Tomato powder as natural colorant and lycopene source in toast bread

Olena Bilyk, Anastasiia Kukhar,
Artem Zabroda, Liudmyla Burchenko

National University of Food Technologies, Kyiv, Ukraine

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Corresponding author:

Olena Bilyk
E-mail:
bilyklena@gmail.com

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Abstract

Introduction. Toast bread is among the most widely consumed bakery products. This study aimed to justify the incorporation of tomato powder into toast bread formulations to expand the range of colored bakery products and enhance their nutritional value.

Materials and methods. Tomato powder was incorporated into toast bread formulations. The baked products were evaluated using sensory and physicochemical indicators, followed by calculation of a composite quality index. Dough structural and rheological properties were assessed using a Brabender farinograph and alveograph, along with monitoring dough diameter changes during proofing. Gas-producing capacity was determined volumetrically and by measuring dough ball floating velocity, while product color parameters were measured using a colorimeter.

Results and discussion. The feasibility of incorporating tomato powder into toast bread technology was substantiated. It was established that the addition of 5% powder (based on flour weight) ensured stable technological properties of the dough and enhanced the nutritional value of the final products without impairing their sensory characteristics. Alveograph and farinograph analyses demonstrated an increase in dough stability from 7.5 to 14.0 min and a reduction in softening from 110 to 50 BU, while maintaining an appropriate balance between dough elasticity and extensibility. The addition of tomato powder contributed to more controlled fermentation behavior: total gas production decreased from 616 to 588 ml CO_2/100 g, and the gas production peak shifted to a later stage, indicating improved gas retention capacity of the dough matrix. Pre-hydrated tomato powder further improved the quality attributes of the baked products: crumb porosity increased to 82%, crumb crumbliness after 72 h decreased from 11.3 to 9.2%, loaf shape stability was preserved, and sensory scores ranged from 8.2 to 8.5 points, confirming good consumer acceptability. The color difference (ΔE^*) reached 15.29 for the crust and 17.33 for the crumb, confirming the effectiveness of tomato powder as a natural colorant and functional ingredient, attributable to its high carotenoid content, particularly lycopene, and its contribution to the development of visually attractive bakery products.

Conclusions. The use of steamed tomato powder positively influences the quality of toast bread and ensures diversification of the assortment of colored bakery products enriched with antioxidants. Tomato powder can be considered a promising natural ingredient for the development of functional bakery products with improved nutritional and sensory properties.

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Introduction

Toast bread is one of the most popular bakery products intended for mass consumption due to its stable demand, convenience of use and regular presence in the daily diet. It is consumed by people of different ages and social groups, in particular as a component of breakfast or as an element of fast meals. This determines the significant role of toast bread in providing the body with energy and basic nutrients. However, the traditional formulation of toast bread is primarily oriented towards energy value and is characterised by an insufficient content of biologically active compounds, which creates prerequisites for its improvement (Falsafi et al., 2025).

The use of natural dyes in colored bakery products enhances their visual appeal while also supplying bioactive compounds such as anthocyanins, polyphenolic pigments, chlorophyll, and β-carotene. Natural colorants including elderberry pomace powder, blackthorn and hawthorn fruit extracts, purple sweet potato, and black carrot concentrate have been tested in bakery and dairy products (Stabnikova et al., 2003; 2025). In addition, barberry fruit powder has been applied as natural dye in caramel production (Sema et al., 2025), while chokeberry and hibiscus extracts have been incorporated into marshmallow formulations (Artamonova et al., 2025). This approach enables the preservation of traditional sensory properties while increasing nutritional value, thereby contributing to the development of a healthy eating culture and meeting the modern demand for original, nutritious, and aesthetically appealing products (Çolak and Karaduman, 2025). Moreover, it addresses consumer demand for bakery products manufactured without the use of synthetic food dyes (Boiko and Bilyk, 2025).

In modern food production, considerable attention is paid to the use of natural functional ingredients, particularly vegetable and fruit powders, in bakery and confectionery technologies. The chemical composition of vegetable and fruit powders is a key factor that determines their functional effects in bakery products (Naknaen and Angsombat, 2016). Tomatoes and other fruits processed into powders contain natural sugars (glucose, fructose, sucrose), organic acids (citric, malic), dietary fibre and pectin, as well as various polyphenols and carotenoids (including lycopene and β-carotene) (Lau and Shafie, 2021). Owing to this combination of bioactive compounds, vegetable powders modify dough texture: dietary fibre and pectin increase water-binding capacity and make the dough more viscous; organic acids reduce pH, stimulate yeast activity and improve crumb porosity. Polyphenols and carotenoids act as natural pigments, providing products with vivid colour, while their antioxidant activity protects lipid components from oxidation and extends shelf life (Djeghim and Zidoune, 2021). Powders also enrich the final product with vitamins (C, A) and minerals, increasing its nutritional value and technological performance during baking (Salanță and Fărcaş, 2024).

