

## Dead honey bee powder as a functional ingredient in sponge-cake technology

**Serhii Bokovets\***

PhD, Associate Professor  
Sumy National Agrarian University  
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine  
<https://orcid.org/0000-0003-0466-2426>

**Tetiana Synenko**

PhD, Associate Professor  
Sumy National Agrarian University  
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine  
<https://orcid.org/0000-0002-5300-5142>

**Tetiana Naumenko**

PhD, Associate Professor  
Sumy National Agrarian University  
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine  
<https://orcid.org/0000-0001-7884-6792>

**Dmytro Kisil**

PhD, Associate Professor  
Sumy National Agrarian University  
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine  
<https://orcid.org/0000-0003-3088-951X>

**Abstract.** The relevance of the study is associated with the growing interest in the development of food products containing unconventional raw materials and the need to determine their technological compatibility with established food formulations. In this context, the use of dead honey bee powder as a partial replacement for wheat flour represents a promising approach that requires experimental assessment of its effects on the physicochemical, rheological and structural-mechanical properties of sponge-cake products. The aim of the study was to evaluate the technological feasibility of using dead honey bee powder in sponge-cake technology and to determine a rational incorporation level. A control formulation and three experimental formulations containing 2%, 4% and 6% dead honey bee powder as a partial replacement for wheat flour were investigated. The methodology included determination of moisture content, active acidity, batter rheology and ultimate shear stress of the baked product. Moisture content was determined gravimetrically, active acidity was characterised by pH, batter rheology was assessed using a rotational viscometer at 12 regulator positions, and structural-mechanical properties were evaluated by penetration testing. Moisture content varied from 31.8 to 32.8%, whereas pH decreased from 7.1 in the control to 6.7 at 4% and 6% powder. The most pronounced changes were observed in batter viscosity and ultimate shear stress. At regulator position 5, viscosity readings were 24.96 for the control, 23.40 at 2%, 53.04 at 4%

### Article's History:

Received: 12.05.2026 Revised: 14.08.2026 Accepted: 29.09.2026 Published: 07.10.2026

### Suggested Citation:

Bokovets, S., Synenko, T., Naumenko, T., & Kisil, D. (2026). Dead honey bee powder as a functional ingredient in sponge-cake technology. *Ukrainian Black Sea Region Agrarian Science*, 30(3), 87-100. doi: 10.56407/bs.agrarian/3.2026.87.

\*Corresponding author (sergiy\_bokovec@ukr.net)



and 54.60 at 6%. Ultimate shear stress increased from 141 Pa in the control to 290, 605 and 911 Pa, respectively. Considering the available physicochemical, rheological and structural-mechanical indicators, the 2% formulation showed the most balanced technological profile. Its moisture content was identical to the control, the pH shift was small, and structural strengthening was moderate compared with the higher addition levels. The practical significance of the study is the identification of a technologically feasible level for incorporating an unconventional bee-derived raw material into a sponge-cake matrix

**Keywords:** *Apis mellifera*; protein-rich biomass; rheological properties; structural resistance; formulation optimisation; food safety

## INTRODUCTION

The development of foods with an improved nutritional profile and additional functional properties remains an important direction of contemporary food technology. Bakery and confectionery products are particularly suitable for such development because they are widely consumed, have established processing technologies and can accommodate moderate amounts of new ingredients without requiring a complete redesign of the production process. Recent reviews show that functional bakery products are commonly developed by incorporating ingredients rich in dietary fibre, proteins, minerals, phenolic compounds or other bioactive substances; however, the technological value of an ingredient cannot be assessed only from its nutritional composition because changes in viscosity, aeration, texture, colour and sensory acceptance may occur simultaneously.

O. Naumenko *et al.* (2021) analysed the use of functional ingredients in baking and emphasised that their technological value should be considered together with their influence on product quality. This approach is consistent with the design of the present study, in which the incorporation of dead honey bee powder was evaluated not only as a source of additional components but also through changes in moisture, acidity and rheological characteristics. Bee-derived materials represent one group of underutilised biological resources with potential for food applications. Honey, pollen, propolis, royal jelly, beeswax and other bee products contain diverse macro- and micronutrients and bioactive compounds, and their incorporation into foods has been investigated for nutritional enrichment, antioxidant activity, preservation and other functional effects. The majority of published food studies, however, concern conventional hive products. Considerably less attention has been paid to naturally dead honey bees as a raw material that can be stabilised, dried and processed into a powder.

M. Kieliszek *et al.* (2023) reviewed recent advances in the use of bee products in food processing and showed that their nutritional composition and functional properties support their incorporation into food

systems, while processing conditions and product quality remain important considerations. This evidence supports the broader technological rationale for investigating bee-derived raw materials in food formulations, but it does not specifically establish the suitability of naturally dead adult bees for sponge-cake production. R.P.F. Guiné *et al.* (2025) reviewed bee brood as a food for human consumption and summarised evidence on its nutritional and phytochemical composition. The review confirms the growing scientific interest in bee-derived biomass as a food resource, but the material considered in that work differs from naturally dead adult bees. Consequently, the available evidence on bee brood cannot by itself establish the technological suitability of whole dead honey bee powder in sponge-cake technology.

In the present study, the term dead honey bees refers to naturally deceased adult honey bees collected from beekeeping operations, rather than bee brood, which denotes larvae and pupae. This distinction is important because the composition and technological properties of these two materials are different. Naturally dead adult bees are more commonly investigated as a source of chitin and chitosan or as a raw material for non-food applications. Honeybee corpses have been demonstrated to contain recoverable chitin, while subsequent work has described chitosan obtained from dead bees. These studies provide a scientific basis for considering dead bee biomass as a source of technologically relevant biopolymers. Z. Draczyński (2008) investigated naturally dead honeybees as a raw material for chitin isolation and established conditions affecting chitin yield and molar mass. M.D. Lootsik *et al.* (2016) characterised honeybee chitosan and reported its heterogeneity and functional properties. J.L. Maicelo-Quintana *et al.* (2024) reviewed the potential application of bee products in the food industry and described opportunities for using bee-derived materials in food formulations. The review supports the broader technological relevance of bee products while also indicating the need for further research into specific raw materials and their processing characteristics.

From an agricultural and rural-economy perspective, naturally dead adult bees can be regarded as a recurring biological residue of beekeeping rather than only as an end-of-cycle material. Managed honey bee colonies experience mortality associated with disease, pests, pesticides, environmental stress and other factors, and therefore dead adult bees are generated as part of routine apiary management (Zapata-Hernández *et al.*, 2024). The experimental material in the present study was not quantified at the apiary level, so a regional estimate of the annual mass of dead bees cannot be reliably derived from the available data. Nevertheless, the recurring generation of this biomass creates a potential resource stream whose value can be increased through controlled collection, stabilisation and subsequent processing. Such an approach corresponds to the principles of circular bioeconomy, in which biological residues are retained in productive cycles and converted into higher-value materials instead of being treated solely as waste (Kircher *et al.*, 2023). For beekeeping farms, the conversion of appropriately selected dead-bee biomass into a stable powder therefore represents a potential route for diversification of bee-derived products and more complete utilisation of biological resources.

