Influence of the dough composition on the heat treatment of low-protein cookies

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Abstract

Introduction. The aim of research was to study the influence of dough components (xanthan gum, maltodextrin, starches) on the heating process of low-protein cookies and changes in the geometrical forms of the dough pieces during thermal treatment.

Materials and methods. Dough for low-protein cookies was made using corn and tapioca starches, maltodextrin, and xanthan gum. Traditional butter cookies with wheat flour were used as a control. Properties of low-protein dough were studied by thermal analysis (thermogravimetric analysis, differential thermal analysis and differential scanning calorimetry).

Results and discussion. Low-protein cookies had similar final height as traditional butter cookies. Low-protein cookies made with corn starch, maltodextrin and xanthan gum and traditional butter cookies made with wheat flour had a similar total weight loss 61.0 and 63.1%, respectively. At the same time, cookies made with corn starch and xanthan gum lost the lowest amount of weight, 39.5%. The temperature at which the moisture removal from the samples ends and their thermal decomposition begins was determined. Low-protein cookies made with corn starch and xanthan gum lost all moisture at 129 °C; low-protein cookies made with corn starch, maltodextrin and xanthan gum, and traditional butter cookies made with wheat flour lost all moisture at 95.4 °C and 98.7 °C, respectively. Endothermic processes (fat melting, starch gelatinization, and water evaporation) and exothermic processes (thermal decomposition) were observed by thermal analysis of dough samples. Differential scanning calorimetry curve of the low-protein cookies made with corn starch and xanthan gum had a different appearance compared to the curves of cookies with maltodextrin (low-protein cookies made with corn starch, maltodextrin, and xanthan gum; low-protein cookies made with corn and tapioca starches, maltodextrin, and xanthan gum). The largest endothermic peak began at 60 °C and reached maximum at 108 °C, while curves for low-protein cookies with maltodextrin had two peaks without overlapping events. Areas under the differential scanning calorimetry curves were calculated to estimate the amount of energy required for the heat treatment process. The lowest amount of energy was required for the heat treatment of dough for traditional butter cookies: ΔH=124.05 J/g. The heat treatment of low-protein dough required more energy: ΔH=199.46 – 268.33 J/g.

Conclusions. The heat treatment process of low-protein cookies was different from heat treatment of traditional cookies and required more energy (60,8–116,3% more). Replacement of 20% of corn starch with tapioca starch in a low-protein formulation leaded to decrease in energy required for heat treatment in 23.9%.

Introduction

Production of functional food for the individuals with specific diseases, and groups with different nutritional requirements is one of the main trend of food technologies in 2021-2030 (Ivanov et al., 2021). There are several diseases that require special diets. One of them is phenylketonuria (commonly known as PKU) caused by inability of the body to break down amino acid phenylalanine. Considering that there is no cure for this disease, patients must follow a diet with individually determined possible amounts of phenylalanine. In any case, this amount is much lower than in traditional diets (Rocha et al., 2021; Van Wegberg et al., 2017). To enable low-protein diets, a wide range of low-protein products should be developed, including flour confectionery such as cookies. Since low-protein products do not contain gluten, the same products can be consumed by people who follow a gluten-free diet.

Several recipe compositions of low-protein cookies are developed. This recipe compositions differ significantly from the composition of traditional butter cookies by the absence of egg products, the absence or very small amount of wheat flour, the use of different starches and hydrocolloids. All these ingredients affected the technological processes of making low-protein cookies, including the heat treatment process, which is a combined of baking and drying processes (Hrytsevich et al., 2023).

There are no studies which describe development, technological process, and heat treatment of low-protein cookies. However, there are studies which describe the development of gluten-free and conventional cookies with increased nutritional, sensory, and textural properties (Gawade et al., 2023; Itagi et al., 2023; Kaur et al., 2023). Low-protein cookies do not contain high protein raw materials, and wheat flour is used in very limited quantities. Xanthan gum, maltodextrin, and tapioca starch are used to improve structural properties. These changes in the recipe composition significantly affect the heat treatment process of low-protein cookies. During the first period of heat treatment the dough piece starts to heat up, the duration of the period is approximately 1.5 minutes. In the second, the longest period of heat treatment, the central layers are significantly heated up and heat is used for endothermic processes. In the third period, moisture evaporation reaches the central layers and moisture loss occurs at a reduced rate, moisture migrates from the central layers to the surface layers (Davidson, 2023). It should be noted that the processes are influenced by the cookie recipe and heat treatment conditions. At the same time, the addition of new recipe components and the removal of certain recipe components may require a change in the parameters (conditions) of cookies' heat treatment.

Changes in molecular structure of sugar-snap cookies during the baking process were studied. The baking process reduced the size of amylopectin molecules and amylose chain lengths and caused change of some starch granules. However, the distribution of amylopectin chains remained similar because of little change in crystallinity and gelatinization temperatures. The study revealed disruptions in starches ordered structure. These findings help understand how starch changes in cookies, impacting their quality, especially the sensory properties (Zhang et al., 2021).