The introduction of vegetable powders such as carrot and pumpkin into bakery products significantly influences the technological properties of dough and the quality of the final product. In particular, the use of black carrot powder enriches bread with polyphenols, improves colour and increases antioxidant activity, which enhances the sensory characteristics of the product (Pandey et al., 2024). Pumpkin powder, due to its high content of dietary fibre and β-carotene, improves dough structure, increases loaf volume and imparts a pleasant colour and flavour to bread (Rakcejeva et al., 2011). Partial substitution of wheat flour (5–15%) with pumpkin cellulose resulted in a 1.1–1.4-fold increase in protein content and a 1.4–2.2-fold increase in dietary fiber compared with the control bread (Stabnikova et al., 2023). Replacement of wheat flour, 5%, with rosehip flour improved dough stabilithy, decrease baking loss and had a positive influence on bread aroma (Chochkov et al., 2022). Incorporation of 10% flour obtained from extruded sunflower seed kernels into muffin

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formulations increased the protein, fat, fiber, and ash contents by 24.7%, 16.9%, 23.3%, and 16.9%, respectively, while reducing total carbohydrates and sugars by 5.2% and 16.2%, respectively. The enriched muffins also exhibited improved textural properties, characterized by a smooth, crack-free surface and a soft, elastic crumb with well-developed porosity and small, and uniformly distributed thin-walled pores (Tsykhanovska et al., 2024).

The use of tomato powder in bread technology improves the rheological properties of dough, reduces stickiness and increases elasticity, which contributes to better shaping of the products. In addition, tomato powder is a rich source of lycopene, a potent antioxidant that reduces oxidative processes in dough and prolongs the shelf life of the final product (Eslami and Ferrari, 2022). Compared with other powders, such as beetroot or carrot powder, tomato powder gives products a more intense colour and improves their sensory characteristics without the need to add synthetic colourants or flavourings (Chabi and Kayodé, 2024; Mehta and Yadav, 2018). This makes it an attractive ingredient for consumers seeking natural and functional products.

The intense colour of bread with tomato powder is positively perceived by consumers; sensory studies showed that such samples received higher scores for crust attractiveness and appetising crumb appearance. In products with 3–5 % tomato powder, most tasting panel participants (approximately 70 %) noted that the new crust colour was vivid and conveyed a "fresh" impression without the need for additional colourants. At the same time, excessively high concentrations (8 % or more) produced an overly dark crust that slightly reduced overall acceptability; however, sensory tests demonstrated that most consumers still preferred the moderate darkening and distinct contrast between crumb and crust (Galvão et al., 2018).

The addition of dried tomato pomace significantly changes the indicators of water absorption capacity of dough and its structure. The addition of 6 % tomato pomace to flour mass increases the water absorption capacity of dough and finished bread, as well as increases titratable acidity due to the presence of organic acids in the powder (Amero and Collar, 1996). In this case, the specific volume of bread decreases by approximately 8 % compared to the control sample without additives, and crumb porosity decreases by 12 % due to the strengthening of the crumb framework by tomato pomace fibres. In addition, the increase in acidity and the presence of soluble compounds from tomato powder moisten the dough, prolonging proofing time by 10–15 %. The introduction of 3 % tomato powder into flour mass increases the water absorption capacity of flour by 5–7 % compared to the control sample, as dietary fibres adsorb more moisture and a denser gluten network is formed (Brighina and Restuccia, 2024). Despite the decrease in overall elasticity due to the strengthening of the gluten framework, a more stable bond between tomato powder fibres and gluten is formed, which ensures better dough stability during deformation in the moulding stage (Guimarães et al., 2025).

The use of tomato powder as a colouring raw material and a source of lycopene in bakery technology is economically justified due to the low cost of the starting material. Tomato pomace, from which tomato powder is produced, is a by-product of tomato paste and juice production and costs 20–30 % less than purchased tomato extract. The inclusion of tomato powder in toast bread technology does not require significant changes: standard equipment and conventional dosing systems can be used to ensure uniform distribution in flour blends (Arias et al., 2025).

The use of tomato powder allows replacement of waste from tomato processing in bakery technologies due to increased water absorption capacity of dough and improved crumb porosity. The growing demand for products with natural functional ingredients makes tomato powder an economically attractive innovation for industrial applications in the baking sector due to its low cost. Thus, tomato powder not only improves the colour and sensory

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profile of products, but also enables manufacturers to implement strategies for sustainable production, reducing waste and use of raw materials and minimising environmental impact (Chabi et al., 2024).

Therefore, the assessment of the feasibility of using tomato powder as a raw material with colouring capacity will ensure the expansion of the assortment of coloured toast bread products with increased nutritional value.

Materials and methods

Materials

Dough samples were prepared according to the formulation, % to flour mass: wheat flour of top grade – 100.0; compressed bakery yeast – 5.0; salt – 1.5; margarine with a fat content of 82 % – 5.0; granulated sugar – 8.0; skimmed milk powder – 2.0.