The possibility of converting naturally dead bees into a stable powder is also described in practical guidance prepared by the Food and Agriculture Organization. The proposed processing sequence includes collection, cleaning, drying and grinding, after which a dry powder can be obtained for further use, Animal Production and Health Division (Animal Nutrition) in FAO (2020). From a food-technology perspective, drying and grinding are particularly important because they transform a heterogeneous biological material into a more uniform ingredient that can be dosed into a formulation. At the same time, the use of such a material in food requires careful control of raw-material origin, contamination, processing conditions and storage. The Animal Production and Health Division (Animal Nutrition) in FAO (2020) describes collection, cleaning, drying and grinding as key stages for converting naturally dead bees into a stable powder. This processing concept is relevant to the present study because the whole dried biomass, rather than purified chitin or chitosan, was used as the experimental ingredient.

The structural characteristics of dead honey bee powder are also relevant to its use in a sponge-cake system. Chitin is a structural polysaccharide, and insect cuticles may contain chitin in association with proteins and melanin. Reviews of insect-derived chitin indicate that its functional properties depend strongly on the source and processing history. Dead honey bees have

been specifically investigated as a source of chitin, with reported recovery demonstrating that the exoskeletal fraction is technologically valuable, Z. Draczyński (2008). A. Khayrova *et al.* (2021) reviewed approaches to obtaining chitin, chitosan and related complexes from insect biomass and showed that the properties of these materials depend on the biological source and processing conditions. This finding is important for the present research because naturally dead honey bees were used as a whole powdered material rather than as an isolated chitin or chitosan preparation.

A sponge cake is a particularly sensitive model for evaluating a new powdered ingredient because its quality depends on the balance between foam formation, batter viscosity and structural setting during baking. The batter is an aerated multiphase system in which the egg proteins, sugar, starch and flour interact before and during heating. An ingredient that substantially increases batter viscosity can modify the stability of air cells, the mobility of the continuous phase and the final cellular structure. Studies of model sponge cakes have shown that the rheological behaviour of the batter is closely related to air retention and the subsequent development of crumb structure. M. Assad-Bustillos *et al.* (2020) showed that protein substitution changes rheological properties, air volume fraction and mechanical characteristics of sponge cakes. These studies support the combined assessment of batter rheology and structural resistance used here. I. Amoah *et al.* (2022) reviewed functional ingredients used in bread and discussed their potential links with nutritional and health-related effects. The authors also highlighted that functional enrichment should be considered in relation to the characteristics of the resulting bakery product. This supports the present approach of combining the functional rationale for using bee-derived biomass with direct technological measurements. This relationship is particularly important when an unconventional functional ingredient replaces a portion of wheat flour. The substitution changes the ratio of starch, gluten-forming proteins and non-gluten particles in the system. Functional bakery research shows that such substitutions may improve nutritional characteristics but may also impair technological and sensory properties when the addition level becomes excessive, Z. Martins *et al.* (2017). Therefore, the selection of an appropriate dosage should be based on a set of complementary indicators rather than on one parameter alone.

The available literature reveals a specific research gap. Considerable attention has been devoted to edible bee brood, conventional bee products and purified chitin or chitosan, while direct application of a whole powder obtained from naturally dead adult honey

bees in a conventional sponge-cake formulation remains insufficiently characterised. In particular, data linking the concentration of dead honey bee powder with batter viscosity and the mechanical resistance of the baked product are limited. This is important because a technically feasible formulation should maintain acceptable moisture and acidity while avoiding excessive structural hardening. The aim of this study was therefore to evaluate the technological feasibility of incorporating dead honey bee powder into a sponge-cake semi-finished product and to determine a rational incorporation level on the basis of moisture content, pH, batter viscosity and ultimate shear stress. The study also sought to relate instrumental changes to the visible appearance and crumb structure of the experimental products.

## MATERIALS AND METHODS

The experimental object was a sponge-cake semi-finished product prepared using a conventional formulation in which part of the wheat flour was replaced by powder obtained from naturally dead honey bees. Four formulations were prepared: a control without the functional ingredient and three experimental formulations containing 2%, 4% and 6% dead honey bee powder relative to the mass of wheat flour. The quantities of starch, granulated sugar and melange were kept constant across the formulations. Thus, the

experimental factor was the concentration of dead honey bee powder, while the total formulation was changed only through the corresponding reduction in wheat flour (Table 1). The raw material was represented by naturally dead adult honey bees collected from bee-keeping operations. The supplied experimental record did not include season of collection, floral/forage base, detailed colony-management conditions, or a separate physiological classification of the bees. These factors were therefore not treated as experimental variables and cannot be separated as sources of variation in the present dataset. This limitation is relevant because seasonal and physiological differences in *Apis mellifera* are associated with changes in metabolic and protein profiles (Koubová *et al.*, 2021). To improve reproducibility, the preparation procedure used in the present work was standardised at the processing stage: naturally dead adults were collected, visible foreign matter was removed, the material was dried, ground to a powder, and the dry ingredients were sieved before formulation. No chemical extraction, deproteinisation or purification of chitin or chitosan was performed. For future application at apiary level, traceability of the collection date and colony, exclusion of visibly contaminated or suspicious material, documentation of drying conditions, and controlled storage of the resulting powder should be incorporated into an internal farm standard before the material is considered for food use.

**Table 1.** Formulation of the experimental sponge-cake semi-finished products

| Raw material             | Control | 2% powder | 4% powder | 6% powder |
|--------------------------|---------|-----------|-----------|-----------|
| Wheat flour, g           | 28.00   | 27.44     | 26.88     | 26.32     |
| Potato starch, g         | 6.90    | 6.90      | 6.90      | 6.90      |
| Granulated sugar, g      | 34.70   | 34.70     | 34.70     | 34.70     |
| Melange, g               | 57.90   | 57.90     | 57.90     | 57.90     |
| Dead honey bee powder, g | -       | 0.56      | 1.12      | 1.68      |