Heat treatment of low glycemic index gluten-free cookies from high amylose rice flour were studied. Higher baking temperature led to increased spread ratio and hardness of cookies. Adding carboxymethyl cellulose rose resistant starch content and overall acceptability while reducing predicted glycemic index and glycemic load. The optimal conditions were determined as 185 °C baking temperature, 22 min baking time, and 0.8% carboxymethyl cellulose concentration. The resulting cookies had 4.66% dietary fiber, 7.20% resistant starch, lower predicted glycemic index, 44.60, and glycemic load, 17.51 (Naseer et al., 2021).

Maillard reaction, or browning, in cookies is intensified along with an increase of the content of sugars and proteins causing darker color of baked products (Lukinac et al., 2022). Meanwhile, due to the limited amount of proteins in low-protein dough, the formation of Maillard reaction products is minimal (Žilić et al., 2016).

Thermal analysis is a powerful tool to describe processes which occur during heat treatment. While traditional dough systems are studied quite well by different thermal analysis techniques (Rumińska et al., 2021; Xu et al., 2022), there are no studies published regarding thermal properties of low-protein dough systems. However, some studies are performed on gluten-free dough systems. Starch transitions of doughs made with different types of gluten free flour are studied by dynamic thermal mechanical analysis and differential scanning calorimetry, and it was found that starch transitions (gelatinization, amylose melting) depend on starch nature (Moreira et al., 2015). Structural support of the zein network to rice, flour gluten-free dough was studied. It was found that three different rice flours have different thermal properties mainly due to the different ratio of amylose to amylopectin (Zhang et al., 2023).

The heat treatment process of low-protein cookies is not studied yet, and the influence of different low-protein recipe components on the baking process requires additional research. The aim of research is to determine the influence of recipe components (xanthan gum, maltodextrin, corn and tapioca starches) on the heat treatment process of low-protein cookies by thermal analysis and to determine changes in the geometrical forms of the dough pieces during the process.

Materials and methods

Low-protein dough preparation. The dough for all samples were prepared in the same way: sugar was dissolved in water and then mixed with butter and eggs (if eggs are present in recipe) in mixer for 4 min. Then the mixture of other ingredients was added followed by mixing for 5 minutes.

Ingredient compositions of the samples under study were as follows:

- Sample 1: corn starch, 100%, butter, white sugar, xanthan gum, vanilla powder, soda, ammonium;
- Sample 2: corn starch, 80%, tapioca starch, 20%, maltodextrin, butter, white sugar, xanthan gum, vanilla powder, baking soda, ammonium;
- Sample 3: corn starch, 100%, maltodextrin, butter, white sugar, xanthan gum, vanilla powder, baking soda, ammonium;
- Control sample: wheat flour, eggs, butter, white sugar, vanilla powder, baking soda, ammonium.
- The follow ingredients were used in the same amounts in all recipes: butter, 27.53% of mass of all recipe ingredients; white sugar, 12%; xanthan gum, 0.1%; vanilla powder, 0.2%; soda, 0.1%, and ammonium, 0.1%.

Change in geometrical dimensions. Dough pieces were formed with diameter 50 mm, height 5 mm, and then baked for 10 min at 220 °C. The change in the geometric dimensions of the dough piece during baking and drying was determined by measuring the diameter and height of the formed dough piece and the height of the piece at each minute of heat treatment.

Thermogravimetric analysis. Thermogravimetric analysis was performed with Derivatograph Q1500 (Hungary), heating temperature 20-240 °C, sample weight in range 60-75 mg, total heat treatment time 35 minutes (Goranova et al., 2019; Ito et al., 2022).

Differential scanning calorimetry. Differential scanning calorimetry was performed with Mettler Toledo DSC 3+ (Switzerland). Calibration of the device was performed with indium. Aluminum pans with lids were used for measurement. Empty sealed pan was used as a reference. The measurement was carried out at temperature range 0-240 °C using nitrogen gas, with temperature increase 5 °C per minute (Ito et al., 2022; Zhang et al., 2021). Enthalpy change (ΔH) was calculated by integrating the area under obtained curves with STAR software.

Statistics. All measurements were performed in triplicate and average values were calculated.

Results and discussion

Change of the height and diameter of the dough after baking

Baked low-protein cookies had homogeneous surface and porosity (Figure 1).

Sample 1

Sample 2

Sample 3

Figure 1. Baked low-protein cookies:

Sample 1, low-protein cookies made with corn starch and xanthan gum;
Sample 2, low-protein cookies made with corn and tapioca starches, maltodextrin, and xanthan gum;
Sample 3, low-protein cookies made with corn starch, maltodextrin, and xanthan gum.

After the heat treatment, the height and diameter of the dough pieces increased (Table 1).

A radical change in the recipe composition in cookies can lead to an increase of their height and diameter after heat treatment compared to traditional cookies (Cappa et.al., 2020; HadiNezhad et.al., 2009).