Preparation of dough samples

Dough was kneaded using a straight dough method with moisture content of 44.0 %. Dough fermentation lasted 20 minutes. Dough was kneaded again using the straight dough method, with fermentation time of 15 minutes. Dough kneading was performed in a two-speed dough mixer Escher (Italy), with kneading duration of 2 minutes at the first speed and 10 minutes at the second speed. Dough pieces weighing 0.275 kg were shaped as elongated rolls and placed in baking tins. Proofing was carried out in a proofing cabinet at a temperature of 35–40 ºC for 45 minutes. Baking was performed without lids in Sveba-Dahlen (Italy) ovens at a temperature of 180–200 ºC for 10–15 minutes. Tomato powder of TM "Pryanyi Svit" was used in the study. According to the manufacturer's data, the chemical composition of the tomato powder is as follows: moisture content – 4.5%, protein content – 12.9%, fat content – 0.43%, carbohydrate content – 74.7%, dietary fiber – 16.5%, ash content, % – 8.9%, calcium – 161 mg/100 g, magnesium – 176 mg/100 g, phosphorus – 296 mg/100 g, potassium – 1931 mg/100 g, iron – 4.65 mg/100 g, vitamin C – 115.0 mg/100 g, tocopherol (vitamin E) – 12.0 mg/100 g, lycopene – 46.260 mg/100 g.

Methods

Specific volume of bread

The grain is filled with the excess, which is raked with the edge of the ruler into the receiving container and removed through the hole. After that, the curtains of the main capacity with grain are opened manually and put through the hole into the bucket. This grain is used for determination. A small amount of grain is put into the main container, bread is put on it, carefully, without passing the grain, and the rest of grain is put in excess of the capacity. Grain is raked with the edge of the ruler and put into the receiving container, and then, after opening the latch – into the measuring cylinder. The volume of grain in a cylinder (ml) is equal to the volume of bread. Measurements are performed twice, deviations between parallel determinations should not exceed 5%.

The specific volume of bread is determined by dividing the volume of bread by its weight and expressed to the nearest 0.01 ml/g (Zhu et al., 2016).

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Porosity of bread

The porosity of bread reflects the volume of the pores in a certain volume of the crumb, expressed as a %age to the total volume (Verheyen et al., 2015).

Comprehensive quality index

The evaluation of finished products was carried out according to sensory and physico-chemical quality indicators of bakery products, and a comprehensive quality index was calculated. The comprehensive quality index represents the total score obtained by the test sample during its assessment. For its calculation, each product was evaluated according to the following indicators: shape accuracy; specific volume; crust colour; crust surface condition; crumb colour; crumb porosity structure; crumb rheological properties; staling after 72 hours; bread aroma; bread taste, and crumb chewability.

The obtained values were evaluated using a five-point scale, taking into account the weighting coefficient determined for each indicator by expert assessment. The assigned score was multiplied by the weighting coefficient, after which the sum of the resulting values was calculated. The higher the total score obtained by the sample, the better its quality indicators (Lebedenko et al., 2014). The expert commission included five candidates of technical sciences, one Doctor of Philosophy, two PhD candidates and twelve higher education students specialising in Food Technologies.

Determination of structural and mechanical properties of dough

The influence of tomato powder on the structural and rheological properties of the dough was assessed using a Brabender farinograph (Germany) and a Chopin alveograph (Drobot et al., 2015)

Falling number. The method is based on measuring the time (in seconds) during which a metal stirrer falls through a gelatinised mixture formed from water and flour (or cereal grain flour), preheated to boiling in a glass test tube (Lebedenko et al., 2014).

Gas production. Gas production capacity was determined volumetrically using an AG-1M device according to the standard methodology (Blazhenko and Falendysh, 2024)

Dough expansion. Dough expansion during fermentation was determined by changes in dough ball diameter at a temperature of 30 °C in a thermostat (Makhynko, 2021).

Dough rising capacity. Dough rising capacity was determined by measuring the duration of dough ball flotation in water at 35–30 °C in a thermostat (Drobot, 2015).

Crust and crumb colour. Colour measurements were performed according to the methodology described by the authors (Coelho and Salas-Mellado, 2015) a chroma meter CR-200 (Minolta, Osaka, Japan) with a Hunter Lab system was used. Lightness (L*) represents sample lightness with values from 0 (black) to 100 (white). The psychometric tone a* characterises red (+a*) to green (–a*) shades, while the psychometric tone b* characterises yellow (+b*) to blue (–b*) shades. The a* and b* values are obtained after instrument calibration. The overall colour difference ΔE describes the total colour difference and is calculated according to formula:

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$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2},$$

where L_0^*, a_0^*, b_0^* are the values for the control sample, and L^*, a^*, b^*– are the values for the test sample. Each parameter was measured at five points, and the mean value was used for calculations.

Statistical analysis

The experiments were carried out in five replicates, and the results were reported as arithmetic means.

