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Development and Quality Evaluation of Mayonnaise Enriched with Ginger (Zingiber Officinale), Garlic (Allium Sativum), and Onion (Allium Cepa) Extracts

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Abstract

The development and quality features of mayonnaise enhanced with onion (Allium cepa), garlic (Allium sativum), and ginger (Zingiber officinale) in both natural and dehydrated forms were investigated in this study. A commercial mayonnaise (Bama®) was utilized as the control, and eight experimental mayonnaise compositions with individual and mixed spice treatments were created.The products were evaluated for proximate composition, selected physicochemical and functional properties, and sensory attributes using standard analytical procedures.The proximate composition revealed significant differences ($p < 0.05$) among the formulations. Moisture content ranged from 41.85 to 54.10%, while fat content varied between 30.23 and 42.42%. Protein content ranged from 1.02 to 2.90%, indicating nutritional improvement following spice incorporation, particularly in garlic-containing formulations. Ash content increased in spice-fortified samples, reflecting the mineral contribution of the added spices. The physicochemical evaluation showed that pH values ranged from 3.70 to 4.60, remaining within the acidic range required for microbiological stability of mayonnaise. Water absorption capacity, oil absorption capacity, bulk density, emulsion stability, foam stability, and peroxide value varied significantly among formulations, demonstrating that spice incorporation influenced the functional properties of the emulsions. Sensory evaluation indicated that all spice-fortified mayonnaise samples were generally acceptable to the panelists, with formulations containing garlic and mixed spice combinations receiving comparatively higher scores for flavour, mouthfeel, and overall acceptability. The incorporation of ginger, garlic, and onion enhanced the nutritional quality of mayonnaise without adversely affecting consumer acceptability. The study demonstrates that natural culinary spices can serve as functional flavouring ingredients in mayonnaise production while improving selected nutritional and quality attributes. These results encourage the use of native plant spices in the creation of value-added mayonnaise products that can satisfy the rising demand from consumers for condiments with natural flavors and improved functionality.

Key words:
Development, Mayonnaise, Ginger; Garlic; Onion, Quality Evaluation.

1. Introduction

One of the most widely utilized oil-in-water emulsified condiments in the world, mayonnaise is typically used as a dressing, sandwich spread, dip, and ingredient in a variety of processed meals. Vegetable oil makes up around 65–80% of the traditional mayonnaise recipe, which also includes egg yolk, vinegar or lemon juice, salt, sugar, and seasonings. The steady emulsion created between the oil and aqueous phases, with egg yolk phospholipids acting as the primary emulsifying agents, is primarily responsible for mayonnaise's distinctive physicochemical characteristics. Mayonnaise greatly enhances the sensory appeal of ready-to-eat foods and convenience items in addition to having a pleasing creamy texture and flavor (Depree & Savage, 2001; McClements, 2020).

Consumer preferences have evolved from traditional foods to products with natural ingredients that have added nutritional and functional qualities as a result of recent advancements in food science and technology. Increasing awareness of the potential health effects connected with synthetic preservatives, artificial flavour enhancers, and chemical antioxidants has driven research into the inclusion of bioactive substances obtained from herbs and spices into processed foods. As a result, natural plant ingredients are being investigated more and more as sources of antioxidants, antibacterial compounds, and nutritionally beneficial phytochemicals that can enhance food quality and prolong shelf life in addition to being used as flavoring agents (Shahidi & Ambigaipalan, 2015; Rather et al., 2023).

Due to their widespread usage in food preparation and their abundance of physiologically active chemicals, ginger (Zingiber officinale), garlic (Allium sativum), and onion (Allium cepa) have significant positions among culinary spices. In addition to offering a number of phytochemicals with antioxidant, antibacterial, anti-inflammatory, and other useful qualities, many spices have distinctive flavors and scents that increase consumer appeal. Interest in using these natural spices as substitutes for artificial additives in processed foods has increased due to the growing appeal of clean-label food items (Rahmani et al., 2024).

Ginger is an important rhizomatous spice belonging to the family *Zingiberaceae*. It contains numerous phenolic compounds including gingerols, shogaols, paradols, and zingerone, which are responsible for its characteristic pungency and biological activities. Several studies have shown that ginger exhibits considerable antioxidant capacity through its ability to scavenge reactive oxygen species and inhibit lipid oxidation. Because of these qualities, ginger is especially appealing for lipid-rich food systems like mayonnaise, where oxidative degradation is one of the main issues with quality during storage (Mao et al., 2019; Sharifi-Rad et al., 2022).

Similarly, garlic is well known for being one of the most abundant natural sources of organosulfur compounds, such as S-allyl cysteine, allicin, diallyl sulfides, and ajoene. These substances' antioxidant and antibacterial properties have drawn a lot of scientific interest. Beyond their health-promoting potential, garlic-derived compounds have demonstrated inhibitory effects against food spoilage microorganisms and oxidative degradation in several food systems. Consequently, garlic has been increasingly investigated as a natural preservative and flavouring ingredient capable of improving both product stability and consumer acceptance (Rahman, 2020; Salehi et al., 2021).

Another economically significant vegetable in the genus Allium is the onion. In addition to sulfur-containing substances that give it its unique flavor and scent, it includes significant amounts of flavonoids, especially quercetin and its glycosides. These phytochemicals have been linked to increased oxidative stability in diets containing lipids and enhance the antioxidant potential of onions.. Also, onion contributes desirable sensory characteristics while providing minerals, dietary fibre, and phenolic compounds that may enhance the nutritional profile of processed food products (Slimestad et al., 2021; Nile et al., 2023).