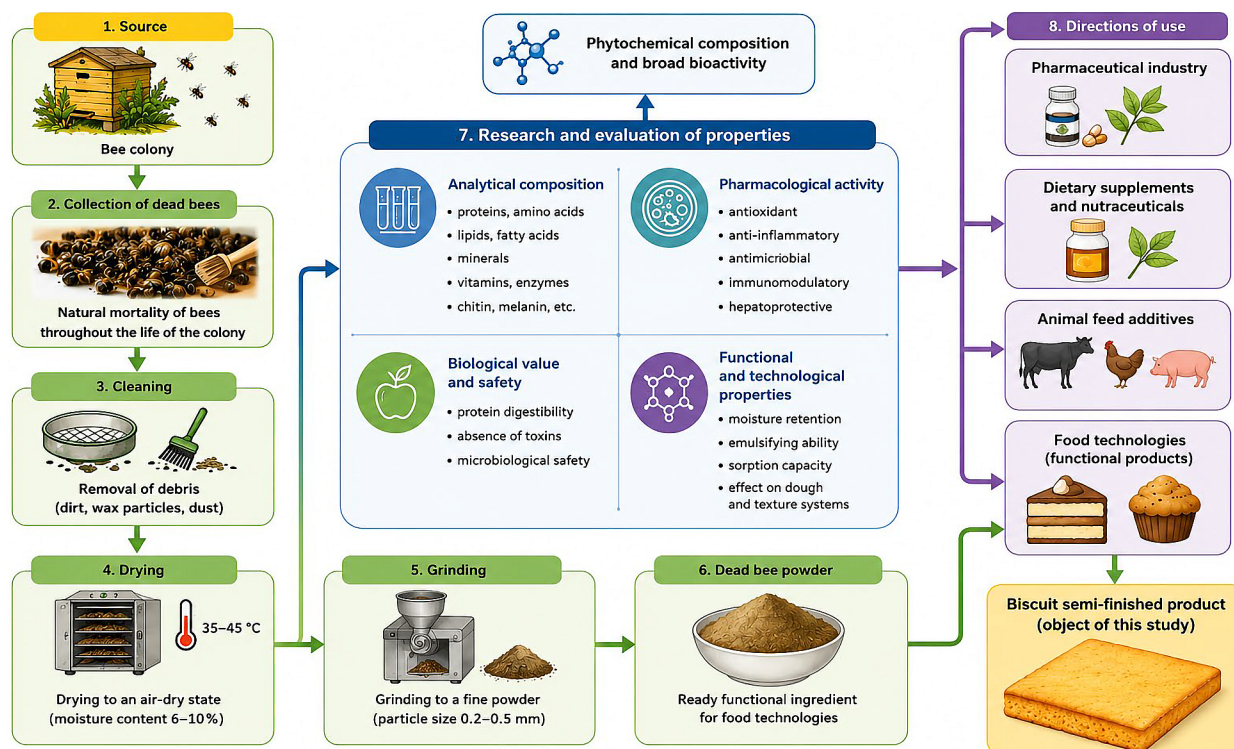
**Source:** developed by the authors

The dead honey bee powder was prepared from naturally dead adult honey bees. The material was cleaned to remove visible foreign matter, dried and ground to a powder suitable for dosing into the formulation. The experimental preparation sequence is summarised in Figure 1. The study did not involve extraction or chemical purification of chitin or chitosan; the whole dried biomass was used as the functional ingredient. This distinction is essential when interpreting the results because the technological behaviour of the whole powder cannot be equated with that of purified chitosan. Before use, the dry ingredients were sieved. Melange was conditioned at approximately 18-20 °C. Melange and sugar were whipped until the volume increased approximately 2.5-3-fold. A dry mixture of wheat flour, potato starch

and the appropriate amount of dead honey bee powder was then incorporated gradually. Mixing was performed with upward folding movements to minimise disruption of the aerated structure. The batter was transferred into moulds to approximately two-thirds of their volume. Baking was carried out at 180-200 °C for 25-35 min. After baking, the products were cooled at approximately 18-25 °C for 8-10 h before instrumental evaluation. The experimental conditions were kept identical for the control and modified formulations. This approach was selected to determine whether the addition of dead honey bee powder could be implemented within the existing sponge-cake process without changing the principal baking parameters. The resulting products were visually documented and compared with respect

to crumb colour and apparent pore structure. Photographs were taken after cooling under the same lighting and background conditions and were used for qualitative comparison of crumb colour and apparent pore

uniformity. The visual criteria were limited to overall colour tone, crumb homogeneity and visible differences in pore size; no instrumental colour measurement or quantitative image analysis was performed.



**Figure 1.** Experimental preparation sequence and incorporation of dead honey bee powder into the sponge-cake formulation

**Source:** developed by the authors based on Animal Production and Health Division (Animal Nutrition) in FAO (2020)

Moisture content was assessed gravimetrically from the change in sample mass after drying. A 5.00 g portion of each sample was used. The moisture content was calculated from the mass loss during drying. The original experimental dataset contains a single recorded value for each formulation; therefore, the present manuscript reports the measured values without calculating standard deviation or inferential statistical significance. The active acidity of the sponge-cake semi-finished products was characterised by pH. The control and experimental samples were compared under the same measurement conditions. The pH values were interpreted primarily as indicators of changes in the chemical environment of the product. No conclusions concerning microbiological stability were drawn solely from pH because microbiological safety requires dedicated microbiological testing.

The rheological behaviour of the sponge-cake batter was evaluated using a rotational viscometer at 12 regulator positions. The instrument readings obtained at each position were recorded for the control and each experimental formulation. The measurement range was

treated as an instrumental response scale because the supplied dataset does not provide a calibrated physical unit for the displayed viscosity readings. Consequently, the results are reported as instrument units rather than being converted to Pa·s or another SI unit. The upper readings of 60.84 observed at high regulator positions were interpreted as the upper limit of the available measurement range rather than as evidence of identical intrinsic viscosity. The mechanical behaviour of the baked semi-finished products was evaluated by a penetration method, with the resulting parameter expressed as ultimate shear stress in pascals. The method was used to compare the resistance of the crumb structure to deformation. Higher values indicate greater resistance of the formed structure to penetration and therefore a more mechanically rigid crumb. The supplied experimental dataset contains one value for each measured indicator and formulation. It does not include the number of independent replicates, standard deviations, standard errors or individual raw measurements. Therefore, statistical significance

testing was not performed and no artificial error bars or p-values were introduced. Percentage changes relative to the control were calculated descriptively to facilitate interpretation of the magnitude of the observed effects. This limitation is explicitly stated because a formal statistical conclusion requires independent replicates and an appropriate statistical model. Relative change compared with the control was calculated as:

$$\Delta X (\%) = [(X_i - X_c)/X_c] \times 100, \quad (1)$$

where  $X_i$  is the value for the experimental formulation and  $X_c$  is the control value. For pH, the difference from the control was reported in pH units rather than as a percentage because pH is a logarithmic measure.

## RESULTS AND DISCUSSION

The progressive replacement of wheat flour by dead honey bee powder resulted in visible changes in the appearance of the baked products. The control product had the lightest crumb and the most uniform visual structure. The 2% formulation showed a slightly darker and greener-grey crumb while retaining a comparatively uniform appearance. At 4% and 6%, the colour became

progressively darker and the crumb appeared less homogeneous, with more pronounced local differences in pore size. These observations are descriptive and are not presented as a formal sensory score because no trained sensory panel was included in the supplied dataset. The visual changes are technologically relevant because colour and crumb structure are among the parameters most frequently assessed in functional bakery research, R. Guiné & S. Florença (2024). They may result from the intrinsic colour of the dead honey bee powder and from the altered composition of the flour fraction. The appearance of the 4% and 6% products also corresponds with the instrumental evidence of stronger batter structuring. However, visual correspondence should not be interpreted as proof of a single causal mechanism because the experiment did not separately quantify pore size, density or crumb cell distribution. Moisture content varied only slightly among the formulations. The control and 2% sample both showed 32.4% moisture, the 4% sample showed 31.8%, and the 6% sample showed 32.8% (Table 2). The full range was therefore 1.0 percentage point. Relative to the control, the changes were 0.0% at 2%, -1.85% at 4% and +1.23% at 6%.