Results and discussions

Selection of optimal tomato powder dosage for toast bread formulation

The initial studies concerned the feasibility of using tomato powder in toast bread technology. For this purpose, laboratory baking trials were carried out. Dough was prepared using the straight dough method according to the toast bread formulation (this sample served as the control). Tomato powder was added in dosages of 1.0; 2.0; 3.0; 4.0; 5.0; 6.0 and 7.0% to flour mass. Bread quality was evaluated according to physico-chemical, sensory indicators and the comprehensive quality index. The results are presented in Table 1 and in Figure 1.

Analysis of physico-chemical indicators (Table 1) demonstrated that the introduction of tomato powder within the range of 1.0–5.0% did not impair specific volume. At a dosage of 5.0%, its value increased to 408 ml/100 g compared with the control sample (394 ml/100 g), which may be attributed to the positive effect of dietary fibres and pectic substances from tomato powder on the gas-holding capacity of dough. Further dosage increase to 6.0–7.0% did not provide any significant improvement of this indicator.

It was established that at tomato powder dosages of 1.0–3.0%, crumb porosity characteristics approached the control sample, although pores were less homogeneous and insufficiently compacted for toast bread requirements. The most optimal fine-porosity characteristics were formed at 4.0–5.0 %: the crumb was dense with fine and medium pores evenly distributed throughout the entire volume. With an increase in dosage to 6.0–7.0%, excessive crumb compaction and disruption of porosity uniformity were observed. Despite the quantitative increase in porosity index, qualitative structural characteristics deteriorated, negatively affecting rheological properties, chewability and overall consumer perception.

Investigation of crumb staling after 72 h of storage revealed a progressive decrease in staling intensity with increasing levels of tomato powder. The most pronounced effect was observed at a 5.0% addition level, indicating delayed crumb firming and enhanced moisture-retention capacity. Further increases in tomato powder content did not result in significant additional improvements.

Sensory evaluation demonstrated that at tomato powder dosages up to 5.0% inclusive, acceptable crust and crumb colour, correct shape and surface condition were maintained. Starting from 6.0–7.0%, crumb colour became excessively dark and taste and aroma exhibited dominant tomato notes, which are undesirable for toast bread with a standard consumer profile.

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Table 1

Effect of tomato powder on dough quality and physico-chemical quality characteristics of bread

Quality indicator of toast bread	**Control**	**Tomato powder dosage, % to flour**						
		1.0	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**
Specific volume, ml per 100 g of bread	394	396	392	394	396	396	398	408
Shape accuracy	Bread with dome-shaped crust							
Porosity, %	82	82	86	87	89	90	94	95
Staling after 72 h, %	11.3	10.9	10.5	10.1	9.7	9.1	8.7	8.2
Crust colour	Light brown				Brown		Dark brown	
Crust surface condition	Smooth, without bubbles or cracks, glossy							
Crumb colour	Light	Light brown to brown, acceptable for perception					Dark colour	Too dark, less acceptable
Crumb porosity structure	Small, thin-walled pores, evenly distributed throughout the crumb, typical for toast bread baked without a lid						Medium and small pores, thick-walled, evenly distributed, typical for toast bread baked without a lid	
Crumb rheological properties	Very soft, tender, elastic						Soft, elastic	
Bread aroma	Aroma characteristic of toast bread						Intense aroma of toast bread, with a tomato note	
	Slightly creamy	Creamy	Creamy, a light tomato aroma					
Bread taste	Taste characteristic of toast bread							
	Slightly creamy	Pronounced, creamy, with a slight tomato note		Pronounced, creamy, with a tomato note			Pronounced, creamy, with an intense tomato flavour	
Crumb chewability	Tender, single-bite chew						Fairly tender	
Comprehensive quality indicator	**96.4**	**96.8**	**96.8**	**96.0**	**95.4**	**95.0**	**81.0**	**80.9**

The integral quality assessment confirmed these patterns: the comprehensive quality index for samples with 1.0–5.0% dosage remained at a high level (95.0–96.8 points), whereas at 6.0 and 7.0% it sharply decreased to 81.0 and 80.9 points, respectively.

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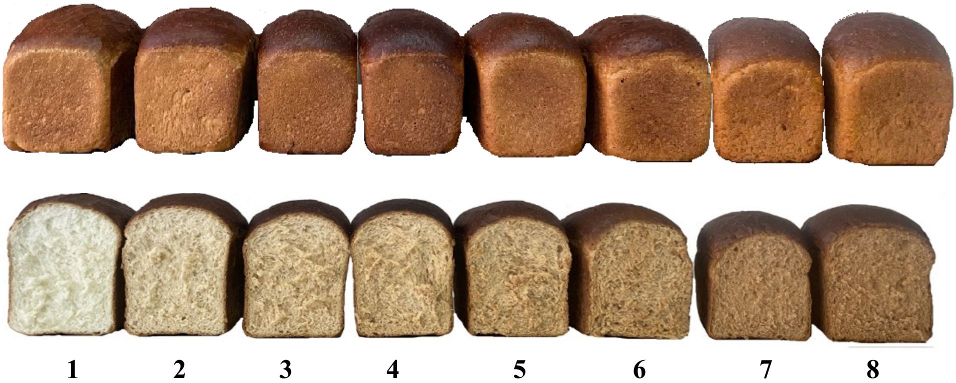

Figure 1. Images of finished toast bread products:
1 – control without additives; bread with tomato powder, %, to flour:
2 – 1.0; 3 – 2.0; 4 – 3.0; 5 – 4.0; 6 – 5.0; 7 – 6.0; 8 – 7.0.