Table 1

Change of the height and diameter of the dough pieces after baking

Low-protein cookies made with	**Diameter, cm**		**Height, cm**		**Increase in diameter, %**	**Increase in height, %**
	Before baking	After baking	Before baking	After baking		
Control sample	5.000	6.250	0.500	0.580	25.000	16.000
Sample 1: Corn starch and xanthan gum	5.000	6.150	0.500	0.595	23.000	19.000
Sample 2: Corn starch, maltodextrin, and xanthan gum	5.000	6.000	0.500	0.580	20.000	16.000
Sample 3: Corn and tapioca starches, maltodextrin, and xanthan gum	5.000	6.450	0.500	0.585	29.000	17.000

Dough expansion (increase in geometrical dimensions) was caused by the action of leavening agents and changes in the chemical state of the recipe components (HadiNezhad et.al., 2009). As a result of this increase in size, the structure of the product was formed, in particular: porosity, looseness, which largely determines the sensory perception of the product (Irondi et al., 2023). In addition, the increase in the diameter of the dough piece during baking and drying of cookies has mainly technological aspects. The cookie dough pieces are formed on the baking chamber floor at a certain distance from each other (Davidson, 2023).

During the heat treatment, the dough pieces increase in diameter and move closer to each other (Zhang et al., 2021). If the increase is not considered when forming the dough pieces, dough pieces may touch each other and stick together at the end of the heat treatment. This is a technological defect, and such products cannot be sold leading to the lost to the company's profit. Therefore, there was a need to determine the increase in the geometric dimensions of low-protein biscuit dough pieces during baking and drying (Zhang et al., 2021).

The changes in the height of the dough pieces during heat treatment at 220 °C for 10 min was shown (Figure 2).

During the heat treatment of traditional types of butter cookies, a decrease in the height of the dough piece is observed in the first period due to the melting of the fat component (Gonzalez-Ortega et al., 2023). As seen from Figure 2, low-protein cookies are also characterized by a decrease in the height of the dough piece and an increase in diameter. Expansion of dough is observed during the second period of heat treatment. This is the longest period – up to 70% of the total duration of the heat treatment process. In the low-protein samples, the height increase of the dough piece during the heat treatment is close to the height increase of the control sample. In sample made with corn and tapioca starches, maltodextrin, and xanthan gum, the height increase is slightly higher than that of the control sample. In the third period of heat treatment of traditional and low-protein cookies, a constant height of the dough piece is observed. In the last, fourth period, the height of the dough piece changes, and a decrease in its height is observed. At the same time, the decrease in the height of the dough piece of low-protein cookies is less than that of traditional cookies. It might be explained by absence of protein substances in the developed products and the presence of structure forming agents that fix the size of the dough piece (Zhang et al., 2023).

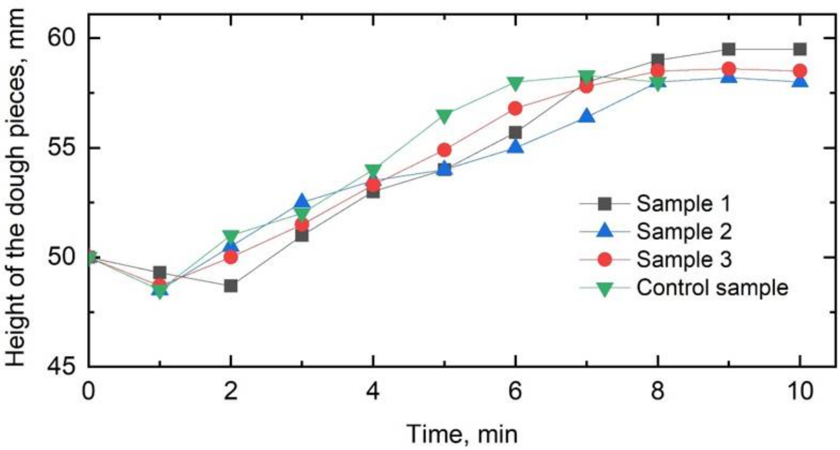

Figure 2. Change in the heigh of dough pieces during termal treatment at 220 °C:
Sample 1, low-protein cookies made with corn starch, and xanthan gum;
Sample 2, low-protein cookies made with corn and tapioca starches, maltodextrin, and xanthan gum;
Sample 3, low-protein cookies made with corn starch, maltodextrin, and xanthan gum, control sample, butter cookies made with wheat flour.

Thermogravimetric analysis

Heat treatment affects key components of food, including carbohydrates, proteins, fats, and water (Zhang et al., 2021). Temperature increase lead to alterations in both the physical aspects (melting, crystallization, evaporation, aggregation, and gelation) and chemical properties (hydrolysis, oxidation, and reduction) of food products (Ito et al., 2022).

These changes significantly impact the final product, influencing its taste, color, appearance, texture, and stability. Thermal analysis is a widely used tool in the food industry, enabling the examination of physical and chemical transformations linked to temperature fluctuations occurring during food manufacturing. Enhancing our comprehension of these processes enables precise control and optimization of production conditions, ultimately leading to improved quality (Ito et al., 2022).

