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Freeze-Dried Chinese Chives (*Allium odorum*) Powder as a Novel Functional Ingredient: Impacts on Quality and Shelf-Life of Dairy and Oil-Based Products

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ABSTRACT

This study examined how the addition of stabilised Chinese chives powder affects the quality, biochemical parameters, and shelf life of various types of functional products, showing that the lyophilised form of *Allium odorum* provides the greatest preservation of biologically active components and technological stability, as the content of chlorophylls a and b in the lyophilisate reached higher value (12.6 ± 0.3 mg/g) with fewer losses (14%) compared to vacuum drying. Microbiological control was performed by sowing on nutrient media, which was also greater: the total number of mesophilic aerobic and facultative anaerobic microorganisms after 60 days did not exceed 1.3×10^2 CFU/g. Thus, based on comprehensive laboratory and sensory tests, freeze-drying was recognised as the most suitable method for stabilising *Allium odorum* for the creation of functional products. The practical value of this study lies in the substantiation of effective dosages and technological solutions for the introduction of Chinese chives into the food industry, which can be used in the creation of enriched products with proven biological activity, stability, and a prominent level of consumer acceptance.

1. INTRODUCTION

The relevance of this study is driven by the need to develop functional food products with stable organoleptic properties and increased biological value. Modern approaches in food science are focused on the inclusion of plant ingredients with antioxidant activity and adaptogenic properties. Chinese chives (*Allium odorum* L.) are of interest as a source of sulphur-containing and phenolic compounds, chlorophylls, and volatile aromatic components that can improve the physiological effect of products and extend their shelf life. The problem addressed in this study stems from the need to scientifically substantiate the choice of a method for stabilising Chinese chives, to specify the acceptable dosage range for different types of products, and to assess the impact on storage stability. The high sensitivity of biologically active compounds to heat treatment and the risk of organoleptic deterioration when concentrations are exceeded require a comprehensive approach. The lack of standardised methods for the use of Chinese chives in various food matrices complicates industrial implementation and makes this study relevant from practical and scientific standpoints.

Extensive research on the genus *Allium* confirms that many species are rich in organosulfur compounds, flavonoids, phenols, saponins, and other bioactive constituents, which endow them with antioxidant, antimicrobial, and health-promoting properties [1-4]. For example, leaf extracts of *Allium odorum* derived via different solvents demonstrated high levels of phenols, flavonoids, and prominent antimicrobial and antioxidant activity. Similarly, studies on Allium ampeloprasum (leek) revealed potent free-radical scavenging and bactericidal effects attributable to sulfides and polyphenols [5-8].

Kenenbayev et al. [9] concluded that the use of local bulbous plants reduced the proportion of artificial stabilisers in agricultural production by 45% without loss of yield. Therewith, food extracts demonstrated resistance to microbial contamination during long-term storage. According to a review by Singh and Khar [10], the most valuable compounds in *Allium cepa* are allyl sulphides, which can lower plasma glucose levels and suppress inflammatory processes. The researchers also noted that heat treatment preserves up to 70% of biological activity under sparing conditions.

According to Khoshkharam et al. [11], sumac, due to its high content of phenolic compounds, slows down lipid peroxidation and helps to extend the shelf life of fatty products. It was also found that the addition of stabilised plant components improves the organoleptic properties and stability

of products during storage. Based on the analysis by Zhao et al. [12], the ability of onion components to inhibit the growth of yeast and mould during long-term storage of emulsion products was demonstrated. A 22% decrease in the peroxide value was also recorded in samples with sulphur-containing metabolites, reflecting a pronounced anti-peroxide effect. The process from leek powder introduction to the final inhibition of lipid oxidation is shown in Figure 1.

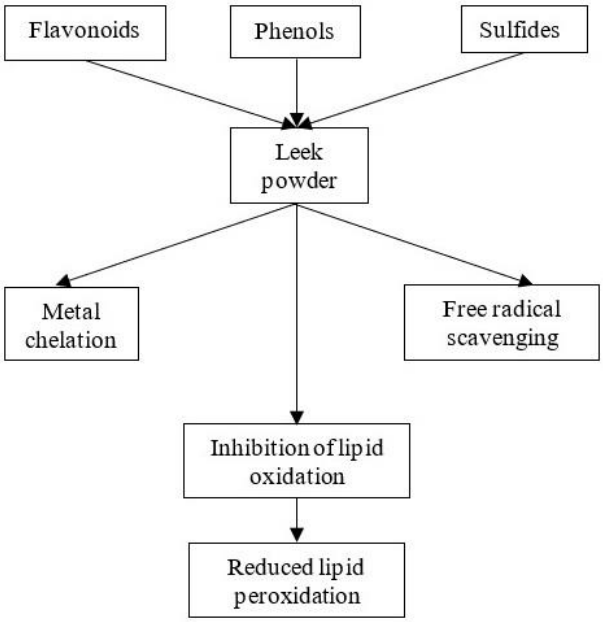

Figure 1. Mechanism of action of bioactive components in leek powder in inhibiting lipid oxidation
Source: Compiled by the authors.

According to the conclusions of Kumar et al. [13], onion peel extracts saturated with phenolic compounds provided up to 70% antioxidant activity in the 2,2-diphenyl-1-picrylhydrazyl (DPPH) model, while stabilising colour and inhibiting peroxidation in fat systems. The effectiveness of such additives in bakery and emulsion products was noted. Sagar et al. [14] confirmed the high biofunctionality of sulphur-containing compounds, including allylpropyl disulphide, which provided an antibacterial barrier and maintained textural stability during storage. These components also did not lose their activity after short-term heat treatment.

Ren and Zhou [15] recorded a significant reduction in microbial count and peroxide value with increased phenolic fractions, especially flavonoids. The best results were achieved under conditions of low temperature and high humidity. Kim et al. [16] revealed the heat resistance of green onions, manifested in the preservation of chlorophylls and volatile aromatic substances after heating to 85°C. This property made it suitable for heat-stable products with a jelly-like texture.