Therefore, the optimal dosage of tomato powder is 5.0% to flour mass, without deterioration of physico-chemical and sensory indicators, with the formation of a fine-porous, dense and uniform crumb structure characteristic of toast bread, as well as a high comprehensive quality index.

Influence of tomato powder on structural and mechanical properties of dough

To conduct a more detailed investigation of the influence of tomato powder on baking properties of dough, instrumental analysis was carried out using an alveograph (Chopin) and a farinograph (Brabender). The research results are presented in Table 2.

According to alveograph data (Table 2), the addition of tomato powder improves the mechanical properties of dough. Dough elasticity (P) increased from 117 to 121 mm, indicating increased resistance to deformation. This may be attributed to interactions between tomato powder components, particularly dietary fibres and pectic substances, and wheat flour proteins, forming a denser and more stable gluten network. Dough extensibility (L) also slightly increased from 31 to 32 m), while the P/L ratio remained unchanged – 3.8, indicating preservation of elastic–plastic properties. Deformation energy (W) increased from 160 to 165 a.u., confirming enhanced flour strength and improved potential dough gas retention. A slight increase in extensibility index (G) from 12.4 to 12.6, with unchanged elasticity index (Ie), also indicates structural stabilisation of dough.

Farinograph analysis revealed a slight decrease in dough water absorption (from 53.3 to 53.1%), which can be explained by the formation of new colloidal bonds in the presence of pectin, binding part of the water and reducing its overall availability for gluten development. Dough development time increased from 1.5 to 2.0 min, indicating slower protein hydration, likely due to competitive water binding by tomato powder fibre. Dough stability remained at zero, although dough formation time also increased to 2.0 min, confirming the above assumption. Meanwhile, dough stability nearly doubled from 7.5 to 14.0 min, indicating structural strengthening and improved resistance to mechanical stress. Dough softening decreased from 110 to 50 B.U., indicating reduced dough weakening and increased dough stability during kneading.

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Table 2

Effect of tomato powder on structural and mechanical properties of dough

Indicator	Control sample (without additives)	With tomato powder (5.0 % to flour mass)
Alveograph		
Dough elasticity, P, mm	117	121
Dough extensibility, L, mm	31	32
Elasticity to extensibility ratio, P/L	3.8	3.8
Deformation energy (flour strength), W, a.u.	160	165
Elasticity index, Ie, %	0	0
Extensibility index, G	12.4	12.6
Farinograph		
Water absorption, %	53.3	53.1
Dough development time, min	1.5	2.0
Dough stability, min	0.0	0.0
Dough formation time, min	1.5	2.0
Stability, min	7.5	14.0
Softening, B.U.	110.0	50.0

These changes are explained by the physico-chemical effects of dietary fibres, pectins and other biologically active components of tomato powder, which interact with flour protein and starch structures, affecting dough rheology. As a result, a stronger and more stable structure is formed, positively influencing toast bread preparation technology.

Evaluation of tomato powder's impact on dough biochemical processes

The study of the influence of tomato powder on the Falling Number makes it possible to evaluate how the introduction of a plant-based additive modifies the enzymatic state of the flour system. Tomato powder contains organic acids, low-molecular-weight carbohydrates, pectic substances and mineral components, which may indirectly affect α-amylase activity by altering medium acidity, starch hydration and substrate availability for enzymes.

For enriched dough, the Falling Number also has additional importance, as it allows prediction of gas production and gas retention intensity. A decrease in the Falling Number indicates increased amylolytic activity, which may lead to excessive formation of fermentable sugars, weakening of the dough structure and formation of sticky crumb. Conversely, an excessively high Falling Number indicates insufficient starch hydrolysis, which restricts yeast nutrition and negatively affects product volume and porosity.

In the control sample, the Falling Number was 328 s, which corresponds to flour with moderate amylolytic activity sufficient for the formation of fermentable sugars and normal fermentation progress. This value is typical for flour suitable for the production of pan and toast bread with stable structural properties.

When 5% tomato powder was added to the flour, the Falling Number significantly increased — up to 484 s, indicating a decrease in the amylolytic activity of the system. The obtained increase can be explained by several interrelated factors.

Firstly, tomato powder contains neither starch nor amylase, therefore its incorporation

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causes a diluting effect on the enzymatically active flour fraction. Secondly, dietary fibre and pectic substances in tomato powder intensely bind water, reducing its availability for starch gelatinisation and limiting its accessibility as a substrate for enzymatic reactions (Wang and Janaswamy, 2001). Thirdly, organic acids in tomato may modify the structure of starch granules and indirectly reduce the hydrolysis rate (Rosell et al., 2001).