The study of the behavior of raw materials and products during heat treatment is of great importance for the food industry. Since there is no literature available on thermal analyzes of low-protein processed foods and dough, we performed the most common thermal analyzes used in academic and industrial food laboratories: thermogravimetric analysis (TGA), differential thermal analysis (DTA), and differential scanning calorimetry (DSC) to characterize low-protein cookies.

Thermogravimetric and differential thermal analyses were performed using a derivatograph (Figure 3).

By observing the curve data, it is possible to determine the temperature at which the mass change of the low-protein semi-finished product begins and the final temperature.

The first derivative of TG, known as TGA, is used to assist in this identification. It is a mathematical parameter, not a thermoanalytical method that is derived from the first derivative of the mass change with time (dm/dt) versus temperature or time (Ito et al., 2022). The TGA curve improves measurement accuracy by identifying the beginning and end of thermal processes and facilitates the differentiation of superimposed events.

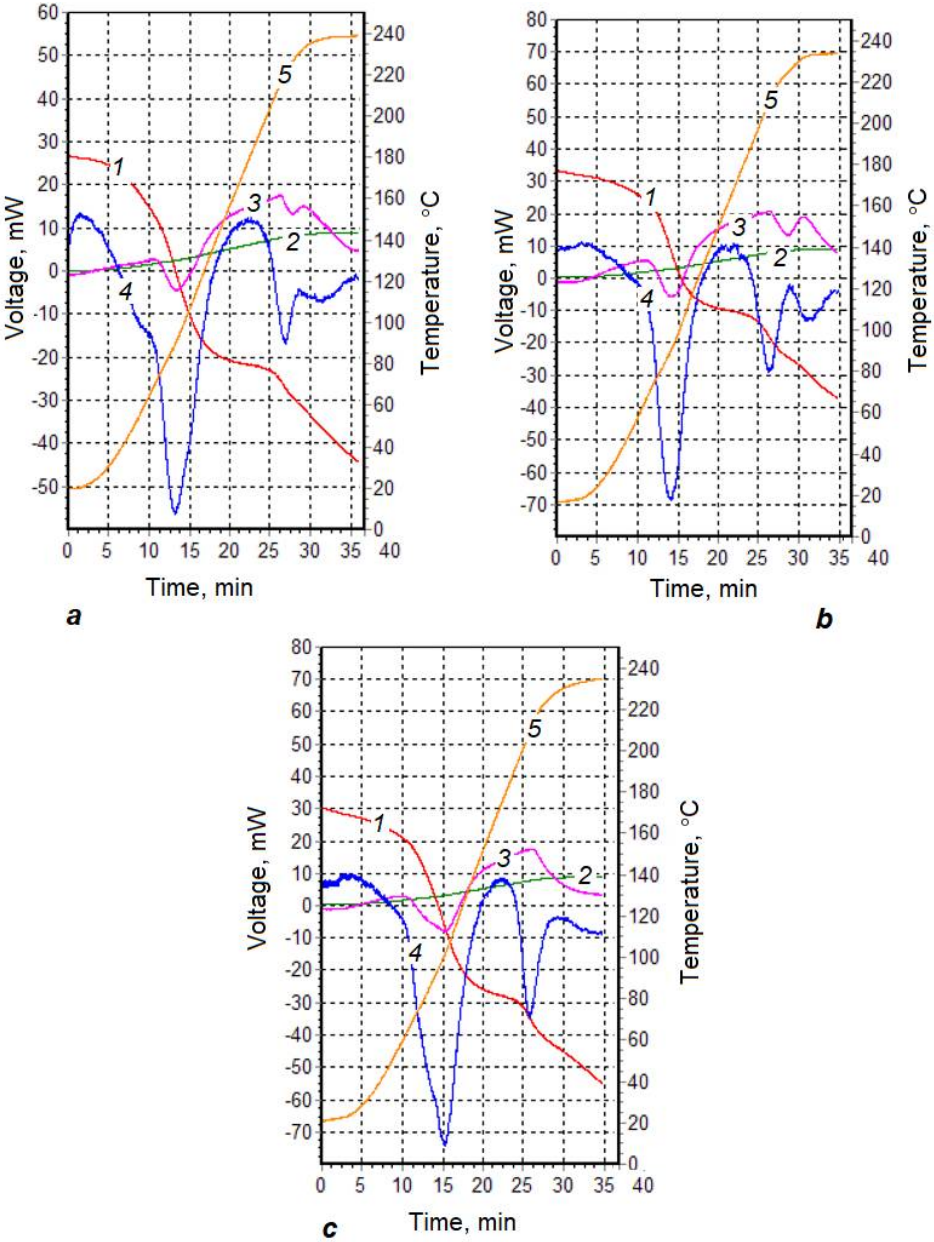

Figure 3. Thermogravimetric analysis of dough at ΔT 20-240 °C:

1, Mass; 2, Temperature (U); 3, DTA; 4, DTG; 5,Temperature (T).

Sample 1, low-protein cookies made with corn starch, and xanthan gum;
Sample 2, low-protein cookies made with corn and tapioca starches, maltodextrin, and xanthan gum;
Sample 3, low-protein cookies made with corn starch, maltodextrin, and xanthan gum, control sample, butter cookies made with wheat flour.

