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RESEARCH ARTICLE
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PHYSICOCHEMICAL AND MICROBIOLOGICAL EVALUATION OF 6-GINGEROL–FORTIFIED FUNCTIONAL MAYONNAISE: A POTENTIAL DIETARY PRODUCT FOR DIABETICS

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ABSTRACT
Ginger oleoresin, rich in 6-gingerol, has emerged as a natural bioactive source with promising antidiabetic, antioxidant, and anti-inflammatory potential for managing type 2 diabetes. This study aimed to formulate and evaluate a 6-gingerol rich ginger oleoresin-fortified functional mayonnaise as a natural, plant-based, and safe dietary product with improved physicochemical stability and microbiological safety, for diabetic consumers. Ginger rhizomes collected from the Ayub Agricultural Research Institute, Faisalabad, were dried, and subjected to ultrasonication-assisted extraction using ethanol to obtain 6-gingerol-rich oleoresin. The fortified mayonnaise was then prepared and evaluated for physicochemical, microbiological, and sensory attributes over an 8-week storage period using four different formulations with varying concentrations of ginger oleoresin. Results demonstrated that ginger oleoresin contributed to maintaining pH, suppressing microbial proliferation, and enhancing emulsion stability during storage. Sensory evaluation showed that treatment with 0.5% ginger oleoresin supplementation achieved superior ratings for mouthfeel, taste, aroma, and overall acceptability. In conclusion, 0.5% supplementation produced the most stable and organoleptically acceptable mayonnaise, underscoring its potential as a safe, functional, and health-promoting dietary product for diabetics.

Keywords: Ginger oleoresin, functional mayonnaise, diabetic diet, physicochemical stability, microbiological safety, sensory evaluation, plant-based functional food

1. INTRODUCTION
Mayonnaise is a widely consumed semisolid oil-in-water emulsion, traditionally prepared by mixing vegetable oil with ingredients such as egg and vinegar to achieve a stable and smooth texture (Relvas *et al.*, 2024). However, its quality and storage stability are highly susceptible to oxidative deterioration, particularly interfacial oxidation, which not only affects sensory attributes but also

shortens shelf life. Factors such as the type of emulsifier, surface area of the oil–water interface, and chemical composition of the formulation play critical roles in governing oxidative stability (Nuchi et al., 2002; Calligaris et al., 2007).

To mitigate rancidity and extend shelf life, synthetic antioxidants including butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), and tert-butylhydroquinone (TBHQ) are frequently employed. Despite their proven efficacy, health concerns surrounding the potential toxicity of synthetic additives (Barlow, 1990), along with rising consumer preference for clean-label, naturally derived functional foods, have accelerated the search for safer and more bioactive alternatives.
Growing awareness about the bioactive potential of ginger (*Zingiber officinale*) and the polyphenolic constituents, especially 6-gingerol, found in its oleoresin (Teng et al., 2019) as well as its flavour has led to marked interest for the ginger oleoresin infusion in various foods at home and in industry. Many studies have found antioxidant, antimicrobial, antilipid oxidation and antidiabetic effects of ginger used in different forms in various types of food. Research indicates that 6-gingerol may regulate glucose metabolism, improve insulin sensitivity, and ameliorate oxidative stress, making it an attractive ingredient for functional foods tailored to individuals with diabetes.

The utilization of ginger powder in mayonnaise preparation has already been proven for improving its oxidative stability, microbial safety and overall sensory appeal (Vitalini et al., 2023). The present project has been carried out to formulate ginger oleoresin supplemented mayonnaise as a readily available dietary source of ginger's bioactive compound for those in need. Based upon this, the present study aims to formulate and evaluate a 6-gingerol–fortified functional mayonnaise as a natural, plant-based, safe-to-use food product with dual benefits: improved physicochemical stability and microbiological safety, alongside potential nutritional value for diabetic consumers. To the best of our knowledge, this is the first comprehensive attempt to integrate 6-gingerol–enriched ginger oleoresin into mayonnaise, thereby reducing dependence on synthetic additives while offering added health functionality.