According to Ateeq et al. [17], the addition of onion skin powder to dough reduced water activity and microbiological contamination while enhancing visual and taste qualities. The aroma stability after baking was also greater compared to the control samples. According to Weng et al. [18], the use of purple onions in a complex food formula led to the inhibition of α-glucosidase and stabilisation of the glycaemic profile in diabetes modelling. The bio-components retained their activity after thermal stress, confirming their nutraceutical potential. Prominent among the understudied aspects are the lack of comprehensive comparisons of Chinese chives drying methods, the lack of data on the effect of its dosage on the texture and organoleptic properties of various matrices, limited information on the relationship between antioxidant activity and taste perception, as well as limited information on the use of Chinese chives in multi-component recipes and during long-term storage. This study aimed to evaluate the impact of Chinese chives powder on the quality, stability, and bioactive content of functional products. The objectives of the study included determining the most suitable dosages of Chinese chives powder for various food matrices, comparing the effectiveness of freeze-drying and vacuum drying, and evaluating the effect of powder addition on the antioxidant activity, organoleptic characteristics, and microbiological stability of products.

2. MATERIALS AND METHODS

2.1 Experimental design and location

The experimental study was performed between May and August 2024 at the Functional Food Biotechnology Laboratory of the Kazakh National Agrarian Research University (Almaty, Republic of Kazakhstan). The Chinese chives (*Allium odorum* L.) used in this study were sourced from the Almaty region of Kazakhstan, cultivated under controlled greenhouse conditions to ensure optimal growth and bioactive compound production. The chives were harvested in the first week of May 2024, at the phenological stage of fully expanded leaves, just before flowering, which is known to maximize the concentration of essential bioactive compounds.

2.2 Plant material and authentication

The botanical material was authenticated as *Allium odorum* L. by the Herbarium of the Functional Food Biotechnology Laboratory of the Kazakh National Agrarian Research University (Almaty, Republic of Kazakhstan). To ensure stable environmental parameters, the laboratory was equipped with a Rittal TopTherm climate control system (Germany). Monitoring was performed using SHT85 digital sensors (Sensirion, Switzerland), integrated into the Ignition SCADA system (Inductive Automation, USA) with visualisation via a Python module.

2.3 Sample preparation and drying method

Chinese chives powder (*Allium odorum* L.) was used as a functional component because of its high concentration of sulphur-containing antioxidants, pronounced aroma, and storage stability. It was obtained by two methods: freeze-drying at -42°C and 0.18 mbar (Martin Christ Alpha 2-4 LDplus, Germany) and vacuum drying at 45°C (Binder VD53, Germany). For the main part of the study, freeze-dried samples were selected due to their better stability of biologically active substances, aroma, and microbiological purity.

2.4 Application in food matrices

Chinese chives powder was added in concentrations ranging from 1% to 5%, depending on the product and technological

compatibility. The product matrices included an acidophilic fermented milk drink (pH = 4.3), ultra-pasteurised butter with 82.5% fat content (FoodMaster LLC, Kazakhstan), unrefined cold-pressed sunflower oil (VostokEcoLine LLP, Kazakhstan), and an agar-based jelly aperitif (HiMedia, India) and demineralised water.

2.5 Instrumental analyses

2.5.1 Colour measurement

Colour characteristics (L*, a*, b*) were determined using a Minolta CR-400 spectrophotometer (Konica Minolta, Japan) on the CIE Lab scale under D65 lighting.

2.5.2 Sensory evaluation

The organoleptic and sensory evaluation of the samples included taste, aroma, texture, and overall impression and was performed by an expert commission of five qualified tasters calibrated according to ISO 8586:2023 [19]. The evaluation was performed on a 10-point scale following ISO 13299:2016 [20].

2.5.3 Antioxidant activity (DPPH assay)

Antioxidant activity was calculated based on the decrease in DPPH radical absorption at 517 nm using a UV-1800 spectrophotometer (Shimadzu, Japan). Activity loss was monitored on days 7 and 60 of storage at + 4°C.

2.5.4 Peroxide value

The peroxide value was determined titrimetrically according to GOST 26593-85 [21] and expressed in mmol O_2/kg.

2.5.5 Viscosity and texture

Viscosity was measured on a Brookfield DV2T (USA) at 25°C, and the result was expressed in centipoise. Structural homogeneity was assessed visually and texturally on a 10-point expert scale formed by a commission of five specialists in the field of sensory analysis who had undergone preliminary calibration training. Panelists underwent calibration sessions to harmonize their perceptions of appearance, aroma, taste, texture, and overall acceptability. Written informed consent was obtained from all panelists; the procedure complied with ethical standards of volunteer participation and data protection.

2.5.6 Volatile compound analysis

The content of volatile compounds (allyl mercaptan and allyl propyl disulfide) was determined by gas chromatography on an Agilent 7890B (USA) with a DB-Sulfur SCD column, and the loss of volatile substances after heating for 15 minutes at 85°C was recorded as a change in peak area. Chromatographic analysis was carried out under the following conditions: column C18, 150 × 4.6 mm, 5 μm, injection volume 20 μL, mobile phase – gradient of water (A) and acetonitrile (B) with 0.1% formic acid, flow rate 1.0 mL/min, column temperature program starting at 25°C, increasing to 35°C at 5°C/min, holding for 10 min, detection wavelength 280 nm for phenolics, 254 nm for sulfur compounds. Carrier gas was helium at a flow rate of 1.2 mL/min.

2.5.7 Phenolic content

Phenolic compounds were determined using the Folin-Ciocalteu method on a UV-1800 (Shimadzu, Japan) at 760 nm, and the result was expressed in mg GE per 100 g [22]. Data analysis was performed using one-way analysis of variance (ANOVA) with Statistica 13.0 (StatSoft, USA). The level of significance was considered statistically significant at $p < 0.05$. All values are presented as mean ± standard deviation (n = 3).

2.5.8 Chlorophyll content

Chlorophylls a + b were measured at 645 nm and 663 nm on a UV-1800, while losses were calculated as a percentage after 30 days of storage. Water activity (Aw) was measured using a LabSwift-aw moisture meter (Novasina, Switzerland). pH (acidity) was recorded using a FiveEasy Plus pH meter (Mettler Toledo, Switzerland). The oxidative stability of the oils was assessed by the induction period on a Rancimat 893 (Metrohm, Switzerland) at 100°C according to the Cd 12b-92 method [23].