When the sample is stable, or with little change in mass, the TG curve is considered as a constant and therefore the derivative is zero (the DTA curve remains a straight line). A plateau may indicate the thermal stability of the material in a given temperature range (Xu et al., 2022). After reaching a temperature of 40 °C, all studied samples tested are thermally unstable during the entire test, as moisture is constantly being removed (Fig. 3).

Each time the sample changes mass, a kink is created in the TG curve, from which the first derivative is calculated, and peaks are formed that delimit areas proportional to the mass changes undergone by the sample. This results in a DTG curve from which the initial, peak, and final temperatures of the process can be determined. The peak temperature corresponds to the temperature at which the reaction rate is maximum. In addition, when sequential reactions occur, the TG curve is not sufficient to interpret the process, so it is supported by the DTG curve (Ito et al., 2022).

Decrease in weight is observed during the heating of the all sample (Table 2).

Table 2

Weight loss during heating of the dough samples with the derivatograph

Temperature, °C	**Weight of the dough samples made with**					
	Corn starch, maltodextrin, and xanthan gum		Corn starch, maltodextrin, and xanthan gum		Wheat flour (control sample)	
	mg	%	mg	%	mg	%
20	62.10	100.0	66.7	100.0	75.40	100.0
40	61.30	98.7	64.28	96.4	72.64	96.3
60	58.11	93.6	61.86	92.74	70.34	93.3
80	55.73	89.7	57.02	85.5	65.28	86.6
100	50.74	81.7	47.35	71.0	55.85	74.1
120	47.76	76.9	42.99	64.5	51.48	68.5
160	45.77	73.7	39.6	59.4	44.58	59.1
175	45.37	73.1	39.1	58.6	44.12	58.5
200	44.97	72.4	37.67	56.5	42.28	56.1
240	37.60	60.5	24.60	36.9	29.40	39.0

Based on data in Table 2, it can be concluded that the minimum weight loss is inherent in low-protein sample made with corn starch, and xanthan gum. In the formulation of this sample, xanthan gum is used as a structuring agent. In a low-protein sample made with corn starch, maltodextrin, and xanthan gum, as a structure forming agents are used xanthan gum and maltodextrin. The weight loss of this sample is close to weight loss of the control sample. In this temperature range, the decrease in the weight of the dough samples is mainly due to the release of moisture. Moisture release at the beginning of heating in all samples is virtually identical. During further heating, the moisture release in low-protein sample made with corn starch, and xanthan gum differs from a low-protein sample made with corn tapioca starch, maltodextrin, and xanthan gum and the control sample. At a temperature of 80 °C, the weight loss in low-protein sample made with corn starch, and xanthan gum is 10.3%, in low-protein sample made with corn starch, maltodextrin, and xanthan gum is 14.5%, and in the control sample is 13.4%. At a temperature of 120 °C, the difference between moisture removal increases: low-protein sample made with corn starch, and xanthan gum – 23.1%, low-protein sample made with corn starch, maltodextrin, and xanthan gum – 35.5%, control sample – 31.5%. The study is carried out up to a temperature of 240 °C. At this temperature, the weight loss in low-protein sample made with corn starch, and xanthan gum is 39.5%, in a low-protein sample made with corn starch, maltodextrin, and xanthan gum – 63.1%, in the control sample 61.0%. The mass fraction of moisture of all the tested dough masses was 23.9 %, so it is seen that in addition to the release of free and bound moisture, other processes occurred in the polymers, which were accompanied by a decrease in the weight of the samples.

It should be noted that the heat treatment to which the dough samples are subjected during the derivatograph tests differs from the heat treatment in the baking chamber during the manufacturing process. This is primarily due to the size of the dough piece. For the derivatographic study, the dough weight ranged from 62.1 to 75.4 mg (0.0621 to 0.0754 g), while the weight of the cookies dough piece usually starts at a few grams. Thus, the samples under study reach a high temperature in the inner layers of the dough piece faster (Rumińska et al., 2021). The duration of the heat treatment also differs. During the derivatographic studies, the duration of the heat treatment is 35 minutes, while the thermal treatment of a low-protein dough mass during the technological process is no more than 10 minutes.

Knowing the moisture content of the semi-finished products, we can determine the temperature at which the moisture removal from the samples ends and their thermal decomposition begins. Low-protein sample made with corn starch, and xanthan gum loses all moisture at 129 °C, low-protein sample made with corn starch, maltodextrin, and xanthan gum loses all moisture at 95.4 °C, and the control sample at 98.7 °C.

The graphs obtained from DTA analysis show the temperature change on the ordinate axis and time or temperature on the abscissa axis.