2. MATERIALS AND METHODS

2.1 Procurement of Raw Material

Fresh ginger rhizomes were procured from Ayub Agriculture Research Institute, Faisalabad. The rhizomes were washed thoroughly and sliced into thin pieces. The slices were completely dried in a tray dryer (R-5A; Harvest Saver; USA) at 55 °C, milled into fine powder using a mechanical grinder, and stored in airtight containers at room temperature until further use.

2.2 Preparation of Ginger Oleoresin

Ethanolic extract of ginger powder was obtained by mixing 40 g of ginger powder with 250 mL of 90% ethanol followed by ultrasonication using an ultrasonic cleaning unit (Elmasonic E 60 H; Singen; Germany) at 50 °C for 35 min (Foudah et al., 2020). The solvent was evaporated using a rotary evaporator (VP30; LabTech; China), and the resulting oleoresin was stored at 4 °C until further use (Jayathilake et al., 2022).

2.3 Product Development

Control mayonnaise was prepared according to Kishk and Elsheshetawy (2013). Experimental formulations were prepared by supplementing the prepared product with varying concentrations of ginger oleoresin (Table 1). All treatments wer stored at 4 °C for a period of 8 weeks.

Table 1. Treatment plan for ginger oleoresin-supplemented mayonnaise

Treatment	Formulation
T_0	100% mayonnaise
T_1	0.25% ginger oleoresin + 99.75% mayonnaise
T_2	0.50% ginger oleoresin + 99.50% mayonnaise
T_3	0.75% ginger oleoresin + 99.25% mayonnaise
T_4	1.00% ginger oleoresin + 99.00% mayonnaise

2.4 Product Quality Analyses
2.4.1 Physicochemical Analyses
pH Measurement: The pH of mayonnaise samples was measured at 0, 4, and 8 weeks of storage using a calibrated digital pH meter (MW150; Milwaukee; USA) at room temperature, following the manufacturer's protocol.
Stability Evaluation: Emulsion stability was determined according to Mun et al. (2009). Ten grams (W_1) of each sample taken in test tube fitted with plastic caps, was centrifuged at 5000 rpm for 15 min to eliminate oil formed as a layer at the top of the sample. The weight of the precipitated fraction (W_2) was recorded, and stability was calculated as:
Stability (%) = $W_2 / W_1 \times 100$

2.4.2 Microbial Analysis
Microbial load was determined following Prisacaru et al. (2023) with modifications. One milliliter of mayonnaise sample was homogenized with 9 mL sterile distilled water to obtain a 10^{-1} dilution. Serial dilutions were prepared up to 10^{-5}, and 0.1 mL aliquots were plated on nutrient agar. Plates were incubated at 30 °C for 48 h, and colonies were enumerated using a digital colony counter (Galaxy 230; UTECH; New York, USA). Results were expressed as colony-forming units per gram (CFU × 10^5/g).

2.4.3 Sensory Evaluation
Sensory evaluation was conducted by a semi-trained panel (n = 12) from National Institute of Food Science and Technology, University of Agriculture Faisalabad, using a 9-point hedonic scale (Meilgaard et al., 2007). Parameters included color, aroma, taste, mouthfeel, and overall acceptability. Panelists were presented with coded mayonnaise samples along with 1.5 inches squared cut white bread slices, under controlled laboratory conditions.

2.5 Statistical Analysis
Data were analyzed using analysis of variance (ANOVA) in Minitab 17 software. Mean separation was performed using Tukey's test at a 95% confidence level.

3. RESULTS
3.1 pH Measurement
The effect of ginger oleoresin supplementation and storage time on mayonnaise pH is shown in Table 2. A significant ($p < 0.05$) decrease in pH was observed across all treatments during 8 weeks of storage. At week 0, the highest pH was recorded in the control sample, which declined significantly after 8 weeks. Among supplemented samples, T_3 maintained the highest pH values at weeks 4 and 8. The least change in pH was observed in T_2, whereas the greatest drop occurred in T_0 (Fig. 1).

