 5 shows the duration of the process at which high-quality coloring of the surface of the products is ensured depending on the temperature of the baking chamber.

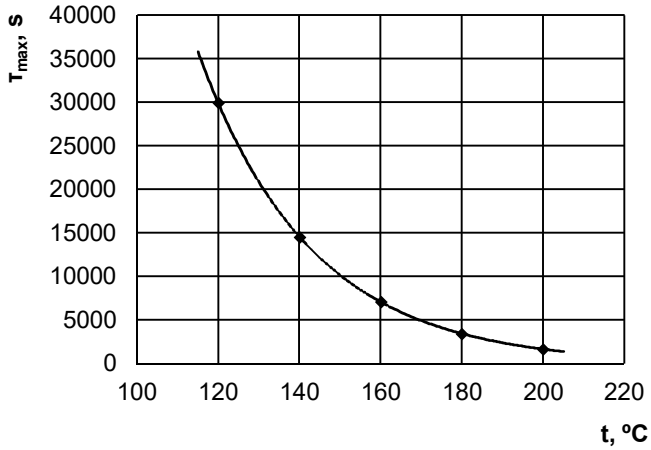

Figure 5. Effect of temperature in baking chamber on duration of heat treatment, which ensures a high-quality rusk surface

As can be seen from Figure 5, the temperature of the baking chamber significantly affects the intensity of the surface color and the duration of the process. The dependence can be described by the equation:

$$\tau_{\max} = 2.25 \cdot 10^6 \cdot e^{-0.036t} .$$

At a rational temperature of the heating chamber, maximum intensity of moisture release is ensured and high quality of the products is maintained, namely, the crusts do not burn. The color of the crust depends on its temperature, the duration of heat treatment, and, accordingly, on the defining size.

The defining size of rusk is proposed to be calculated by the formula:

$$R = i\frac{V}{F},$$

where: V is a volume of loaf, m^3;

F is a heat exchange surface area, m^2;

i is the coefficient of the product dimensions ratio, which takes into account the ratio of the 3 final dimensions of the loaf. This coefficient is defined as the sum of the ratios of the dimensions along which heating passes to all dimensions of the loaf:

$$i = \frac{x}{x} + \frac{x}{y} + \frac{x}{z},$$

where x is the size of the loaf along which the heat flow is directed, m;
y, z is two another sizes, m.

When the air temperature increases from 120 to 190 °C, the duration of the drying process is reduced by more than half (Figure 6).

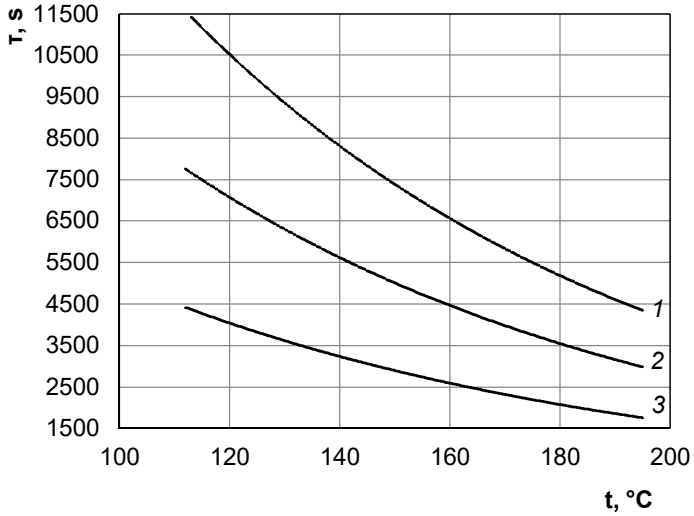

Figure 6. Effect of baking chamber temperature on duration of baking-drying of rusk loaf. Defining size of loaf: R, m: 1 – 0.02, 2 – 0.015, 3 – 0.01.

To prevent overheating of the crust, consider the dependence of the surface temperature of the rusk loaves on the temperature of the baking chamber (Figure 7).