Microbiological stability tests were conducted by incubating samples on appropriate culture media at 37°C for 24-48 hours for mesophilic bacteria; 30°C for yeast/moulds for 48-72 hours, following standard microbiological protocols (plate count method).

Microbiological indicators included CFU of mesophilic microflora, total microbial count, mould and yeast content (60 days), and the concentration of *Lactobacillus* spp. in the beverage. Cultures were performed on meat peptone agar and MRS agar (HiMedia, India), and colonies were counted on ColonQuant 2100 (Analytik Jena, Germany).

The DPPH assay is used to evaluate the antioxidant capacity of a sample by measuring its ability to scavenge the DPPH free radical. We used Eq. (1) to calculate the percentage of inhibition:

$$\% \text{ Inhibition} = \frac{(A_{\text{control}} - A_{\text{sample}})}{A_{\text{control}}} \times 100 \quad (1)$$

where, A_{control} is the absorbance of the control (without sample) at 517 nm; A_{sample} is the absorbance of the sample at 517 nm after reaction with DPPH.

The peroxide value is determined by titration and is calculated using Formula (2):

$$\text{Peroxide Value (PV)} = \frac{(V_1 - V_2) \times N \times 1000}{W} \quad (2)$$

where, V_1 is the volume of sodium thiosulfate solution used to titrate the sample; V_2 is the volume of sodium thiosulfate solution used for the blank titration; N is the normality of the sodium thiosulfate solution; W is the weight of the sample in grams.

3. RESULTS

3.1 Impact of stabilisation methods on the quality and bioactive components of Chinese chives powder

The freeze-dried form of Chinese chives demonstrated the greatest efficiency in terms of preserving biologically active components and technological suitability for subsequent use in food products. The total chlorophyll a and b content in the powder obtained by freeze-drying was 12.6 ± 0.3 mg/g of dry matter, while the same indicator in samples dried at a lower temperature under vacuum conditions did not exceed 9.1 ± 0.5 mg/g (Table 1). The difference between the samples was statistically significant ($p < 0.01$), reflecting more pronounced

degradation of the pigment complex under less gentle drying conditions. The relative loss of chlorophylls compared to the initial level in fresh raw materials was 14% for the lyophilised form and 35% for the vacuum-dried form.

Table 1. Comparative characteristics of Chinese chives powders obtained by different stabilisation methods

Indicator	Lyophilisation	Vacuum Drying
Chlorophylls a + b, mg/g (dry weight)	12.6 ± 0.3	9.1 ± 0.5
Chlorophyll loss, %	14	35
Antioxidant activity (DPPH), % inhibition	85.3 ± 1.9	61.2 ± 2.5
Decrease in DPPH after 60 days of storage, %	4.8	12.6
Colour (L/a/b*)**	45.8/-9.4/14.7	41.3/-6.7/11.2
Allyl mercaptan, µg/g	2.18	1.35
Allylpropyl disulfide, µg/g	3.74	2.01
Aroma loss after heat treatment, %	9.8	24.1
Total microbial count after 60 days, CFU/g	1.3×10^2	7.5×10^2
Mould and yeast after 60 days, CFU/g	6.1×10^1	2.8×10^2
Water activity (Aw)	0.28 ± 0.01	0.36 ± 0.02
Organoleptic assessment (10-point scale)	8.4	6.9

Source: Compiled by the authors of this study.

The total antioxidant potential was also greater in the stabilised component obtained by sublimation. The degree of DPPH radical inhibition reached 85.3 ± 1.9% in the lyophilisate versus 61.2 ± 2.5% in the powder that underwent thermal vacuum drying. After 60 days of storage under controlled conditions, the antioxidant activity decreased by 4.8% in the lyophilised form, while the decrease in vacuum-dried raw materials was 12.6%, which also confirms the greater stability of biofunctional properties when using low-temperature drying.

The evaluation of the colour characteristics of the powders showed that the freeze-dried form retained a rich green colour with coordinates L* = 45.8 ± 1.1, a* = -9.4 ± 0.6, and b* = 14.7 ± 0.5. The vacuum-dried sample had duller shades (L* = 41.3 ± 1.4, a* = -6.7 ± 0.9, b* = 11.2 ± 0.6), which indicated a partial loss of coloured pigments and the onset of darkening processes. The differences persisted even after the introduction of stabilised forms into food matrices. The colour of finished products with lyophilisate was characterised by greater uniformity and naturalness, while in vacuum-dried samples, there was a pronounced unevenness in colour and a tendency towards brown tones [24-28].

The volatile aroma profile was also sensitive to the stabilisation method. The level of the key aromatic markers – allyl sulphides and thioesters – was greater in the freeze-dried form: the content of allyl mercaptan was 2.18 µg/g versus 1.35 µg/g, and allylpropyl disulphide was 3.74 µg/g versus 2.01 µg/g. The total aroma intensity on a five-point expert scale was rated at 4.3 for products with a lyophilised component and 3.2 for analogues with a vacuum-dried additive. After heat treatment (baking or pasteurisation), the loss of aromatic compounds was 9.8% for the lyophilisate and 24.1% for the second variant, which further indicated the thermolability of the unstabilised fraction.

The microbiological stability of the powders during storage also varied depending on the stabilisation method. The number of mesophilic aerobic and facultative anaerobic microorganisms after 60 days did not exceed 1.3×10^2 CFU/g in the freeze-dried sample, while in the vacuum sample this figure was 7.5×10^2 CFU/g. The content of mould and yeast was within acceptable limits, but was also lower in the first group (6.1×10^1 CFU/g versus 2.8×10^2 CFU/g). Water activity (Aw) was 0.28 ± 0.01 for the freeze-dried form and 0.36 ± 0.02 for the vacuum-dried form, which explains the differences in biological stability.

Organoleptic evaluation of products enriched with stabilised Chinese chives revealed a consistent preference for compositions with a freeze-dried form. The average integral score (taste, aroma, texture, colour) was 8.4 points out of 10, compared to 6.9 points in the vacuum-dried group. The purity of taste and the absence of foreign bitter and musty notes observed in thermally processed raw materials were particularly emphasised (Table 1).