When the sample is heated, unless physical or chemical phenomena occur, a parallel line of temperature change is recorded with respect to the time axis. However, when heat is released in exothermic processes, an increase in temperature is recorded, which is reflected by a kink in the temperature-time profile. This is also true for endothermic processes, in which heat is absorbed by the sample and a temperature decrease is recorded, also represented by an inflection point, i.e. a shift from the baseline will be observed. Thus, DTA monitors the change in the physical property (temperature) of a sample by comparing it to a thermally inert material (neither absorbing nor emitting heat), called a reference (Ito et al., 2022). However, this method differs from DSC in that measurements are based on the change in temperature of the sample relative to the inert reference material, whereas in DSC, a calorimetric method, the change in energy between the sample and the reference can be estimated, which can even be used as a quantitative analysis, unlike DTA (Ito et al., 2022).

From the derivatograms (Fig. 3), it is evident that up to 80 °C, the DTA curve is linear, when the samples reach 80 °C and continue to expand, a distinct endothermic peak is observed, reaching its maximum at 120 °C. At 150-160 °C, an exothermic peak is observed, which coincides with an acceleration of mass loss on the TG scale.

Thus, the endothermic peak at 80 °C can be explained by the intensification of moisture evaporation, and the exothermic peak at 150-160 °C by the thermal decomposition of the studied marks.

Differential scanning calorimetry

For a more detailed study of the endothermic and exothermic processes occurring in low-protein dough masses during heat treatment, DSC was performed (Figure 4).

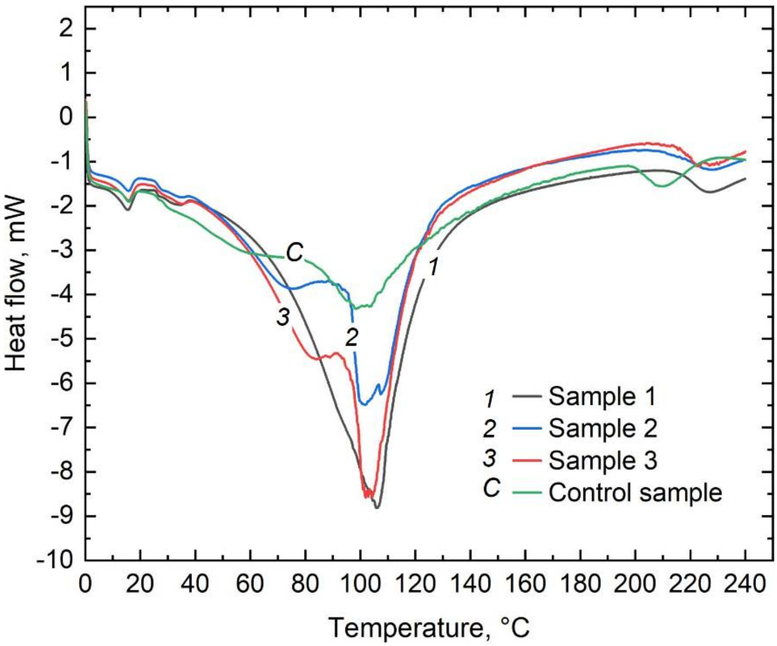

Figure 4. DSC curves of dough at ΔT 0-240 °C:
Sample 1, low-protein cookies made with corn starch, and xanthan gum;
Sample 2, low-protein cookies made with corn and tapioca starches, maltodextrin, and xanthan gum;
Sample 3, low-protein cookies made with corn starch, maltodextrin, and xanthan gum, control sample – butter cookies made with wheat flour.

Physical or chemical changes in a substance cause a change in its enthalpy. DSC determines the change in enthalpy that occurs between a sample and a reference during the heating process. This analysis is both quantitative, as the enthalpy is known from the area of the peaks recorded during the analysis, and qualitative, as it provides information such as the shape, position and number of peaks (Ito et al, 2022). The areas under the peaks are proportional to the enthalpy changes that occur in each transformation (Lucas et al., 2001). The DSC plot clearly shows that all the tested samples consume different amounts of energy during the heating process. The DSC curves are somewhat similar to the DTA curves but reflect endothermic processes. All samples were heated at temperatures ranging from 0 to 240 °C. At the beginning of the curve, it is seen that all samples behave similarly and actively absorb heat. In the temperature range from 20 to 30 °C, endothermic peak is seen associated with the melting transition of the fat phase corresponding to low melting and medium melting (Gonzalez-Ortega et al., 2023). When the temperature reaches 40 °C, the endothermic process is observed again in all the samples. This is due to a change in the aggregate state of the fat phase: the transition of butter from a solid to a liquid state associated with high melting (Gonzalez-Ortega, et al., 2023). With a further increase in temperature, the behavior of the curves of all the samples under study is slightly different.

In contrast to the low-protein dough, in the control sample, the endothermic process of changing the aggregate state of butter is immediately followed by the beginning of denaturation of wheat flour proteins and then by starch gelling. Thus, these successive endothermic processes overlap to some extent, which is why the graph does not show clear peaks for each process. At a temperature of 90 °C, the intensification of moisture removal from the sample begins. The endothermic process peaks at 102 °C. The DSC curves for low-protein samples which contain maltodextrin (samples 2 and 3) have a similar character. At a temperature of 55 °C, the endothermic process of gelling of the starches in the samples begins (Moreira et al., 2015). Compared to the low-protein sample made with corn starch, and xanthan gum, the endothermic peak begins at a lower temperature. At 78 °C, the energy absorption of the sample 2 decreases, which is explained by the partial replacement of corn starch with tapioca starch in this recipe. At a temperature of 100 °C, another rapid endothermic peak begins due to moisture removal. In sample without tapioca starch (sample 3), the intensification of the moisture removal process begins for 2 °C earlier compared to the sample with tapioca starch (sample 2).