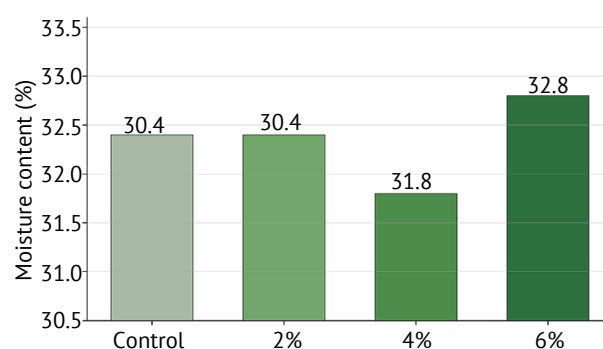
**Table 2.** Moisture content of the experimental sponge-cake semi-finished products

| Sample    | Sample mass, g | Mass after drying, g | Moisture content, % |
|-----------|----------------|----------------------|---------------------|
| Control   | 5.00           | 3.38                 | 32.4                |
| 2% powder | 5.00           | 3.38                 | 32.4                |
| 4% powder | 5.00           | 3.41                 | 31.8                |
| 6% powder | 5.00           | 3.36                 | 32.8                |

**Source:** developed by the authors

The small magnitude of the changes indicates that replacing a limited proportion of wheat flour with the tested powder did not substantially alter the final moisture level under the selected baking conditions. This is technologically useful because large changes in moisture would normally require reconsideration of the baking regime or the water balance of the formulation. The stability of the moisture content at 2% is particularly notable because the same formulation also produced only a small change in pH and a moderate increase in structural strength. The lower moisture value at 4% may reflect a change in the distribution of water between the wheat-based continuous phase and the additional solid particles introduced with the powder. At 6%, the value increased again and slightly exceeded the control. It is possible that the finely divided particles increased the amount of water retained within the crumb matrix after cooling. However, the present experiment did not measure water-holding capacity, particle-size distribution or water activity, so this explanation should be considered a plausible

technological interpretation rather than a demonstrated mechanism (Fig. 2).



**Figure 2.** Effect of dead honey bee powder concentration on moisture content of the sponge-cake semi-finished product

**Source:** developed by the authors

The result is consistent with the general principle that the incorporation of functional powders into

bakery systems may modify water distribution without necessarily producing a proportional change in final moisture. Reviews of functional bakery products emphasise that the effect depends on the chemical composition, particle size, concentration and processing history of the added ingredient, R. Guiné & S. Florença (2024). In the present case, the relatively narrow moisture range suggests that the tested concentrations can be processed under the same general baking conditions without a pronounced moisture imbalance. I. Amoah *et al.* (2022) reviewed functional ingredients in bread and emphasised that enrichment can modify several quality attributes simultaneously. This supports the present approach of considering moisture, rheology and structural resistance together.

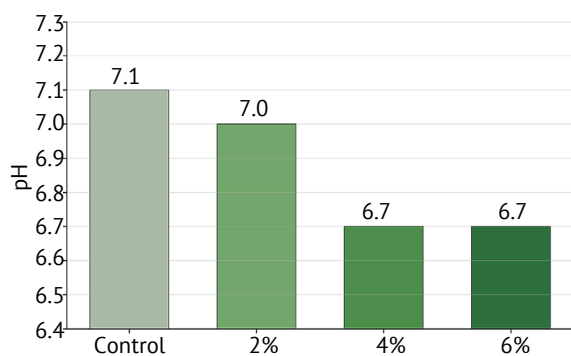
From a formulation perspective, the moisture result does not by itself identify the optimum concentration. All four samples remained close to one another, meaning that the decisive differences must be sought in rheological and mechanical behaviour. This is important because a functional ingredient can be technologically acceptable with respect to moisture while simultaneously making a sponge-cake batter excessively viscous or the final crumb excessively firm. The pH decreased from 7.1 in the control to 7.0 at 2% powder and to 6.7 at both 4 and 6% (Table 3). Thus, the maximum observed shift relative to the control was 0.4 pH units. The identical value for the 4 and 6% formulations suggests that the increase in powder concentration beyond 4% did not produce an additional measurable change in the pH under the experimental conditions.

**Table 3.** Active acidity of the experimental sponge-cake semi-finished products

| Sample    | Dead honey bee powder, % | pH  |
|-----------|--------------------------|-----|
| Control   | 0                        | 7.1 |
| 2% powder | 2                        | 7.0 |
| 4% powder | 4                        | 6.7 |
| 6% powder | 6                        | 6.7 |

**Source:** developed by the authors

The gradual shift towards a lower pH may reflect the chemical contribution of the added biomass and the altered balance of buffering components in the formulation. The result should not, however, be interpreted as evidence that the powder acts as an acidifying agent in a general sense because the experiment measured the final product pH rather than the acid-base properties of the powder itself (Fig. 3).



**Figure 3.** Effect of dead honey bee powder concentration on the pH of the sponge-cake semi-finished product

**Source:** developed by the authors

The small change at 2% is consistent with the overall technological suitability of this formulation. At 4 and 6%, the pH shift becomes more pronounced, but it remains moderate in absolute terms. Importantly, the present study does not establish a direct

relationship between the observed pH and microbial shelf life. Research on insect-derived foods demonstrates that microbial and chemical safety must be assessed independently, and that drying conditions, storage and contamination history can strongly influence safety, V. Borkovcová *et al.* (2022). Therefore, pH should be considered here as a physicochemical descriptor rather than a safety endpoint.

M. Borkovcová *et al.* (2022) evaluated foods based on bee drone brood for microbial and elemental safety and showed that nutritional and sensory potential must be considered together with contamination risks. The study supports treating pH in the present work as a physicochemical descriptor rather than as evidence of microbiological safety. Z. Ma *et al.* (2023) reviewed the protein composition, processing approaches and allergenicity of edible insect proteins and emphasised that allergenic potential should be considered when insect-derived materials are introduced into foods. Although their review does not concern dead honey bees specifically, it supports the need for dedicated allergenicity assessment of the tested bee-derived powder before its broader use as a food ingredient.

The pH results also show that the most substantial technological effects of the dead honey bee powder are not related to acidity. The difference between the control and the 2% formulation is only 0.1 pH unit, whereas the mechanical and rheological changes become much larger as the powder concentration

increases. This distinction helps identify which quality attributes are most sensitive to the addition of the functional ingredient. From a technological perspective, the small pH change at 2% indicates that this level did not substantially alter the acid-base environment of the product, whereas the larger shift at 4% and 6% should be considered together with the pronounced rheological and mechanical changes. The clearest concentration-dependent response was obtained for

batter viscosity. At the first regulator position, the control, 2% and 4% formulations all showed a reading of 6.24, whereas the 6% formulation showed 7.80. With increasing regulator position, the separation between the curves became progressively more pronounced. At position 4, the readings were 18.72 for the control, 21.06 for 2%, 27.30 for 4% and 39.00 for 6%. At position 5, the corresponding values were 24.96, 23.40, 53.04 and 54.60, respectively (Table 4).