The increase of the Falling Number to 484 s indicates a reduction in the intensity of amylolytic processes, which is particularly relevant for enriched dough systems with initially elevated sugar content. In such systems, excessive α-amylase activity is undesirable, as it may lead to excessive starch degradation, dough weakening and formation of sticky crumb. Therefore, the increase in the Falling Number upon addition of tomato powder may be considered a stabilising factor that ensures controlled fermentation progress.

Thus, the obtained Falling Number values indicate that the incorporation of 5 % tomato powder reduces the amylolytic activity of the flour system without suppressing dough fermentation and creates prerequisites for the formation of a dense, fine-porosity crumb structure characteristic of toast bread.

Further investigations concerned the influence of tomato powder on gas production in dough. Dough was prepared using the straight dough method, 5 % tomato powder was added, and dough water content was 38%. Considering that dough rest lasted 15 min, dough proofing of shaped pieces lasted approximately 60 minutes, and gas production was measured during 120 min of fermentation. The results are shown in Figures 2 and 3.

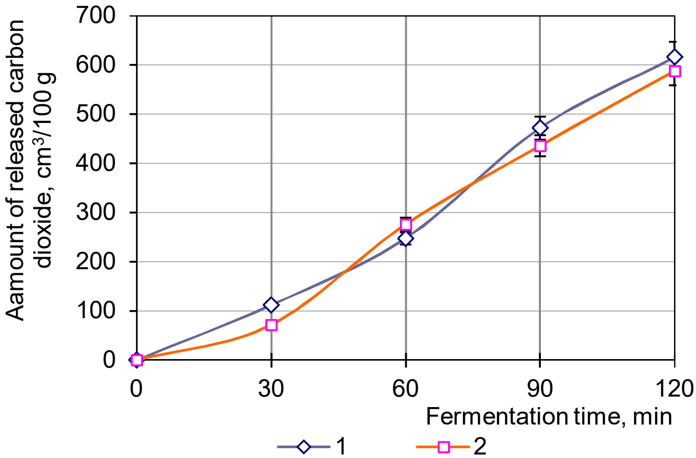

Figure 2. Gas production capacity of dough:
1 – control (without additives); 2 – with tomato powder, 5.0% to flour weight

The results of the investigation of gas production intensity in enriched dough for toast bread with the addition of 5% tomato powder demonstrate regular changes in the amount of carbon dioxide released during 120 min of fermentation. The total quantity of CO_2 released in dough with tomato powder reached 588 ml/100 g, which only slightly differed from the control sample (616 ml/100 g). The obtained data indicate that the addition of tomato powder does not cause a significant inhibition of gas production in dough, but provides moderate and controlled CO_2 release.

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From a technological point of view, such gas production is optimal for toast bread, as it promotes the formation of a fine-porous, uniform and dense crumb structure without the risk of excessive aeration. Controlled gas production intensity combined with stable dough structure creates prerequisites for obtaining products with predictable consumer properties and high quality.

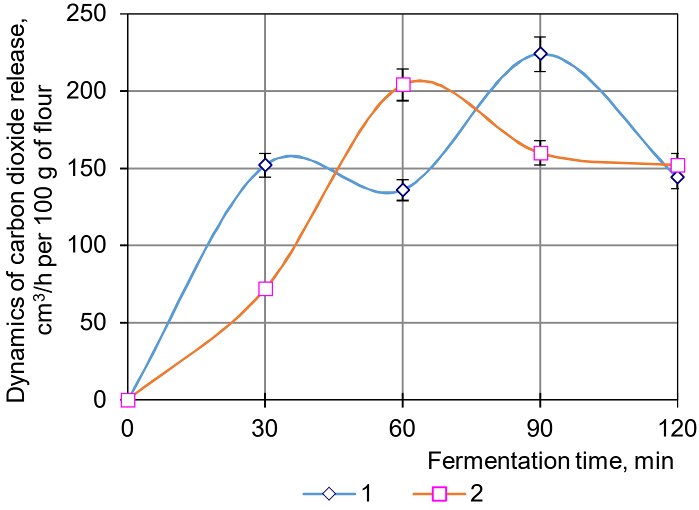

Figure 3. Dynamics of gas production during 2 hours of dough fermentation:
1 – control (without additives); 2 – with tomato powder, 5.0% to flour weight

Analysis of CO_2 release over a 120-min fermentation period showed that the control dough reached its first gas-production peak earlier, at 30 min, with a value of 152 ml/100 g. In contrast, dough containing 5% tomato powder exhibited substantially lower CO_2 release at 30 min (72 ml/100 g), and the maximum was shifted to 60 min, reaching 204 ml/100 g. These results indicate that the incorporation of tomato powder delays the onset of intensive fermentation while ultimately promoting a higher peak level of CO_2 production.

The early peak in the control enriched dough is explained by faster yeast activation in a medium where sugar is readily available as a substrate and water is not bound by additional hydrophilic components. After the initial peak at 60 minutes, the control sample demonstrated a decrease in gas production intensity (136 ml/100 g), which can be interpreted as the completion of the initial phase of fermentation of readily accessible sugars and a transition to another fermentation mode.