Thus, the aggregate results demonstrated the technological advantage of the lyophilised form of Chinese chives in terms of all key quality indicators: preservation of the pigment and antioxidant profile, stability of volatile compounds, colour saturation, microbiological safety, and organoleptic appeal. This form can be considered the most suitable for the development of functional food products with predictable quality characteristics and prolonged stability.

3.2 Effects of freeze-dried Chinese chives on fermented milk drink quality

The change in the integral sensory evaluation score for the fermented milk drink as the dosage of freeze-dried Chinese chives powder increases is shown in Figure 2.

Antioxidant activity (DPPH) in the control sample was 41.3%. At a dosage of 1%, an increase to 52.4% was observed, which exceeded the control by 11.1 percentage points. At 2%, the activity reached 59.6% (+18.3 p.p.), at 3% – 62.5% (+21.2 p.p.), at 4% – 64.8% (+23.5 p.p.), and at 5% – 66.3% (+25 p.p.). Despite the increase in indicators at greater dosages, the growth rate slowed down, and the organoleptic perception decreased (Table 2).

DPPH losses after 7 days of storage amounted to 7.4% in the control sample. In beverages with 1% Chinese chives, the activity decreased by 6.9%, at 2% – by 6.2% at 3% – by 5.1%, at 4%, by 5.6%, and at 5% – by 6.0%. All samples with additives showed better stability of antioxidant activity, especially within 2-3%.

The pH of the control sample was 4.35. At a dosage of 1%, the value decreased to 4.33 (-0.02), at 2% – to 4.29 (-0.06), at 3% – to 4.24 (-0.11), at 4% – to 4.21 (-0.14), and at 5% – to 4.18 (-0.17). The changes stayed within the normal range and did not affect the microbiological stability of the product.

The viscosity in the control group was 118 cP. Beverages with a 1% addition showed a viscosity of 124 cP (+6), with 2% – 129 cP (+11), with 3% – 134 cP (+16), with 4% – 141 cP (+23), and with 5% – 147 cP (+29). Up to 3%, the increase in density was assessed as positive, while at 4-5%, sedimentation and uneven texture occurred compared to the control.

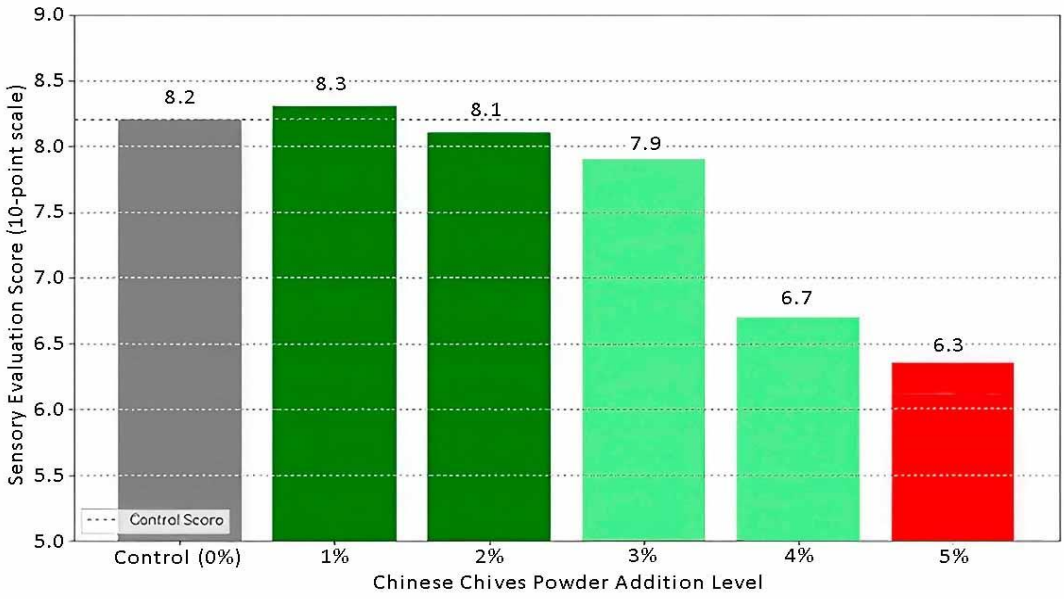

Figure 2. Integral sensory evaluation of fermented milk drink with Chinese chives powder
Source: Compiled by the authors.

Table 2. Effect of freeze-dried Chinese chives dosage on the properties of fermented milk drinks

Indicator	Control	1% Addition	2% Addition	3% Addition	4% Addition	5% Addition
Antioxidant activity (DPPH), %	41.3	52.4	59.6	62.5	64.8	66.3
DPPH loss after 7 days of storage, %	7.4	6.9	6.2	5.1	5.6	6.0
pH	4.35	4.33	4.29	4.24	4.21	4.18
Viscosity, cP	118	124	129	134	141	147
Colour L*/a*/b	89.1/-1.7/6.1	87.9/-2.8/7.4	86.8/-4.1/8.5	86.3/-4.8/9.2	85.2/-5.6/9.9	84.0/-6.3/10.3
Allyl mercaptan, μg/ml	-	1.13	1.48	1.72	2.11	2.39
Sensory evaluation (10-point scale)	8.2	8.3	8.1	7.9	6.7	6.3
Lactobacillus content, × 10^8 CFU/ml	1.4	1.3	1.2	1.5	1.2	1.1
Total microflora, log CFU/ml	2.1	1.8	1.5	1.2	1.3	1.3

Source: Compiled by the authors of this study.

The colour (L/a/b*)** in the control sample was characterised by the coordinates L* = 8 9.1, a* = -1.7, b* = 6.1. At 1% Chinese chives, the values changed to 87.9/-2.8/7.4; at 2% – 86.8/-4.1/8.5; at 3% – 86.3/-4.8/9.2; at 4% – 85.2/-5.6/9.9; at 5% – 84.0/-6.3/10.3. Thus, each level of the additive enhanced the green-yellow colour, making it distinguishable from the control. At 2-3%, the tone was assessed as natural, at 5% as excessive.

Allyl mercaptan was not detected in the control sample. At a dosage of 1%, its concentration was 1.13 μg/ml, at 2% – 1.48, at 3% – 1.72, at 4% – 2.11, and at 5% – 2.39. The presence of this compound in beverages with the additive provided a characteristic spicy-garlic aroma that was absent in the control. However, at 4-5%, excessive saturation was noted, which is uncharacteristic of fermented milk products.