The DSC curve of the sample made with corn starch, and xanthan gum has a different appearance compared to the samples containing maltodextrin (samples 2 and 3). The largest endothermic peak begins at 60 °C and reaches its maximum at 108 °C. This endothermic peak is the result of two main endothermic processes: starch gelling and intensive moisture removal from the dough piece.

With increasing temperature, exothermic processes are observed in all samples, which may indicate thermal decomposition of all the samples tested (Ito et al., 2022).

From the DSC curves, we can compare the amount of energy required for the heat treatment of the low-protein doughs and the control sample. The lowest amount of energy is required for the heat treatment of dough for traditional butter cookies, ΔH=124.05 J/g. The heat treatment of low-protein doughs requires more energy. This is due to the presence of xanthan gum and starches in the recipe. The largest amount of energy is required for heat treatment of dough sample made with corn starch, and xanthan gum, 268.33 J/g. Dough sample made with corn starch, maltodextrin, and xanthan gum requires less energy because the total area of the endothermic peak is smaller, 262.01 J/g. This may be due to the fact that the maltodextrin in the formulation of this sample absorbs some water, and this water is released more easily during heat treatment compared to the water absorbed by starches and xanthan gum. It could happen due to competition for water between maltodextrin and starch in the formulation of low-protein doughs (Xu et al., 2022). The heat treatment of the dough sample made with corn and tapioca starches, maltodextrin, and xanthan gum requires the least amount of energy, 199.46 J/g, among all the low-protein doughs studied. This is due to the properties of tapioca starch included in the recipe, since less energy is required for the gelling of tapioca starch.

Conclusions

1. The heat treatment process of low-protein cookies is different from the heat treatment of traditional cookies and has more similarities with heat treatment of gluten-free products due to absence of gluten network.

2. The presence of maltodextrin in a formulation of low-protein dough for butter cookies increases moisture removal during heat treatment process. Low-protein sample made with corn starch, and xanthan gum loses all moisture at 129 °C, low-protein sample made with corn starch, maltodextrin, and xanthan gum loses all moisture at 95.4 °C, and the control sample at 98.7 °C during TGA measurement.
3. The presence of maltodextrin in a formulation of low-protein cookies leads to slight decrease in energy required for baking: 268.33 J/g without maltodextrin and 262.01 J/g with maltodextrin.
4. Replacement of 20% of corn starch with tapioca starch in formulation leads to significant decrease in energy required for baking: sample with 100% corn starch has ΔH=262.01 J/g, sample with corn and tapioca starch has ΔH=199.46 J/g.
5. The lowest amount of energy is required for the heat treatment of dough for traditional butter cookies: ΔH=124.05 J/g. The heat treatment of low-protein dough requires more energy: ΔH=199.46–268.33 J/g.

References

Cappa C., Kelly J., Perry Ng. (2020). Baking performance of 25 edible dry bean powders: Correlation between cookie quality and rapid test indices, *Food Chemistry*, 302, 125338, https://doi.org/10.1016/j.foodchem.2019.125338

Davidson I. (2023), Baking process, In: Pacific P. ed., *Biscuit Baking Technology (Third Edition)*, Academic Press, pp. 45-56, https://doi.org/10.1016/B978-0-323-99923-6.00026-0

Gawade D., Patil K., Hemangi Jayram G. (2023), Development of value-added cookies supplemented with giloy and tulsi powder, *Materials Today: Proceedings,* 73, pp. 530-534, https://doi.org/10.1016/j.matpr.2022.11.409

Gonzalez-Ortega R., Rajagukguk Y., Ferrentino G., Morozova K., Scampicchio M. (2023), Detection of butter adulteration with palm stearin and coconut oil by differential scanning calorimetry coupled with chemometric data analysis, *Food Control,* 157, 110165, https://doi.org/10.1016/j.foodcont.2023.110165

Goranova Z., Marudova M., Baeva M. (2019), Influence of functional ingredients on starch gelatinization in sponge cake batter, *Food Chemistry,* 297, 124997, https://doi.org/10.1016/j.foodchem.2019.124997

Hrytsevich M., Dorochovych V. (2023), Development of low-protein cookies formulations, *International Science Journal of Engineering & Agriculture*, 5, pp. 31-39, https://doi.org/10.46299/j.isjea.20230205.04

Irondi E., Imam Y., Ajani E., Alamu E. (2023), Natural and modified food hydrocolloids as gluten replacement in baked foods: Functional benefits, *Grain & Oil Science and Technology*, Available online 15 October 2023, https://doi.org/10.1016/j.gaost.2023.10.001