Table 2. Effect of ginger oleoresin supplementation on pH of mayonnaise

Treatments	Week 0	Week 4	Week 8	Overall mean
T_0 (0% GO)	4.3±0.03 a	3.96±0.02 f	3.52±0.02 h	3.93±0.33 D
T_1 (0.25% GO)	4.27±0.02 ab	4.04±0.02 e	3.79±0.03 g	4.03±0.21 C
T_2 (0.5% GO)	4.25±0.02 ab	4.12±0.02 d	3.93±0.01 f	4.10±0.14 B

T_3 (0.75% GO)	4.21±0.03 bc	4.16±0.02 cd	4.12±0.02 d	4.16±0.04 A
T_4 (1.0% GO)	4.17±0.02 cd	4.12±0.02 d	4.04±0.04 e	4.11±0.06 B
Overall mean	4.24±0.05 A	4.08±0.07 B	3.88±0.22 C	4.07±0.20

GO = Ginger Oleoresin; Values are mentioned as mean ± SD; n=3; Values in a column not sharing a letter differ significantly with each other

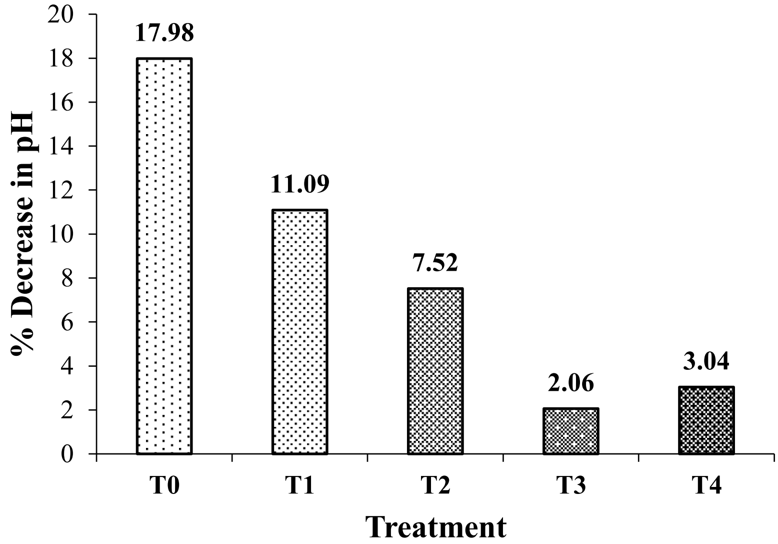

Fig. 1: % Decrease in pH of mayonnaise after storage

3.2 Microbial Analysis

Table 3 shows the microbial counts of mayonnaise samples. Initial microbial loads were similar across treatments. During storage, all treatments exhibited an increase in microbial population, but the magnitude differed significantly ($p < 0.05$). By week 8, T_0 reached the highest microbial count, while T_4 exhibited the lowest. The highest relative increase was observed in T_0 (65.22%), whereas T_4 displayed only a 3.15% rise (Fig. 2).

Table 3. Effect of ginger oleoresin supplementation on microbial load of mayonnaise

Treatments	Week 0	Week 4	Week 8	Overall mean
T_0 (0% GO)	5.70±0.03 i	7.72±0.03 b	9.42±0.05 a	7.62±1.61 A
T_1 (0.25% GO)	5.70±0.02 i	6.39±0.04 d	7.64±0.05 c	6.57±0.85 B
T_2 (0.5% GO)	5.70±0.01 i	6.14±0.03 e	6.45±0.04 d	6.10±0.33 C
T_3 (0.75% GO)	5.71±0.01 i	5.82±0.02 gh	6.01±0.04 f	5.85±0.13 D
T_4 (1.0% GO)	5.71±0.01 i	5.78±0.01 hi	5.89±0.02 g	5.79±0.08 E
Overall mean	5.70±0.01 C	6.37±0.74 B	7.08±1.37 A	6.38±1.05

GO = Ginger Oleoresin; Values are mentioned as mean±SD; n=3; Values in a column not sharing a letter differ significantly with each other.