The sensory evaluation (on a 10-point scale) in the control group was 8.2. At 1% addition, the rating increased to 8.3 (+0.1), at 2% – 8.1 (-0.1), at 3% – 7.9 (-0.3), at 4% – 6.7 (-1.5), and at 5% – 5.8 (-2.4). The decrease after 3% was explained by oversaturation of taste and disruption of texture uniformity, in contrast to the balanced profile in the control sample.

The *Lactobacillus* content in the control sample was 1.4 × 10^8 CFU/ml. In drinks with Chinese chives, the values ranged from 1.2 × 10^8 CFU/ml to 1.5 × 10^8 CFU/ml. At 1%, it was 1.3 × 10^8 CFU/ml; at 2% – 1.2 × 10^8 CFU/ml; at 3% – 1.5 × 10^8 CFU/ml; at 4% and 5% – 1.2 × 10^8 and 1.1 × 10^8 CFU/ml. No significant differences from the control were found; Chinese chives did not inhibit the viability of lactic acid bacteria.

The total microflora in the control sample was 2.1 log CFU/ml. With the addition of Chinese chives, a decrease was observed: at 1% – 1.8 (-0.3), at 2% – 1.5 (-0.6), at 3% – 1.2 (-0.9), at 4% and 5% – 1.3 (-0.8). The greatest antimicrobial effect was recorded at 3%, where the total contamination level was almost an order of magnitude lower than the control (Table 2).

Thus, in all indicators from antioxidant activity to microbiological stability, beverages with 2-3% addition of Chinese chives substantially outperformed the control group, staying within the limits of technological and sensory optimisation. Dosages below 2% showed a moderate effect, while exceeding 3% was accompanied by a decrease in consumer acceptability, despite the biochemical advantages.

3.3 Sensory and functional characteristics of butter enriched with Chinese chives

At a dosage of 0.5%, the butter retained its conventional consistency, while the colour was practically indistinguishable from the control. Changes in colour coordinates (L/a/b*)** were minimal: L* decreased from 91.4 (in the control) to 90.2, a* from -2.1 to -2.7, and b* from 14.6 to 15.8. At a 1% addition, a more pronounced colour change was observed: L* = 87.2, a* = -4.1, b* = 18.3. Visually, the product became bright yellow with a slight greenish undertone. At a dosage of 2%, the colour became a rich greenish-yellow (L* = 84.5, a* = -5.3, b* = 20.1), which was perceived as a deviation from the standard butter.

Table 3. Change in the properties of butter upon the addition of freeze-dried Chinese chives

Indicator	Control	0.5% Addition	1% Addition	2% Addition
Colour coordinates (L/a/b*)**	91.4/-2.1/14.6	90.2/-2.7/15.8	87.2/-4.1/18.3	84.5/-5.3/20.1
Organoleptic assessment on a 10-point scale, points	7.5	7.9	8.2	6.3
Antioxidant activity (DPPH), %	23.1	31.7	34.0	35.5
Loss of antioxidant activity after 7 days of storage, %	7.4	-	3.8	3.1
Peroxide value on Day 7 of storage, mmol O_2/kg	1.74	1.32	1.04	0.91
Structural homogeneity (expert assessment), points	8.3	-	9.1	7.0
Allyl mercaptan content, μg/g	-	-	2.42	3.17
Amount of mesophilic microflora, CFU/g	6.7×10^1	-	4.1×10^1	-
Water activity (Aw)	0.28	0.28	0.27	0.27

Source: Compiled by the authors of this study.

The organoleptic assessment on a 10-point scale was 8.2 points at a 1% addition, which exceeded the control assessment (7.5) due to the emergence of a pleasant herbal note and freshness in the taste. At 0.5%, the increase was insignificant (7.9), while at 2%, the rating dropped to 6.3 points due to a sharp garlic flavour, changes in texture, and oversaturation of taste. Thus, the most suitable dosage from a sensory standpoint was 1%.

According to the results of the antioxidant activity (DPPH) analysis, the control butter showed an activity level of 23.1%. When 0.5% of Chinese chives was added, the value increased to 31.7% (+8.6 p.p.), at 1%, the value increased to 34.0% (+10.9 p.p.), and at 2%, to 35.5% (+12.4 p.p.). Considering the moderate effect of increasing the dosage on the increase, the level of 1% was considered rational in terms of effectiveness and organoleptic stability.

The loss of antioxidant activity over 7 days of storage at 4°C was minimal at 1% (a decrease of 3.8%), while in the control group, the decrease was 7.4%. At 2%, the loss was 3.1%, but it was accompanied by a deterioration in taste properties. Thus, the addition of Chinese chives not only enhanced the antioxidant protection of the butter but also slowed down the oxidative processes during storage.

Analysis of oxidative stability revealed that the peroxide value in the control sample was 1.74 mmol O_2/kg on Day 7 of storage. In the sample with 0.5% Chinese chives, it decreased to 1.32 mmol O_2/kg, with 1%, to 1.04 mmol O_2/kg, and with 2%, to 0.91 mmol O_2/kg. The difference between the control and enriched samples was statistically significant ($p < 0.05$), reflecting a pronounced inhibitory effect of Chinese chives phytocomponents on the primary oxidation of fats.

The consistency of the butter stayed stable, plastic, and easily spreadable when up to 1% was added. At 2%, individual microinclusions appeared due to the excessive content of plant particles, and at a storage temperature of 2°C, partial crystallisation of Chinese chives in the fat matrix was observed, which deteriorated the textural properties. The structural homogeneity index, determined by expert assessment, was 9.1 points at 1%, which exceeded the control sample index (8.3), and decreased to 7.0 at 2%.

According to the results of the analysis of volatile aromatic compounds, the content of allyl mercaptan in the sample with 1% Chinese chives was 2.42 μg/g, while it was absent in the control sample. The aroma was characterised as "natural herbal with a slight garlic note" – stable during storage and not disturbing the typical butter matrix. At 2%, the content increased to 3.17 μg/g, which led to a sharp and narrow-profile aroma, undesirable for the consumer.