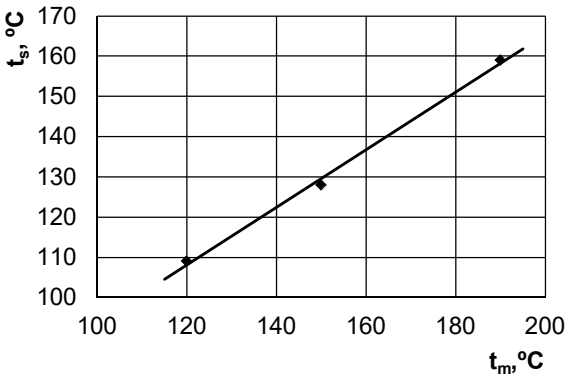

Figure 7. Effect of temperature of the baking chamber (t_m) on the surface temperature of rusk loaves (t_s) at end of drying process

If the crust temperature exceeds 150 °C, it burns and the rusks taste deteriorates. Therefore, when producing butter rusks by combining baking and drying, a baking chamber temperature of 150 to 170 °C is recommended to obtain a high-quality surface. Lowering the baking chamber temperature below 150 °C leads to an increase in the duration of the process.

Therefore, the following data: (1) dependence of the duration of the baking-drying process on the defining size (Figure 6), and (2) dependence of the final surface temperature of the rusk loaves and the duration of heat treatment, which ensures a high-quality surface, on the temperature of the baking chamber (Figure 4, Figure 5) allow to determine the rational temperature of the baking chamber depending on the defining size of the dough loaves (Figure 8).

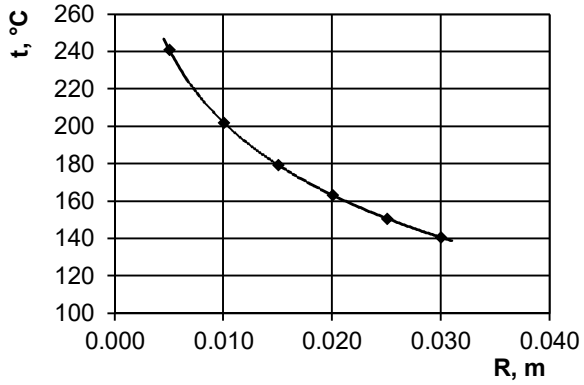

Figure 8. Effect of defining size of rusk loaves on rational temperature of baking chamber

The dependence of the rational temperature of the baking chamber on the determining size is logarithmic:

$$t_r = -56\ln(R) - 55.67\ ^\circ\mathrm{C}$$

Since the defining size of the products R is within 0.01–0.02 m, from the point of view of ensuring high-quality crust coloring at high intensity of the drying process, it is necessary to ensure a baking chamber temperature of 160–200 °C. Lowering the temperature significantly slows down the process duration. Increasing the baking chamber temperature is limited by the thickness and coloring of the crust (Helou et al., 2016; Telychkun et al., 2012).

Conclusions

1. The feasibility of combining the baking-drying processes of rusk loaves in one baking chamber has been confirmed. The process should be divided into 2 periods - baking and drying. The duration of the drying process is significantly longer than baking.
2. The drying period can be reduced by increasing the temperature of the baking chamber, but the maximum temperature value is limited by the color of the crust. The duration of the drying period is determined by an empirical equation depending on the temperature of the baking chamber.

3. With an increase in the baking time of rusk loaves from 20 to 140 min and an increase in the temperature of the baking chamber from 120 to 190 °C, the reflectivity of the surface of rusk loaf crust decreases from 43–53 to 12–30% according to a logarithmic dependence.
4. The permissible value of the reflectivity is 20–30%. With a decrease in the permissible value, the surface of the crust will be excessively dark. The maximum duration of heat treatment, which ensures the required surface quality, decreases exponentially from 8 hours at a temperature of 120 °C to 33 minutes at 200 °C.
5. It is proposed to calculate the defining size of a rusk loaf as the ratio of the volume of the loaf to its surface area, taking into account the coefficient of the ratio of product proportions. This allows you to take into account the shape and dimensions of the product to determine rational modes of combined baking and drying processes.
6. When the air temperature increases from 120 to 190 °C and the value of the defining size decreases from 0.02 to 0.01 m, the duration of the drying process is reduced from 180 to 33 minutes.
7. With an increase in the defining size of the rusk loaves from 0.005 to 0.03, the rational temperature of the baking chamber medium decreases from 240 to 140 °C. Excess temperature leads to a deterioration in the quality of the crust.
8. The using of results allows to ensure high drying intensity and proper reflectivity of the surface of rusk loaf crust. The rational temperature of the baking chamber is 160–200 °C.

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