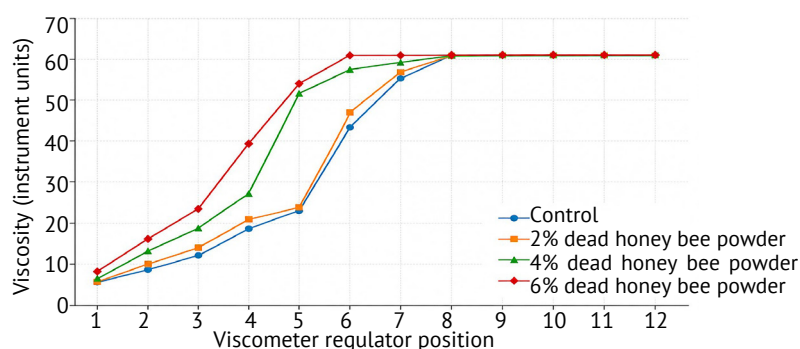
**Table 4.** Viscosity readings of sponge-cake batter at different viscometer regulator positions

| Regulator position | Control | 2%    | 4%    | 6%    |
|--------------------|---------|-------|-------|-------|
| 1                  | 6.24    | 6.24  | 6.24  | 7.80  |
| 2                  | 9.36    | 10.14 | 13.26 | 15.60 |
| 3                  | 12.48   | 14.04 | 18.72 | 22.62 |
| 4                  | 18.72   | 21.06 | 27.30 | 39.00 |
| 5                  | 24.96   | 23.40 | 53.04 | 54.60 |
| 6                  | 43.68   | 46.80 | 58.50 | 60.84 |
| 7                  | 56.16   | 57.72 | 60.84 | 60.84 |
| 8                  | 60.84   | 60.84 | 60.84 | 60.84 |
| 9                  | 60.84   | 60.84 | 60.84 | 60.84 |
| 10                 | 60.84   | 60.84 | 60.84 | 60.84 |
| 11                 | 60.84   | 60.84 | 60.84 | 60.84 |
| 12                 | 60.84   | 60.84 | 60.84 | 60.84 |

**Source:** developed by the authors

The response pattern is characterised by a pronounced increase in the apparent resistance of the 4 and 6% batters at intermediate regulator positions. The difference is particularly clear at position 5, where the 4% and 6% formulations exceeded the control by 112.5% and 118.8%, respectively, whereas the 2% formulation was 6.25% lower than the control. This result is more informative than the high-position readings because positions 8-12 reached the same value of 60.84 for all samples and therefore approached the upper limit of the instrument response. The increase in batter viscosity can be interpreted in terms of the additional solid phase introduced by the powder and its interaction with water and the other formulation

components. In a sponge-cake system, an increase in the viscosity of the continuous phase can influence the mobility of particles and the stability of air bubbles. Research with model sponge cakes has shown that modifying batter rheology can alter air retention and the resulting cellular structure, J. Bousquière *et al.* (2017), M. Assad-Bustillos *et al.* (2020). In the pea-protein study, increasing protein substitution produced a substantial increase in rheological properties and was associated with changes in the air volume fraction and cake mechanical properties, M. Assad-Bustillos *et al.* (2020). The present results show a qualitatively similar technological principle, although the composition of the added material is different (Fig. 4).



**Figure 4.** Viscosity response of sponge-cake batter as a function of viscometer regulator position and dead honey bee powder concentration

**Source:** developed by the authors

K. Dybdal-Grasberger *et al.* (2026) showed that batter properties, microstructure and baked cake structure are interconnected but that no single rheological parameter fully predicts the final structure. This agrees with the present interpretation of viscosity together with ultimate shear stress and visual observations. At 2%, the powder caused only a moderate change in the viscosity profile. This may be advantageous because the batter remains sufficiently structured to retain its aerated state without reaching the much higher resistance observed at 4% and 6%. In contrast, the sharp increase in the middle of the viscosity curve at higher concentrations indicates that the powder begins to dominate the flow behaviour of the system. Such a change may complicate mixing and mould filling and may restrict the redistribution of air cells during baking. The interpretation is supported by the photographic observations. The 2% sample retained a relatively uniform crumb appearance, whereas the 4% and 6% samples showed more heterogeneous pores and localised structural differences. The correspondence between the rheological and visual results does not prove a direct one-to-one causal relationship, but it supports the conclusion that the higher powder concentrations changed the structural state of the batter sufficiently to affect the final crumb.

The viscosity curve also demonstrates why the concentration of a functional ingredient cannot be selected solely on the basis of its potential nutritional value. A higher concentration may increase the amount of the target ingredient in the product but simultaneously shift the batter outside the desirable processing window. Recent work on functional bakery products similarly

emphasises that successful enrichment requires a balance between functional composition and technological performance, R. Guiné & S. Florença (2024). For the present formulation, the 2% level provides the most moderate rheological modification among the tested concentrations. M.E. Ronie *et al.* (2021) reviewed functional ingredients and novel approaches in bakery products and noted that formulation changes can affect both nutritional characteristics and technological quality. This reinforces the use of several complementary indicators for selecting the powder concentration.

A. Cappelli & E. Cini (2021) reviewed bakery innovations and stressed the importance of maintaining product quality when introducing new ingredients. O. Naumenko *et al.* (2021) likewise described functional ingredients as factors capable of modifying bakery-product properties. These observations are consistent with the present finding that a low addition level is technologically more balanced than higher levels. R.P.F. Guiné *et al.* (2025) emphasised that successful functional bakery products require a balance between enrichment and technological performance. The present results support this conclusion because higher powder levels increased structural resistance while producing less homogeneous crumb characteristics. The ultimate shear stress increased systematically with dead honey bee powder concentration. The control value was 141 Pa, while the 2, 4 and 6% formulations reached 290, 605 and 911 Pa, respectively (Table 5). Relative to the control, these values correspond to increases of 105.7%, 329.1% and 546.1%. The effect was therefore substantially larger than the changes observed for moisture content and pH.