The microbiological indicators of the butter with Chinese chives were comparable to the control. The amount of mesophilic microflora in the 1% sample was 4.1×10^1 CFU/g versus 6.7×10^1 CFU/g in the control. The presence of Chinese chives had a slight antimicrobial effect without suppressing beneficial microflora. Therewith, the water activity index did not change and stayed within 0.27-0.29 for all samples (Table 3).

Thus, adding 1% freeze-dried Chinese chives to the butter recipe resulted in a comprehensive improvement of the product: an increase in antioxidant activity by 10.9 percentage points compared to the control, a decrease in the peroxide value by 0.7 mmol O_2/kg, an increase in the organoleptic rating by 0.7 points, and stabilisation of the aroma without destroying the structure. Values below 0.5% had a moderate effect, while values above 1.5-2% were accompanied by a deterioration in consistency, aroma, and consumer characteristics.

3.4 Influence of Chinese chives powder on microbiological stability and shelf life of functional products

Antioxidant activity (DPPH) in the control sample was 41.7%. When 1.0% of Chinese chives was added, the value increased to 62.9%, and when 1.5% was added, it reached 68.1%. Thus, the increase in activity was +21.2 percentage points and +26.4 percentage points, respectively, compared to the control sample, which reflected a considerable increase in the antioxidant potential of the oil (Table 4).

The induction period of oxidation at 100°C, reflecting resistance to peroxide decomposition, was 4.9 hours in the control sample. In the sample with 1.0% Chinese chives, this indicator increased to 6.8 hours, and at 1.5%, to 7.4 hours. The prolongation of the induction period by 2.5 hours compared to the control confirmed the effectiveness of Chinese chives phytocomponents in suppressing oxidative processes.

The organoleptic assessment, performed on a 10-point scale, was 7.3 points for the control sample. At a dosage of 1.0%, it increased to 7.8 points, while at 1.5%, to 8.0. Experts noted a more intense, natural taste, pronounced freshness, and a characteristic herbal aroma in the enriched samples. At 1.5%, there was no oversaturation, and the aroma stayed balanced.

The colour (L/a/b*)** also changed in proportion to the enrichment level. In the control sample, the colour coordinates were L* = 49.8, a* = -2.4, b* = 12.0. At a dose of 1.0%, the indicators changed to L* = 45.6, a* = -4.9, b* = 14.1, while at 1.5%, L* = 43.2, a* = -6.2, b* = 15.1. This reflected a gradual intensification of the green hue and an increase in the colour intensity of the oil. Therewith, the colour change was perceived by consumers as natural and aesthetically appealing.

Analysis of the allyl mercaptan content showed its absence in the control sample. When 1.0% of Chinese chives was added, the content of this volatile sulphur-containing compound was 1.74 μg/g, while at 1.5% – 2.18 μg/g. This provided a characteristic, fresh garlic aroma without bitterness

or overpowering taste. The aroma was retained throughout the storage period (30 days at 4°C) without turning into oxidised or sulphurous tones.

The total microflora (CFU/g) in the control sample was 5.2 × 10^1 CFU/g. In the sample with 1.0% Chinese chives, the level decreased to 4.3 × 10^1 CFU/g, and at 1.5%, to 3.8 × 10^1 CFU/g. Thus, the addition of Chinese chives had a moderate antimicrobial effect without destroying the oil matrix or causing foreign odours. The natural phytoncides and antioxidants contained in Chinese chives ensured the preservation of the product without the addition of preservatives.

Table 4. Effect of freeze-dried Chinese chives dosage on salad oil properties

Indicator	Control	1.0% Addition	1.5% Addition
Antioxidant activity (DPPH), %	41.7	62.9	68.1
Induction period of oxidation at 100°C, hours	4.9	6.8	7.4
Organoleptic assessment (out of 10 points)	7.3	7.8	8.0
Colour (L/a/b*)**	49.8/-2.4/12.0	45.6/-4.9/14.1	43.2/-6.2/15.1
Allyl mercaptan, µg/g	-	1.74	2.18
Total microflora, CFU/ml	5.2 × 10^1	4.3 × 10^1	3.8 × 10^1
Water activity (Aw)	0.26	0.25	0.24

Source: Compiled by the authors of this study.

Water activity (Aw) remained consistently low across all samples, with values of 0.26 in the control, 0.25 at 1.0%, and 0.24 at 1.5% chive powder concentration. These values exclude the development of microorganisms and favour long-term storage of the product without signs of spoilage.

In terms of texture characteristics, all samples retained their usual consistency. Visually, the oil with Chinese chives had a uniform suspension of microparticles, well distributed in the oil phase. When stored at 4°C for 30 days, the structure stayed homogeneous. After shaking, the suspension stayed stable for more than 3 hours at room temperature, making the product convenient for use in salads and cold dishes (Table 4).

Thus, adding 1.0-1.5% freeze-dried Chinese chives to salad oil provided statistically significant improvement in all key indicators. The product demonstrated greater antioxidant activity (+26.4%), resistance to oxidation (+2.5 hours of induction period), improved colour characteristics and aroma, and maintained microbiological stability. A particularly pronounced positive effect was achieved at a dosage of 1.5%, which allows considering this formula a functional product with a preventive focus, an extended shelf life, and improved organoleptic qualities.

3.5 Quality characteristics of the aperitif at various levels of Chinese chives addition

Antioxidant activity (DPPH) showed steady growth with increasing Chinese chives content. In the control sample, the value was 38.2%. At a dosage of 1%, the activity increased to 54.6%, at 2%, to 61.3%, at 3%, to 66.7%, and reached to 67.9% at 4%. Thus, the introduction of Chinese chives at a dose of 3-4% provided an almost twofold increase in antioxidant potential compared to the initial level, which reflects the high functional value of the phytocomponent (Table 5).

Table 5. Comprehensive quality indicators for plant-based appetite suppressants with added Chinese chives

Indicator	Control	1% Addition	2% Addition	3% Addition	4% Addition
Antioxidant activity (DPPH), %	38.2	54.6	61.3	66.7	67.9
Organoleptic evaluation, DPPH, %	7.1	7.7	8.2	8.4	7.4
Allyl mercaptan content, µg/g	0.0	0.41	1.62	2.91	3.45
Water activity (Aw)	0.89	0.88	0.87	0.86	0.86
Amount of mesophilic microflora, CFU/g	340.0	320.0	290.0	260.0	230.0
Total phenol content, mg GAE/100 g	41.2	59.6	71.3	78.5	80.1
Viscosity, mPa·s	2,480.0	2,570.0	2,685.0	2,810.0	2,890.0
Coordinate L* (brightness)	44.8	42.3	40.5	39.1	38.2

Source: Compiled by the authors of this study.