Itagi H., Sartagoda K., Gupta N., Pratap V., Roy P., Tiozon R., Sreenivasulu N. (2023), Enriched nutraceuticals in gluten-free whole grain rice cookies with alternative sweeteners, *LWT,* 186, 115245, https://doi.org/10.1016/j.lwt.2023.115245

Ito V., Bet C., Schnitzler E., Demiate I., Lacerda L., Soccol C. (2022), Thermal analysis of food materials, In: Pandey A. ed., *Advances in Food Engineering,* Elsevier, pp. 65-91. https://doi.org/10.1016/B978-0-323-91158-0.00007-7

Ivanov V., Shevchenko O., Marynin A., Stabnikov V., Gubenia O., Stabnikova O., Shevchenko A., Gavva O., Saliuk A. (2021),Trends and expected benefits of the breaking edge food technologies in 2021–2030, *Ukrainian Food Journal*, 10(1), pp. 7-36, https://doi.org/10.24263/2304-974X-2021-10-1-3

Kaur S., Panesar P., Chopra H. (2023), Extraction of dietary fiber from kinnow (*Citrus reticulata*) peels using sequential ultrasonic and enzymatic treatments and its application in development of cookies, *Food Bioscience,* 54, 102891, https://doi.org/10.1016/j.fbio.2023.102891

Lukinac J., Komlenić D., Čolić M., Nakov G., Jukić M. (2022), Modelling the browning of bakery products during baking: a review, *Ukrainian Food Journal,* 11(2), pp. 217-234, https://doi.org/10.24263/2304-974X-2022-11-2-3

MacDonald A. (2017), Phenylketonuria. In: MacDonald A. ed., *Reference Module in Life Sciences,* Elsevier, Birmingham, https://doi.org/10.1016/B978-0-12-809633-8.06896-5

Moreira R., Chenlo F., Arufe S. (2015), Starch transitions of different gluten free flour doughs determined by dynamic thermal mechanical analysis and differential scanning calorimetry, *Carbohydrate Polymers,* 127, pp.160-167, https://doi.org/10.1016/j.carbpol.2015.03.062

HadiNezhad M., Butler F. (2009), Effect of flour type and dough rheological properties on cookie spread measured dynamically during baking, *Journal of Cereal Science*, 49(2) pp. 178-183, https://doi.org/10.1016/j.jcs.2008.09.004

Naqash F., Gani A., Gani A., Masoodi F. (2017), Gluten-free baking: Combating the challenges – A review, *Trends in Food Science and Technology,* 66, pp. 98-107, https://doi.org/10.1016/j.tifs.2017.06.004

Naseer B., Naik H.R., Hussain S.Z., Zargar I., Beenish, Bhat T.A., Nazir N. (2021), Effect of carboxymethyl cellulose and baking conditions on in-vitro starch digestibility and physico-textural characteristics of low glycemic index gluten-free rice cookies, *LWT,* 141, 110885, https://doi.org/10.1016/j.lwt.2021.110885

Rocha J., Bausell H., Bélanger-Quintana A., Bernstein L., Gökmen-Özel H., Jung A., Heddrich-Ellerbrok M. (2021), Development of a practical dietitian road map for the nutritional management of phenylketonuria (PKU) patients on pegvaliase, *Molecular Genetics and Metabolism Reports,* 28, 100771, https://doi.org/10.1016/j.ymgmr.2021.100771

Rumińska W., Markiewicz K., Wilczewska A., Nawrocka A. (2021), Effect of oil pomaces on thermal properties of model dough and gluten network studied by thermogravimetry and differential scanning calorimetry, *Food Chemistry,* 358, 129882, https://doi.org/10.1016/j.foodchem.2021.129882

Van Wegberg, A., MacDonald A., Ahring K., Bélanger-Quintana A., Blau N., Bosch A., Van Spronsen F. (2017), The complete European guidelines on phenylketonuria: Diagnosis and treatment, *Orphanet Journal of Rare Diseases,* 12(1), 162, https://doi.org/10.1186/s13023-017-0685-2

Xu, F., Liu, W., Zhang, L., Liu, Q., Wang, F., Zhang, H., Blecker, C. (2022), Thermal, structural, rheological and morphological properties of potato starch-gluten model dough systems: Effect of degree of starch pre-gelatinization, *Food Chemistry,* 396, 133628, https://doi.org/10.1016/j.foodchem.2022.133628

Zhang X., Wang Z., Wang L., Ou X., Huang J., Luan G. (2023), Structural support of zein network to rice flour gluten-free dough: Rheological, textural and thermal properties, *Food Hydrocolloids,* 141, 108721, https://doi.org/10.1016/j.foodhyd.2023.108721

Žilić S., Kocadağli T., Vančetović J., Gökmen V. (2016), Effects of baking conditions and dough formulations on phenolic compound stability, antioxidant capacity and color of cookies made from anthocyanin-rich corn flour, *LWT,* 65, pp. 597–603, https://doi.org/10.1016/j.lwt.2015.08.057