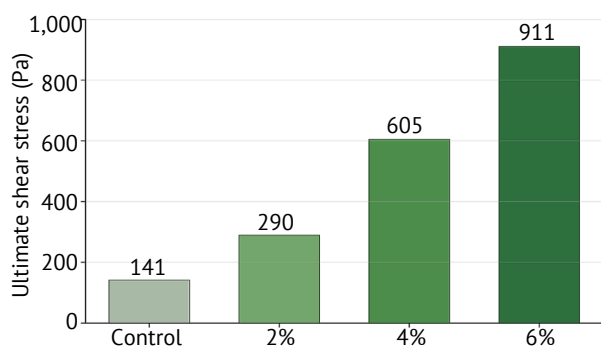
**Table 5.** Ultimate shear stress of the experimental sponge-cake semi-finished products

| Sample    | Dead honey bee powder, % | Ultimate shear stress, Pa |
|-----------|--------------------------|---------------------------|
| Control   | 0                        | 141                       |
| 2% powder | 2                        | 290                       |
| 4% powder | 4                        | 605                       |
| 6% powder | 6                        | 911                       |

**Source:** developed by the authors

The systematic increase indicates progressive strengthening of the crumb structure as the powder concentration rises. This effect can reasonably be related to the increasing proportion of non-wheat solid particles and structural biopolymers in the formulation. Dead honey bee exoskeletons contain chitin associated with proteins and pigments, and chitin-containing insect materials can contribute to the structural and sorption behaviour of composite systems. The present study did not isolate chitin from the powder and therefore cannot attribute the mechanical effect to chitin alone. Instead, the

observed increase should be interpreted as the combined effect of the whole powder and its interactions with the wheat-based matrix. A. Khayrova *et al.* (2021) reviewed insect-derived chitin and chitosan and showed that their functional properties depend on source and processing history. M. Sharaf *et al.* (2024) demonstrated technological potential of bee-derived chitosan in a specialised antimicrobial application. These studies support the relevance of chitin-containing bee biomass as a technological material, but they do not establish that chitin alone caused the mechanical changes observed here (Fig. 5).

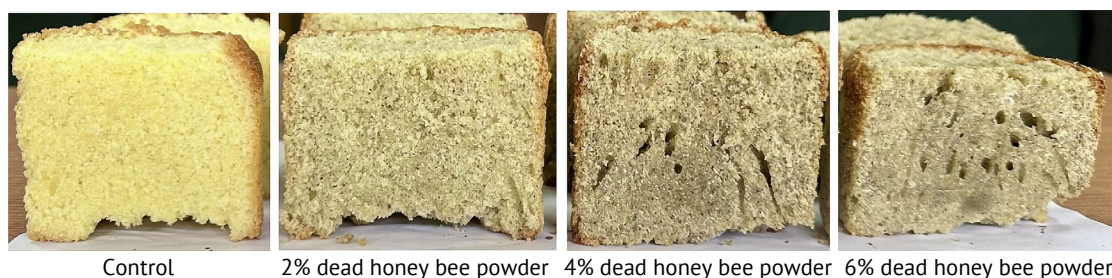


**Figure 5.** Effect of dead honey bee powder concentration on the ultimate shear stress of the sponge-cake semi-finished product

**Source:** developed by the authors

The 2% formulation produced a two-fold increase in ultimate shear stress compared with the control, but the absolute value remained substantially below those of the 4% and 6% formulations. From a technological standpoint, this moderate strengthening may be useful because it can improve structural integrity without producing the very high resistance observed at higher concentrations. In contrast, the 6% formulation produced a more than six-fold increase relative to the control, indicating a considerable change in crumb firmness (Fig. 6). The increase in mechanical resistance agrees with the rheological results obtained for the batter. The same formulations that showed the largest increase in

viscosity also showed the largest increase in ultimate shear stress. This relationship suggests that the structural modification begins at the batter stage and persists after baking. Nevertheless, it would be inappropriate to assume that batter viscosity alone determines final mechanical properties. Recent multiscale research on sponge cakes has shown that the transition from batter to baked structure involves aeration, protein aggregation, starch gelatinisation and thermal transitions, and that batter properties alone may not fully predict the final cake structure, K. Dybdal-Grasberger *et al.* (2026). Accordingly, the mechanical data should be interpreted together with the visual observations and moisture results. The 4% and 6% formulations showed greater structural resistance but also more pronounced visual heterogeneity. This suggests that increasing powder concentration beyond 2% does not simply improve the product; instead, it changes the balance between structural stability and the characteristic soft, aerated texture expected from a sponge cake. The four measured indicators provide complementary information about the effect of dead honey bee powder. Moisture content remained within a narrow range, pH changed moderately, while viscosity and ultimate shear stress responded strongly to the concentration of the added powder. This difference in sensitivity is important because it identifies the rheological and mechanical properties as the principal technological constraints for the tested ingredient (Table 6).



**Figure 6.** Cross-sectional appearance of sponge-cake semi-finished products containing different levels of dead honey bee powder

**Source:** developed by the authors

**Table 6.** Relative change in selected quality indicators compared with the control

| Indicator                                   | 2%     | 4%     | 6%      |
|---------------------------------------------|--------|--------|---------|
| Moisture content, relative change, %        | 0.0    | -1.85  | +1.23   |
| pH, change from control, units              | -0.1   | -0.4   | -0.4    |
| Viscosity at position 5, relative change, % | -6.25  | +112.5 | +118.75 |
| Ultimate shear stress, relative change, %   | +105.7 | +329.1 | +546.1  |

**Source:** developed by the authors

The established 2% dosage can also be expressed in practical raw-material terms for a beekeeping enterprise.

According to the experimental formulation, 0.56 g of dead honey bee powder replaces 0.56 g of wheat flour

in a formulation containing 28.00 g of flour. Thus, the selected level corresponds to 20 g of powder per 1 kg of wheat flour, or 2 kg per 100 kg of wheat flour. At this ratio, 1 kg of standardised powder would theoretically be sufficient for formulations containing approximately 50 kg of wheat flour. Using the proportions of the 2% experimental formulation, this amount would correspond to approximately 228.7 kg of total batter before baking, including flour, starch, sugar, melange and powder. This value represents a theoretical formulation load rather than the final baked yield because baking losses were not measured in the present study. The calculation demonstrates that even a relatively low incorporation level can provide a technically meaningful utilisation route for a recurring apiary biomass stream without requiring a major change in the basic sponge-cake formulation.

The relative changes show that the 2% formulation occupies an intermediate technological position. Its moisture content is identical to the control, the pH differs by only 0.1 unit, and the viscosity at the most informative intermediate regulator position is slightly lower than that of the control. At the same time, the ultimate shear stress is more than twice the control value, indicating that the powder has already produced a measurable strengthening effect. This combination is consistent with the concept of a moderate functional modification rather than a major restructuring of the product. The 4% formulation marks a clear transition. Moisture and pH remain within a relatively narrow range, but viscosity at position 5 more than doubles and ultimate shear stress increases more than four-fold. The 6% formulation intensifies this effect further. Because the moisture and pH do not change proportionally to the mechanical parameters, the higher concentration primarily affects the structural state of the system rather than its overall moisture balance or acidity.

The visual evidence provides additional context. The control had a light and relatively uniform crumb, the 2% sample retained a comparatively homogeneous structure with a darker tone, and the 4 and 6% samples showed stronger colour changes and more visible heterogeneity. Functional bakery research indicates that colour and texture are among the most commonly evaluated quality attributes because they strongly influence product acceptance, R. Guiné & S. Florença (2024). In the present study, the photographs are therefore useful as qualitative evidence, but they cannot replace instrumental colour analysis or a formal sensory panel. Because no calibrated image-analysis procedure was applied, these observations should be interpreted only as qualitative evidence of structural change rather than as quantitative porosity measurements.