Organoleptic evaluation on a 10-point scale also showed positive dynamics up to a certain threshold. The control sample received a score of 7.1. At 1% Chinese chives, the score was 7.7, at 2%, the score was 8.2, and the maximum score of 8.4 was recorded at a 3% addition. Increasing the dosage to 4% led to a deterioration in organoleptic perception to 7.4 points due to increasing garlic and sulphurous notes.

The content of allyl mercaptan, as the primary carrier of garlic aroma, increased in proportion to the dosage. The compound was not detected in the control. At 1%, it was 0.41 µg/g, at 2% – 1.62 µg/g, at 3% – 2.91 µg/g, and at 4% it reached 3.45 µg/g. The correlation between the increase in this indicator and the decrease in sensory scores at high doses was confirmed.

Water activity (Aw) remained within the technologically acceptable range for gelatinous products. In the control sample, the Aw value was 0.89. With the addition of 1% chive powder, it decreased slightly to 0.88; at 2%, to 0.87; and at 3%, to 0.86. Increasing the concentration to 4% did not result in further changes, with the Aw remaining at 0.86. This indicates that water activity remained stable despite the increasing amount of plant-based additive.

The amount of mesophilic microflora (CFU/g) showed a moderate decrease under the influence of Chinese chives. In the control, the level was 340 CFU/g, at 1% – 320 CFU/g, at 2% – 290 CFU/g, at 3% – 260 CFU/g, and at 4% – 230 CFU/g. The moderate antimicrobial effect of Chinese chives ensured a reduction in potentially undesirable microflora without suppressing beneficial microflora.

The following parameters were also measured. The total content of phenolic compounds was 41.2 mg GAE/100 g in the control sample. At 1% Chinese chives, this figure reached 59.6 mg GAE/100 g, at 2% – 71.3 mg GAE/100 g, at 3% – 78.5 mg GAE/100 g, and at 4% – 80.1 mg GAE/100 g. The increase in phenol content correlated with increased antioxidant activity.

The viscosity of the aperitif also showed an increasing

change. When 1% Chinese chives were added, the viscosity of the aperitif increased from the control value of 2,480 mPa·s to 2,570 mPa·s. At 2%, the indicator was 2,685 mPa·s, at 3%, 2,810 mPa·s, and at 4%, it reached 2,890 mPa·s. Up to a level of 3%, the consistency stayed homogeneous and technologically stable, but at 4% it began to be perceived as excessively thick, with signs of unevenness during storage.

Colour retention was assessed visually and instrumentally. The L* coordinate decreased from 44.8 in the control to 42.3 at 1% Chinese chives, 40.5 at 2%, 39.1 at 3%, and 38.2 at 4%, reflecting a gradual darkening of the product. The a* and b* coordinates showed an increase in green and yellow hues, which was visually perceived as a "natural plant colour" at doses up to 3%, but at 4% it looked overly saturated (Table 5).

Thus, the optimal level of the additive in terms of the set of indicators was 3%. It provided maximum antioxidant activity (66.7%), a prominent level of organoleptic properties (7.9 points), acceptable viscosity (2,810 mPa·s), and stable water activity (0.86). At a dose of 4%, the sensory and chemical profile became saturated, which limits further increases in dosage. The product created can be considered a promising functional aperitif with pronounced preventive potential and a stable structure.

4. DISCUSSION

During the discussion of the findings obtained, it was established that the freeze-drying method provides the most effective preservation of biologically active substances in Chinese chives powder. The elevated level of chlorophylls and antioxidant activity in the freeze-dried form correlated with better colour saturation, aromatic profile, and microbiological stability compared to vacuum drying. This was confirmed by a reduction in pigment and volatile compound losses, as well as lower water activity and microbial contamination. When using the powder in a fermented milk drink, the optimal dosage was 2-3%, at which maximum antioxidant activity (up to 66.3%), pH stabilisation, and a reduction in total microflora were observed without any deterioration in taste. Dosages above 3% caused undesirable changes in texture and sensory perception. In the case of butter, the best result was achieved with a 1% addition, which provided a balance between enhanced antioxidant protection and preservation of typical organoleptic properties. Exceeding this threshold led to oversaturation of taste and disruption of consistency.

The observed optimal effect at 3% addition of Chinese chives powder may be explained by the balanced delivery of bioactive sulfur-containing compounds (e.g., allicin and other thiosulfinates) together with phenolic antioxidants, which in moderate amounts provide maximal radical-scavenging and antimicrobial effects without compromising sensory and physicochemical stability. High concentrations may lead to over-concentration of sulfur compounds, causing off-flavours or pro-oxidant activity, while too low concentrations may not deliver sufficient levels to affect the food matrix [29-32]. The high efficacy of 3% aligns with prior evidence on *Allium* species, where moderate enrichments optimized antioxidant and preservative benefits without impairing organoleptic or structural quality.

Shahrajabian et al. [33] and Giuffrè and Giuffrè [34] emphasised the potential of Chinese chives and fermented products as sources of functional compounds. However, Shahrajabian et al. did not conduct applied tests with different types of raw material stabilisation and their effect on food properties. The study of Giuffrè and Giuffrè was limited to theoretical analysis and did not cover the behaviour of plant components in complex matrices. In contrast to these studies, the presented study covered distinct product groups and demonstrated quantitative indicators of the compatibility of Chinese chives with fat, protein, and gel-forming systems. This makes it focused on real technological implementation.

Aziz et al. [35] and Bansal et al. [36] considered phytonutrients from vegetable sprouts and spices as elements of functional nutrition. Aziz et al. summarised information on bioactive compounds but did not provide data on their behaviour under thermal or mechanical stress. Bansal et al. [36] lacked information on the quantitative organoleptic acceptability of plant additives in specific products. Unlike these generalised reviews, the present study included experimental testing of dosage ranges (from 1% to 5%) for each product, which helped to identify the limits of functional effectiveness and sensory balance. This ensures concrete recommendations for recipe development.