In dough containing tomato powder, the shift of the gas-production peak to 60 min is expected and can be attributed to the high water-binding capacity of dietary fiber and pectic substances present in tomato, which increase the viscosity of the dough system. In enriched formulations containing sugar and fat, these effects further hinder initial hydration and yeast adaptation, resulting in reduced CO_2 formation at 30 min. Following yeast adaptation and stabilization of enzymatic activity, CO_2 release increases, reaching 204 ml/100 g at 60 min, indicating that the main fermentation activity in the experimental dough occurs at a later stage.

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At 90 min, the control dough continues to intensify gas production (224 ml/100 g), whereas the tomato powder–enriched dough shows a lower value (160 ml/100 g), reflecting more pronounced, peak-type fermentation kinetics in the control and a more moderated fermentation profile in the experimental sample during the later stages. By 120 min, CO_2 production values in both systems become comparable (144 ml/100 g in the control and 152 ml/100 g in the tomato-enriched dough), suggesting similar fermentation intensity at the final stage.

Overall, the delayed gas-production peak observed in dough enriched with tomato powder is technologically advantageous for toast bread manufacture, as it supports controlled gas accumulation and ensures maximal CO_2 release during the dough-piece proofing stage.

Improvement of toast bread technology and investigation of consumer properties

The addition of tomato powder alters enzymatic, rheological and fermentation processes in enriched dough: amylolytic activity decreases (Falling Number increases), gas production kinetics changes and dough rising rate slightly decreases. Without adjustment of technological parameters, this may lead to deviations in crumb structure formation, specific volume and porosity uniformity.

For this purpose, laboratory baking trials were carried out, in which 5 % tomato powder (to flour mass) was dosed in dry form, soaked form and scalded form. The soaked powder was prepared at a tomato powder to water ratio of 1:2, with swelling duration of 30 minutes. The scalded powder was prepared at a tomato powder to water ratio of 1:2, using water at 95–97 °C followed by cooling to 28–30 °C. The results of laboratory baking trials are presented in Table 3 and Figure 4.

The obtained results indicate that the form in which tomato powder is incorporated (dry, soaked or scalded) differently affects dough development processes and the formation of toast bread quality, for which controlled gas production, limited dough spreading and the formation of a fine- to medium-pored, uniform crumb are essential.

The reduction of dough gas production in the experimental samples compared with the control from 616 to 568–588 ml/100 g is technologically desirable for toast bread, as excessive gas formation in enriched dough may lead to coarse-porous crumb. The lowest gas production was observed in the sample with scalded tomato powder.

The indicator of specific dough volume increase demonstrated notable differences depending on the powder preparation method. In the case of dry powder addition, volume increase was lower than the control, whereas the use of soaked and especially scalded tomato powder ensured notably higher volume increase relative to the dry powder sample. For toast bread, this means that preliminary hydration of tomato powder promotes more efficient and uniform expansion of gas cells without structural collapse.

The increased proofing time of dough pieces and the increase in dough rising strength (up to 62–66 min and 10 min, respectively) indicate delayed CO_2 release at the initial fermentation stage, which is favourable for toast bread.

The reduction of dough spreading from 172 to 160% in the case of scalded tomato powder confirms enhanced dough shape stability, which is critically important for pan-baked toast bread and uniform slice cutting.

From the perspective of finished products, specific volume, porosity and crumb texture are the most informative indicators. The use of scalded tomato powder ensured the highest bread specific volume (388 ml/100 g) and porosity (82%), which correspond to toast bread requirements with a light but not excessively developed crumb structure.

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Table 3

Effect of tomato powder on quality indicators of toast bread,

Indicator	**Control (without additives)**	**Experimental samples**		
		1	**2**	**3**
		with 5% tomato powder (to flour mass)		
		Dry	**Soaked**	**Scalded dough**
Dough				
Gas production, ml CO_2/100 g	616	588	580	568
Increase in specific dough volume, % to initial	324	308	373	378
Proofing time to readiness, min	50	62	62	66
Increase in ball diameter, % to initial	172	170	166	160
Dough rising strength, min	7	8	10	10
Finished products				
Specific volume, ml/100 g	385	372	376	388
Porosity, %	76	68	68	82
External appearance	Correct shape, surface uniform			
Crumb texture	Tender, single-bite chew			
Crumb porosity structure	Fine, thin-walled pores evenly distributed throughout the crumb, typical for toast bread baked without a lid	Medium and fine, thin-walled pores evenly distributed throughout the crumb, typical for toast bread baked without a lid	Medium and fine, thin-walled pores evenly distributed throughout the crumb, typical for toast bread baked without a lid	Medium and fine, thin-walled pores evenly distributed throughout the crumb, typical for toast bread baked without a lid
Crust colour	Dark brown		Brown	Light brown
Crumb colour	White with creamy shade	Light brown		
Taste and aroma	**Characteristic of toast bread**			
	Creamy	Pronounced, creamy, with light tomato note		Pronounced, , creamy, with tomato note

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1 2 3 4

Figure 4. Dough rising strength:
1 – control (without additives); 2 – with dry tomato powder, 5.0% to flour mass;
3 – with soaked tomato powder, 5.0% to flour mass;
4 – with scalded tomato powder, 5.0% to flour weight

Crumb porosity characteristics in all experimental samples corresponded to toast bread (fine to medium pores, thin walls), although scalded tomato powder ensured the most uniform and stable crumb structure, which was confirmed by sensory assessment ("very tender, single-bite chew").