The selection of 2% as the rational level should consequently be understood as a technological conclusion within the tested experimental range, not as a universal recommended intake level. The study demonstrates that 2% provides the most balanced combination of the measured parameters while 4% and 6% produce progressively stronger structural effects. A different base formulation, particle size, drying regime or baking schedule could shift the optimum concentration. Further work should therefore test the same powder under controlled particle-size conditions and with independent experimental replicates.

The agricultural origin of the raw material also introduces a source of biological variability that should be considered when scaling the technology. Honey bees show seasonal changes in physiology and biochemical composition, and differences between summer and winter workers have been documented at the metabolic and proteomic levels (Koubová *et al.*, 2021). Consequently, the composition of a dead-bee powder may depend not only on the proportion of adults collected but also on the season, age structure, colony condition, forage environment and circumstances preceding mortality. These factors were not experimentally separated in the present work; therefore, the observed rheological and structural responses should be attributed to the tested powder batch rather than generalised to all dead-bee biomass. Future studies should compare standardised batches collected in different seasons and from defined apiary conditions. Such work would make it possible to determine whether the 2% technological level remains stable across raw-material batches and would provide the evidence required for a practical internal standard for collection and primary preparation.

## CONCLUSIONS

The study demonstrated the technological feasibility of incorporating powdered naturally dead honey bees into a sponge-cake semi-finished product at levels of 2%, 4% and 6% relative to wheat flour. The modification had only a limited effect on moisture content, which remained within 31.8–32.8%, and produced a moderate decrease in pH from 7.1 in the control to 6.7 at the two highest addition levels. The strongest concentration-dependent response was observed in the rheological and structural-mechanical properties. Increasing the powder level markedly increased batter viscosity at intermediate viscometer positions and increased ultimate shear stress from 141 Pa in the control to 290, 605 and 911 Pa at 2%, 4% and 6%, respectively. The visual examination of the products supported the instrumental findings by showing progressive darkening and greater crumb heterogeneity at higher addition

levels. Within the investigated range, 2% dead honey bee powder provided the most balanced technological profile. At this level, moisture content was identical to the control, the pH shift was minimal and the increase in structural resistance was moderate compared with the substantially stronger changes at 4% and 6%. Therefore, 2% can be considered a rational concentration for further technological development of the tested formulation. From an agricultural perspective, the 2% level corresponds to 20 g of standardised powder per kilogram of wheat flour and therefore provides a realistic basis for incorporating a recurring apiary biomass stream into a value-added food formulation. The approach may support diversification of bee-derived products and more complete utilisation of beekeeping resources, but implementation should be preceded by traceable collection, primary processing and safety control. An internal apiary standard covering collection records, exclusion criteria, cleaning, drying, grinding, storage and batch identification is therefore proposed as a practical prerequisite for further development.

The findings should be interpreted as a technological proof of concept rather than evidence of a health claim or confirmed food-safety status. Further studies should include independent replicate measurements with statistical analysis, detailed chemical

characterisation of the powder and finished product, sensory evaluation, instrumental texture and colour measurements, microbiological and contaminant assessment, allergenicity evaluation and storage-stability studies. These investigations will be necessary to establish whether dead honey bee powder can be developed into a safe and reproducible functional ingredient for bakery products. The final assessment of suitability for food use also requires microbiological and contaminant testing, allergenicity evaluation and storage-stability studies of the powder and finished product.

## ACKNOWLEDGEMENTS

None.

## FUNDING

This study was conducted within the research project "Integrated Assessment of the Impact of War-Related Activities on the Production of Safe Bee Products" (State Registration No. 0126U000483), funded by the State Budget of Ukraine in accordance with Order No. 22 of the Ministry of Education and Science of Ukraine dated 9 January 2026.

## CONFLICT OF INTEREST

None.

## REFERENCES

- [1] Amoah, I., Cairncross, C., Ofori Osei, E., Yeboah, J.A., Cobbinah, J.C., & Rush, E. (2022). Bioactive properties of bread formulated with plant-based functional ingredients before consumption and possible links with health outcomes after consumption – a review. *Plant Foods for Human Nutrition*, 77, 329-339. doi: 10.1007/s11130-022-00993-0.
- [2] Animal Production and Health Division (Animal Nutrition) in FAO. (2020). *How to make added value products with dead bees*. Retrieved from <https://www.fao.org/family-farming/detail/en/c/1616055/>.
- [3] Assad-Bustillos, M., Jonchère, C., Garnier, C., Réguerre, A.L., & Della Valle, G. (2020). Rheological and microstructural characterization of batters and sponge cakes fortified with pea proteins. *Food Hydrocolloids*, 101, article number 105553. doi: 10.1016/j.foodhyd.2019.105553.
- [4] Borkovcová, M., Mlček, J., Adámková, A., Adámek, M., Bednářová, M., Musilová, Z., & Ševčíková, V. (2022). Use of foods based on bee drone brood: Their sensory and microbiological evaluation and mineral composition. *Sustainability*, 14(5), article number 2814. doi: 10.3390/su14052814.
- [5] Bousquière, J., Michon, C., & Bonazzi, C. (2017). Functional properties of cellulose derivatives to tailor a model sponge cake using rheology and cellular structure analysis. *Food Hydrocolloids*, 70, 304-312. doi: 10.1016/j.foodhyd.2017.04.010.
- [6] Cappelli, A., & Cini, E. (2021). Challenges and opportunities in wheat flour, pasta, bread, and bakery product production chains: A systematic review of innovations and improvement strategies to increase sustainability, productivity, and product quality. *Sustainability*, 13(5), article number 2608. doi: 10.3390/su13052608.
- [7] Draczyński, Z. (2008). Honeybee corpses as an available source of chitin. *Journal of Applied Polymer Science*, 109(3), 1974-1981. doi: 10.1002/app.28356.
- [8] Dybdal-Grasberger, K., Laursen, N.F., Li, R., Gregersen, S.B., Mokso, R., Christensen, C.H., & Corredig, M. (2026). A multiscale approach linking batter properties to baked cake structure in sponge cakes. *Food Structure*, 48, article number 100522. doi: 10.1016/j.foostr.2026.100522.
- [9] Guiné, R.P.F., & Florença, S.G. (2024). Development and characterisation of functional bakery products. *Physchem*, 4(3), 234-257. doi: 10.3390/physchem4030017.