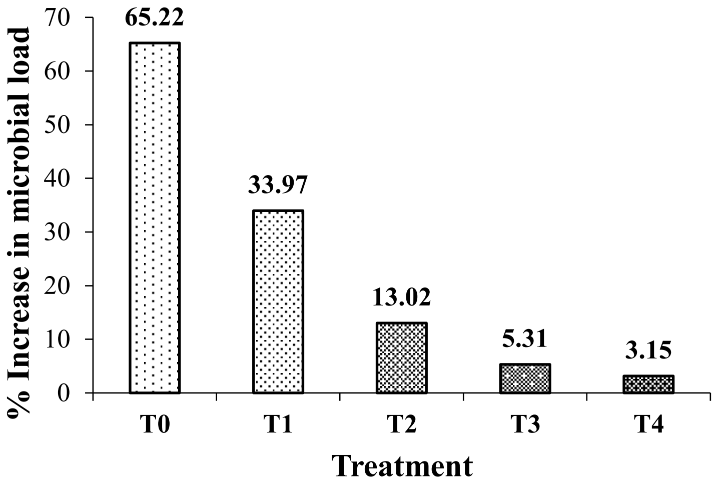

Fig. 2: % Increase in microbial load of mayonnaise after storage

3.3 Stability Test

The stability of mayonnaise samples after storage is summarized in Table 4. All formulations showed a decrease in stability during storage. T_3 exhibited the highest stability, followed by T_1, whereas T_4 demonstrated the lowest. The T_0 showed moderate stability. The smallest reduction in stability was noted in T_2 (0.77%), while the largest was in T_4 (6.9%) (Fig. 3).

Table 4. Effect of ginger oleoresin supplementation on stability of mayonnaise

Mayonnaise treatments	Stability (%)		
	Before storage	After storage	Change in stability
T_0 (0% GO)	86.33±0.57	82.00±1.00 CD	-4.33±1.53 AB
T_1 (0.25% GO)	86.33±0.57	84.33±0.58 AB	-2.00±1.00 BC
T_2 (0.5% GO)	86.33±0.57	83.00±1.00 BC	-0.67±0.58 C
T_3 (0.75% GO)	86.33±0.57	85.67±0.58 A	-3.33±0.58 ABC
T_4 (1.0% GO)	86.33±0.57	80.33±0.58 D	-6.00±1.00 A

GO = Ginger Oleoresin; Values are mentioned as mean±SD; n=3; Values in a column not sharing a letter differ significantly with each other.