Colour changes in crust and crumb are consistent: the use of dry powder resulted in darker colouring, while scalded tomato powder produced a light brown crust and pleasant light-brown crumb colour, which is desirable for toast bread and does not interfere with toasting of slices in a toaster.

Sensory evaluation of taste and aroma showed that all tomato powder forms impart a characteristic tomato note, although the scalded powder ensured the most harmonious flavour and aroma with a subtle tomato note that does not dominate over the creamy bread profile of toast bread.

The positive results of using tomato powder made it possible to develop a new product – "TomatoToast" toast bread.

To determine the influence of tomato powder on crust and crumb colouring, colour measurements were carried out using a digital colourimeter (Chroma Meter CR-200). The influence on the parameters L* (lightness, where L* = 0 and L* = 100 are taken as black and white, respectively), a* (psychometric tone ranging from green (−) to red (+) from −120 to120) and b* (psychometric chromaticity ranging from blue (−) to yellow (+) from −120 to 120) was determined, and the colour difference relative to the control sample (ΔE*) was calculated (Abdulazeez et al., 2023). The research results are presented in Table 4.

One of the most important quality indicators of bakery products is colour, which directly influences consumer perception and overall product appeal. In this study, the effect of tomato powder on colour characteristics of toast bread was evaluated using the CIELAB colour model, which allows quantitative assessment of changes in lightness (L*), red/green component (a*) and yellow/blue component (b*), as well as general colour difference expressed as ΔE*.

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Table 4

Colour characteristics of bread samples in the CIELAB model

Bread sample	Colour characteristics			
	L_0*	a_0*	b_0*	ΔE_0*
Crust				
Toast bread	38.39	7.8	6.87	-
"TomatoToast" bread	48.43	11.37	17.82	15.29
Crumb				
Toast bread	73.57	1.37	12.77	-
"TomatoToast" bread	63.77	11.01	23.31	17.33

The results indicate that the addition of tomato powder to the formulation substantially changes the colour of both crust and crumb. For the "TomatoToast" sample, the L* value of crust increased by 10.04 units, indicating increased surface lightness. Simultaneously, a* and b* values increased by 3.57 and 10.95 units, respectively, indicating enrichment with red and yellow tones. A similar trend was observed in the crumb: lightness decreased (by 9.8 units), while a* and b* increased by 9.64 and 10.54 units, respectively.

The overall colour difference ΔE* was 15.29 for the crust and 17.33 for the crumb, which exceed the threshold of perceptible visual difference (ΔE* > 3) and indicate a significant change in colour profile. This confirms the effectiveness of tomato powder as a natural colourant. The pronounced colouring is determined by carotenoid pigments (primarily lycopene), which are natural antioxidants. Their thermal stability allows retention of intense colouring even after baking, making tomato powder a promising functional additive for bakery products with not only aesthetic but also physiological and sensory value.

Thus, the application of tomato powder in toast bread formulation allows controlled colouring of the product without deterioration of technological or sensory properties, and potentially enhances its biological value, which is relevant under the growing demand for functional bakery products.

Conclusions

The feasibility of incorporating tomato powder at 5% of flour mass in toast bread was demonstrated, ensuring stable dough properties and enhanced nutritional value without compromising sensory quality. Alveograph and farinograph analyses showed improved dough stability (from 7.5 to 14.0 min) and reduced softening (from 110 to 50 B.U.), while maintaining the elasticity-to-extensibility ratio. Tomato powder also promoted a more controlled fermentation, with a slight decrease in total gas production (from 616 to 588 ml CO_2/100 g) and a later gas peak, contributing to a fine-porous, uniform crumb. The Falling Number increased from 328 to 484 s, indicating reduced amylolytic activity and stabilisation of the starch–protein matrix, advantageous for doughs with higher sugar content. Scalded tomato powder proved most effective, ensuring better hydration of dietary fibres and pectic substances and stabilising the protein–polysaccharide matrix. Colour measurements (ΔE*) of 15.29 for crust and 17.33 for crumb confirmed a significant colour change, attributed to carotenoids, mainly lycopene, which also provide antioxidant activity.

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Author identifiers ORCID

Olena Bilyk	0000-0003-3606-1254
Anastasiia Kukhar	0009-0000-8428-5768
Artem Zabroda	0009-0001-2100-1235
Liudmyla Burchenko	0000-0002-5413-961X

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