- [10] Guiné, R.P.F., Florença, S.G., Barroca, M.J., & Costa, C.A. (2025). Bee brood as a food for human consumption: An integrative review of phytochemical and nutritional composition. *Insects*, 16(8), article number 796. doi: [10.3390/insects16080796](https://doi.org/10.3390/insects16080796).
- [11] Khayrova, A., Lopatin, S., & Varlamov, V. (2021). Obtaining chitin, chitosan and their melanin complexes from insects. *International Journal of Biological Macromolecules*, 167, 1319-1328. doi: [10.1016/j.ijbiomac.2020.11.086](https://doi.org/10.1016/j.ijbiomac.2020.11.086).
- [12] Kieliszek, M., Piwowarek, K., Kot, A.M., Wojtczuk, M., Roszko, M., Bryła, M., & Trajkovska Petkoska, A. (2023). Recent advances and opportunities related to the use of bee products in food processing. *Food Science & Nutrition*, 11(8), 4372-4397. doi: [10.1002/fsn3.3411](https://doi.org/10.1002/fsn3.3411).
- [13] Kircher, M., et al. (2023). Treatment and valorization of bio-waste in the EU. *EFB Bioeconomy Journal*, 3, article number 100051. doi: [10.1016/j.bioeco.2023.100051](https://doi.org/10.1016/j.bioeco.2023.100051).
- [14] Koubová, J., Sábová, M., Brejcha, M., Kodrlik, D., & Čapková Frydrychová, R. (2021). Seasonality in telomerase activity in relation to cell size, DNA replication, and nutrients in the fat body of *Apis mellifera*. *Scientific Reports*, 11, article number 592. doi: [10.1038/s41598-020-79912-9](https://doi.org/10.1038/s41598-020-79912-9).
- [15] Lootsik, M.D., Bilyy, R.O., Lutsyk, M.M., Manko, N.O., Navytka, S.A., Kutsiaba, V.I., & Stoika, R.S. (2016). Honeybee (*Apis mellifera*) chitosan: Purification, heterogeneity and hemocoagulating activity. *Biotechnologia Acta*, 9(6), 39-49. doi: [10.15407/biotech9.06.039](https://doi.org/10.15407/biotech9.06.039).
- [16] Ma, Z., Mondor, M., Goycoolea Valencia, F., & Hernández-Álvarez, A.J. (2023). Current state of insect proteins: Extraction technologies, bioactive peptides and allergenicity of edible insect proteins. *Food & Function*, 14(18), 8129-8156. doi: [10.1039/D3FO02865H](https://doi.org/10.1039/D3FO02865H).
- [17] Maicelo-Quintana, J.L., Reyna-Gonzales, K., Balcázar-Zumaeta, C.R., Auquiñivin-Silva, E.A., Castro-Alayo, E.M., Medina-Mendoza, M., Cayo-Colca, I.S., Maldonado-Ramirez, I., & Silva-Zuta, M.Z. (2024). Potential application of bee products in food industry: An exploratory review. *Heliyon*, 10(1), article number e24056. doi: [10.1016/j.heliyon.2024.e24056](https://doi.org/10.1016/j.heliyon.2024.e24056).
- [18] Martins, Z.E., Pinho, O., & Ferreira, I.M.P.L.V.O. (2017). Food industry by-products used as functional ingredients of bakery products. *Trends in Food Science & Technology*, 67, 106-128. doi: [10.1016/j.tifs.2017.07.003](https://doi.org/10.1016/j.tifs.2017.07.003).
- [19] Naumenko, O., Polonska, T., & Hetman, I. (2021). Functional ingredients in baking. *Food Resources*, 9(16), 135-143. doi: [10.31073/foodresources2021-16-13](https://doi.org/10.31073/foodresources2021-16-13).
- [20] Ronie, M.E., Zainol, M.K., & Mamat, H. (2021). A review on the recent applications of gluten-free flour, functional ingredients and novel technologies approach in the development of gluten-free bakery products. *Food Research*, 5(5), 43-54. doi: [10.26656/fr.2017.5\(5\).721](https://doi.org/10.26656/fr.2017.5(5).721).
- [21] Sharaf, M., et al. (2024). Bee chitosan nanoparticles loaded with apitoxin as a novel approach to eradication of common human bacterial, fungal pathogens and treating cancer. *Frontiers in Microbiology*, 15, article number 1345478. doi: [10.3389/fmicb.2024.1345478](https://doi.org/10.3389/fmicb.2024.1345478).
- [22] Zapata-Hernández, G., Gajardo-Rojas, M., Calderón-Seguel, M., Muñoz, A.A., Yáñez, K.P., Requier, F., Fontúrbel, F.E., Ormeño-Arriagada, P.I., & Arrieta, H. (2024). Advances and knowledge gaps on climate change impacts on honey bees and beekeeping: A systematic review. *Global Change Biology*, 30(3), article number e17219. doi: [10.1111/gcb.17219](https://doi.org/10.1111/gcb.17219).

## **Бджолиний підмор як функціональний інгредієнт у технології бісквітного напівфабрикату**

### **Сергій Боковець**

Доктор філософії, доцент  
Сумський національний аграрний університет  
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна  
<https://orcid.org/0000-0003-0466-2426>

### **Тетяна Синенко**

Доктор філософії, доцент  
Сумський національний аграрний університет  
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна  
<https://orcid.org/0000-0002-5300-5142>

### **Тетяна Науменко**

Доктор філософії, доцент  
Сумський національний аграрний університет  
440021, вул. Герасима Кондратьєва, 160, м. Суми, Україна  
<https://orcid.org/0000-0001-7884-6792>

### **Дмитро Кісіль**

Доктор філософії, доцент  
Сумський національний аграрний університет  
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна  
<https://orcid.org/0000-0003-3088-951X>

**Анотація.** Актуальність дослідження зумовлена зростанням інтересу до розроблення харчових продуктів із використанням нетрадиційної сировини та необхідністю визначення її технологічної сумісності з усталеними рецептурними композиціями. У цьому контексті використання порошку з мертвих медоносних бджіл як часткового заміника пшеничного борошна є перспективним напрямом, що потребує експериментальної оцінки його впливу на фізико-хімічні, реологічні та структурно-механічні властивості бісквітних виробів. Мета дослідження полягала в тому, щоб оцінити технологічну доцільність використання порошку бджолиного підмору у технології бісквітного напівфабрикату та визначити раціональний рівень його внесення. Досліджено контрольний зразок і три зразки з частковою заміною пшеничного борошна порошком бджолиного підмору у кількості 2, 4 і 6 % від маси борошна. Методика передбачала визначення масової частки вологи, активної кислотності, реологічних властивостей тіста та граничного напруження зсуву готового виробу. Масову частку вологи визначали гравіметрично, активну кислотність характеризували значенням рН, реологічні властивості оцінювали за показами ротаційного віскозиметра у 12 положеннях регулятора, а структурно-механічні властивості – пенетраційним методом. Встановлено, що вологість зразків змінювалася у межах 31,8-32,8 %, а рН – від 7,1 у контролі до 6,7 за внесення 4 і 6 % добавки. Найбільш виражені зміни спостерігалися для в'язкості тіста та граничного напруження зсуву. За п'ятого положення регулятора значення в'язкості становили 24,96 у контролі, 23,40 за 2 %, 53,04 за 4 % та 54,60 за 6 %. Граничне напруження зсуву зросло від 141 Па у контролі до 290, 605 і 911 Па відповідно. За сукупністю доступних показників найбільш збалансованим виявився зразок із 2 % порошку підмору. Практичне значення полягає у встановленні технологічно придатного рівня внесення нетрадиційної апісировини у бісквітну систему

**Ключові слова:** *Apis mellifera*; білковмісна біомаса; реологічні властивості; структурна стійкість; оптимізація рецептури; безпечність харчових продуктів