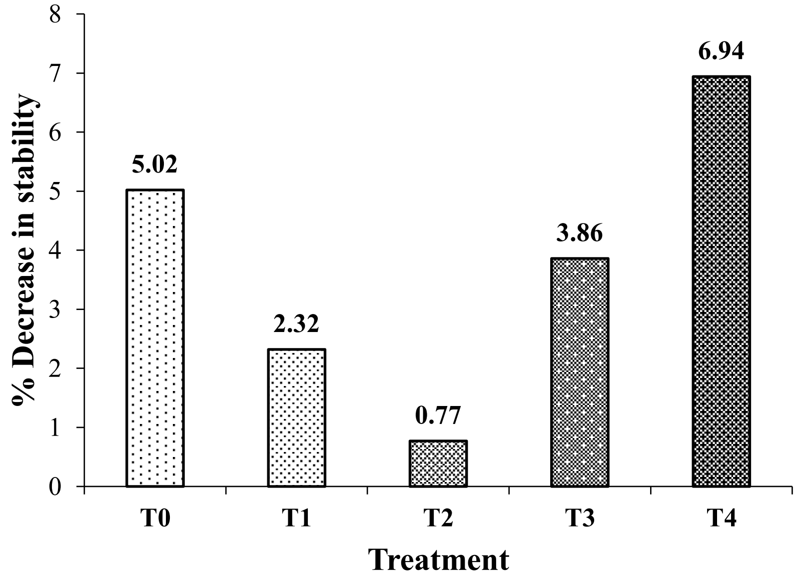

Fig. 3: % Decrease in stability of mayonnaise after storage

3.4 Sensory Evaluation

Mean sensory scores are presented in Table 5. Significant differences ($p < 0.05$) were observed among treatments for all attributes. T_1 received the highest score for colour. T_2 scored highest for taste, mouthfeel, aroma, and overall acceptability. In contrast, T_4 consistently received the lowest scores, particularly for taste and mouthfeel. Radar plots (Fig. 4) illustrate the superior sensory profile of T_2 compared to other treatments.

Table 5. Sensory properties of different treatment of mayonnaise

Treatments	Colour	Mouthfeel	Taste	Aroma	Overall acceptability
T_0 (0% GO)	6.75±1.14 ^{b}	5.50±1.00 ^{bc}	5.33±0.88 ^{b}	6.33±1.48 ^{abc}	6.00±0.85 ^{b}
T_1 (0.25% GO)	8.00±0.95 ^{a}	6.42±1.24 ^{ab}	5.92±1.16 ^{ab}	5.83±0.94 ^{bc}	7.16±0.72 ^{a}
T_2 (0.5% GO)	7.50±1.00 ^{ab}	7.58±0.99 ^{a}	6.92±1.08 ^{a}	7.33±1.07 ^{a}	7.25±1.14 ^{a}
T_3 (0.75% GO)	7.58±0.79 ^{ab}	6.17±0.94 ^{b}	6.67±0.78 ^{ab}	7.00±1.28 ^{ab}	5.92±0.79 ^{b}
T_4 (1.0% GO)	6.83±0.94 ^{b}	4.75±1.05 ^{c}	4.83±1.12 ^{b}	5.17±1.12 ^{c}	5.25±0.96 ^{b}

GO = Ginger Oleoresin; Values are mentioned as mean ± SD; n=12; Values in a column not sharing a letter differ significantly with each other.