On the other hand, Sun et al. [37] and Hong et al. [38] focused on the microbiological aspects of fermentation and the use of fruits as functional agents. Sun et al. [37] did not consider the stability of bio-components under long-term storage conditions and interaction with emulsifiers. Hong et al. [38] emphasised the nutritional value of pears but did not cover practical issues of recipe adaptation and texture compatibility. In contrast to these studies, the present study demonstrated a comprehensive approach – from the selection of the drying method to organoleptic thresholds and structural homogeneity – accounting for the specifics of each product matrix. Such a level of detail provides a basis for industrial testing of functional additives based on Chinese chives.

Onoruoiza et al. [39] and Lai and Wong [40] provided information on the effect of functional products on the state of the microbiota and the possibilities for optimising polyphenolic compounds. Onoruoiza et al. [39] pointed out the significance of metabolic interactions with probiotics; however, concrete matrices and models for the application of ingredients were not presented. Lai and Wong [40] focused on the delivery of quercetin in functional systems, but their calculations were not supported by data on stability or organoleptic properties. In contrast to these approaches, the present study included direct experimental data on sensory stability, texture, and acceptable doses of Chinese chives powder at various levels of incorporation into real samples.

Avinash et al. [41] and Otunola and Martirosyan [42] placed the emphasis on the physicochemical properties of conventional components and the selection of food carriers for functional products. Avinash et al. [41] detailed the morphological, nutritional, and phytochemical characteristics of *Phyllanthus emblica*, emphasising its potential as a functional ingredient. However, the analysis focused on the raw material and did not include data on its interaction with food matrices or its effect on textural and organoleptic properties. Otunola and Martirosyan [42] substantiated approaches to selecting suitable carriers for encapsulating bioactive substances, including bioavailability and stability criteria, but without concrete adaptation to actual recipes or products. In contrast, the present study tested various dosages of Chinese chives powder (*Allium odorum*) in four food systems: fermented milk drink, oil, salad dressing, and vegetable pâté.

Mishra et al. [43] and Ponte et al. [44] discussed the global

scale of functional product use and consumer perception characteristics. Mishra et al. [43] mentioned the potential of plant antioxidants in regulating peroxide oxidation, but did not provide data on concrete local cultures. Ponte et al. [44] identified a trend towards the use of unprocessed ingredients, but the review lacked information on composition and sensory acceptability. The present study filled these gaps by providing empirical indicators of texture uniformity, acidity, phenolic content, and sensory scores when using various doses of Chinese chives, including 1% and 5%, depending on the product properties.

Almeida et al. [45] and Martínez and Campos [46] discussed the effects of adding bioactive additives to functional products. Almeida et al. [45] investigated the effect of spirulina biomass on the physicochemical parameters and microstructure of the product, but without comparison with other sources of natural phytocomponents. Martínez and Campos [46] focused on the anticoagulant properties of individual compounds but did not present model food systems involving them. In contrast to these studies, the presented study demonstrated the use of stabilised *Allium odorum* in various products, considering its sensory, technological, and antioxidant properties, confirmed by instrumental and sensory methods.

In thematic publications by Fernández-Ochoa et al. [47] and Agrawal et al. [48], the emphasis was placed on the molecular composition and potential role of plant components. Fernández-Ochoa et al. [47] emphasised the significance of high-resolution analytical methods (LC-MS, HPLC) in the standardisation of functional products but did not consider concrete examples of the application of the data obtained. Agrawal et al. [48] summarised the functional characteristics of phytochemicals but did not provide quantitative indicators or applications in food products. In contrast, the present study presented not only an analysis of the composition of *Allium odorum*, but also data on its action in real food matrices, including dairy, oil, and plant products.

Sharma and Yadav [49] and Casari et al. [50] focused on the broad potential of functional products in disease prevention. Sharma and Yadav [49] considered the role of bioactive compounds in promoting health, but without localising them to concrete crops or technological parameters. Casari et al. [50] investigated the epigenetic mechanisms of action of food compounds on cancer processes, but without data on their stability in food systems. Unlike these studies, the present study focused on the functionality of Chinese chives as an ingredient with concrete antioxidant properties. The data presented confirm the technological feasibility of using Chinese chives powder in various food systems. A combination of physicochemical, rheological, and sensory analyses helped to identify the most suitable concentrations and substantiate the effectiveness of the addition both in terms of structure stabilisation and consumer characteristics. The findings demonstrated the possibility of integrating Chinese chives into the formulations of functional products, considering the characteristics of each matrix in terms of texture-forming and sensory effects in food production conditions, which was confirmed by a series of field tests.

5. CONCLUSIONS

Freeze-drying proved to be the most effective method for preserving the bioactive components, colour, and aromatic properties of Chinese chives. Compared to vacuum drying, freeze-drying retained higher levels of chlorophylls (12.6 mg/g vs. 9.1 mg/g), antioxidant activity (85.3% vs. 61.2%), and aromatic compounds such as allyl mercaptan and allylpropyl disulfide. Additionally, freeze-dried samples showed greater stability, with less loss in bioactive substances over time, making it the superior method for producing high-quality Chinese chives powder for functional food applications.

The optimal dosage of Chinese chives powder varied depending on the product. For fermented milk drinks, a 2-3% addition provided the best balance of antioxidant activity, pH stabilization, and sensory characteristics, without causing texture or taste degradation. In butter, a 1% addition was most effective in enhancing antioxidant protection and preserving organoleptic qualities, while higher doses negatively impacted taste and consistency. Similarly, for salad oil, 1.0-1.5% was ideal, improving antioxidant activity and shelf life, while maintaining a natural and balanced aroma and taste.

This study demonstrates the feasibility of incorporating Chinese chives powder into various food matrices, offering potential for enhancing the functional properties of products with natural antioxidants and antimicrobial effects. The findings provide practical insights for food manufacturers seeking to improve the shelf life and health benefits of their products without the use of artificial additives. Future research should focus on long-term stability tests across various storage conditions, further mechanistic studies on the interaction of Chinese chives' bioactive compounds with food matrices, and the exploration of its health benefits through in vivo studies.

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