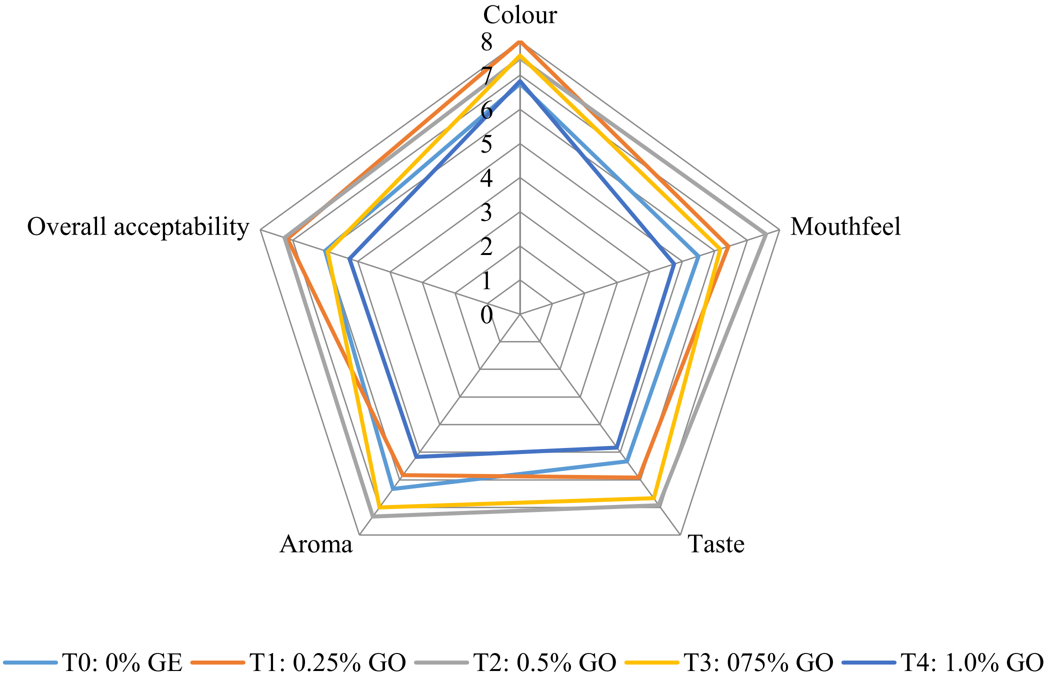

Fig. 4: Radar diagram of sensory characteristics of mayonnaise

4. DISCUSSION

The findings of this study demonstrate that supplementation of mayonnaise with ginger oleoresin significantly influenced its physicochemical, microbiological, and sensory properties.

All mayonnaise formulations showed a progressive decline in pH during storage, consistent with earlier studies (Worrasinchai et al., 2006; El-Bostany et al., 2011). The pronounced drop in pH in the control sample is attributable to lactic acid bacteria activity (Marinescu et al., 2011). Ginger oleoresin supplementation checked this decline, with T_2 showing the smallest pH reduction. This supports the antimicrobial role of ginger, likely linked to phenolic compounds such as 6-gingerol (Sebiomo et al., 2011; Lobiuc et al., 2023).

Emulsion stability was influenced by ginger oleoresin supplementation. While T_2 demonstrated the best stability, higher supplementation (T_4) unexpectedly reduced stability, possibly due to disruption of the emulsion system at elevated concentrations of acidic substances. Control mayonnaise (T_0), nevertheless, showed more stability than T_4. The change in the stability of mayonnaise was recorded to be decreased with time in to varying extents all treatments. Recent findings were consistent with those reported by Ayu et al. (2021), where product pH and protein interactions influenced emulsion integrity.

A general increase in the microbial population was noticed in all treatments at the end of the trial. The highest increase was seen in T_0, whereas T_4 manifested the least rise in microbial load aligning with recent studies on ginger's antimicrobial effects in various food systems (Muhialdin et al., 2020; Sethunga et al., 2023; Vitalini et al., 2023). Before storage microbial count of each treatment was statistically alike but a varying trend in the growth of microbial load was seen in the control and supplemented mayonnaise. A significant increase in microbial population was observed in the control and supplemented samples throughout the storage period, though the greatest microbial load was recorded in T_0 at week 8. Variations in antimicrobial efficiency may depend on concentration and oleoresin composition (Akullo et al., 2022).

Sensory evaluation revealed that consumers preferred mayonnaise with moderate ginger oleoresin concentration. T_2 (0.5% ginger oleoresin) scored highest for taste, aoma, mouthfeel as well as overall acceptability, likely due to its balanced flavor and organoleptic properties. Higher concentrations (T_4) adversely affected taste and mouthfeel, reducing consumer acceptability. The current findings are consistent with Kishk & Elsheshetawy (2013), who reported that optimal ginger levels enhanced sensory attributes, while excessive levels had the opposite effect.

Conclusion

Our study showed that adding ginger oleoresin to mayonnaise significantly influenced its physicochemical, microbiological, stability and sensory properties during 8 week refrigerated storage. The ginger oleoresin helped maintain pH levels, inhibited microbial growth, and improved emulsion stability. Mayonnaise with 0.5% ginger oleoresin achieved the best balance, offering enhanced antioxidant protection, microbial safety, and sensory appeal. However, higher concentrations, while effective against microbes, compromised taste and mouthfeel. The findings suggest ginger oleoresin is a promising natural ingredient for extending shelf life and reducing synthetic preservatives, aligning with demand for healthier, clean-label and plant-based products. Moreover, its incorporation into mayonnaise offers a safe, readily available, and functional dietary approach for diabetics, addressing both nutritional and health-related concerns.

Future research could focus on scaling up production, optimizing oleoresin levels, and assessing the retention of ginger's bioactive compounds in real-world market conditions. By optimizing ginger oleoresin levels, manufacturers can create high-quality, consumer-friendly mayonnaise with added nutritional value, gaining a competitive edge in the health-focused condiment market.

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