The incorporation of natural spices into mayonnaise has attracted growing scientific interest because mayonnaise is highly susceptible to oxidative rancidity as a result of its elevated lipid content. In addition to creating unwanted tastes and smells, lipid oxidation lowers nutritional value and shortens product shelf life. To stop these deteriorating changes, conventional manufacturers frequently use artificial antioxidants and preservatives. However, the desire of consumers for naturally preserved goods has prompted scientists to look for plant-based substitutes that can serve similar technological purposes while enhancing customer perception and product marketability (Liu et al., 2022). In addition to oxidative stability, the incorporation of spice powders or extracts may influence many quality attributes of mayonnaise, including emulsion stability, viscosity, pH, water-holding capacity, oil-binding capacity, colour, flavour, and overall sensory acceptability. Because mayonnaise is an emulsion system, any added ingredient has the potential to alter the interactions between the dispersed oil droplets and the continuous aqueous phase, thereby influencing its physicochemical and rheological properties. Understanding these interactions is therefore essential for the successful development of spice-enriched mayonnaise formulations (McClements, 2020; Dickinson, 2021).

Numerous studies have evaluated the incorporation of plant extracts, herbs, essential oils, and functional ingredients into mayonnaise to improve quality characteristics. However, most investigations have focused on isolated plant extracts or purified bioactive compounds rather than the direct application of commonly consumed culinary spices in both fresh and dehydrated forms. Additionally, there is still a dearth of comparative data on the effects of ginger, garlic, onion, and their combinations on the physicochemical, functional, and sensory characteristics of mayonnaise, especially in settings that are typical of locally accessible raw materials in developing nations.This knowledge gap restricts the wider utilization of indigenous spices in value-added condiment production.

The development of naturally flavoured mayonnaise using readily available indigenous spices offers several advantages. Besides improving flavour diversity and consumer appeal, such products may contribute to increased utilization of locally produced agricultural commodities, reduction in dependence on imported flavouring agents, and promotion of sustainable food processing practices. Moreover, the integration of natural spices into mayonnaise aligns with current global trends emphasizing functional foods, clean-label ingredients, and reduced reliance on synthetic food additives.

Therefore, the present study was designed to develop mayonnaise formulations fortified with ginger, garlic, and onion in both natural and dehydrated forms and to evaluate their proximate composition, physicochemical characteristics, functional properties, and sensory acceptability in comparison with a commercial mayonnaise. The idea was that adding these natural spices would enhance some functional and nutritional qualities without sacrificing consumer acceptance. In addition to offering useful information for food processors, researchers, the condiment business, and other stakeholders, the findings are anticipated to aid in the creation of novel mayonnaise formulations using local plant resources.

This study compares fresh and dehydrated ginger, garlic, and onion, both separately and in combination, in mayonnaise formulations, in contrast to earlier research that mostly looked at specific spice extracts or artificial flavorings. The paper supports the creation of clean-label, naturally flavored mayonnaise products using locally accessible plant ingredients by offering thorough data on their effects on proximate composition, physicochemical behavior, functional qualities, and sensory quality.

2.0 Materials and Methods

2.1 Study Design

This study employed a completely randomized experimental design to investigate the effects of incorporating ginger (*Zingiber officinale*), garlic (*Allium sativum*), and onion (*Allium cepa*) in natural and dehydrated forms on the quality characteristics of mayonnaise. Eight experimental mayonnaise formulations were produced using individual and combined spice treatments, while a commercially available mayonnaise (Bama®, Nigeria) served as the control. Each analysis was conducted in triplicate, and the results were expressed as mean ± standard deviation.

2.2 Procurement of Raw Materials

Fresh ginger rhizomes, garlic bulbs, onion bulbs, fresh hen eggs, refined vegetable oil, white vinegar, granulated sugar, sodium chloride (table salt), white pepper, mustard stabilizer, and other ingredients used in mayonnaise production were purchased from Umuahia Main Market, Abia State, Nigeria. Commercial dehydrated ginger, garlic, and onion powders were obtained from Relief Market, Onitsha, Anambra State, Nigeria.

All raw materials were inspected to ensure freshness, freedom from physical defects, and compliance with acceptable food quality standards before use.

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2.3 Chemicals and Reagents

All chemicals and analytical reagents used for laboratory analyses were of analytical grade. Distilled water was used throughout the experimental procedures. Analytical reagents required for proximate and physicochemical analyses were obtained from accredited laboratory suppliers.

2.4 Equipment

The laboratory analyses were conducted using standard food analytical equipment available at the National Root Crops Research Institute (NRCRI), Umudike, Nigeria. Major equipment included:Laboratory grinder (Jenway Model 6051), Electric mixer (Vecstar Model 054321), Hot air oven, Muffle furnace, Soxhlet extraction apparatus, Kjeldahl digestion and distillation units, pH meter, Water bath, Centrifuge, Analytical balance, Laboratory glassware.

Prior to use, every piece of equipment was calibrated in accordance with laboratory quality assurance protocols.

2.5 Preparation of Spice Powders

2.5.1 Preparation of Ginger Powder

Fresh ginger rhizomes were washed thoroughly under running potable water to remove adhering soil particles. The rhizomes were peeled manually using stainless-steel knives and sliced into thin sections to facilitate drying. The slices were sun-dried for three (3) consecutive days until constant weight was achieved before being milled into fine powder using a laboratory grinder. The powdered ginger was sieved through a fine mesh sieve to obtain a uniform particle size and stored in airtight polyethylene containers until required for mayonnaise production.

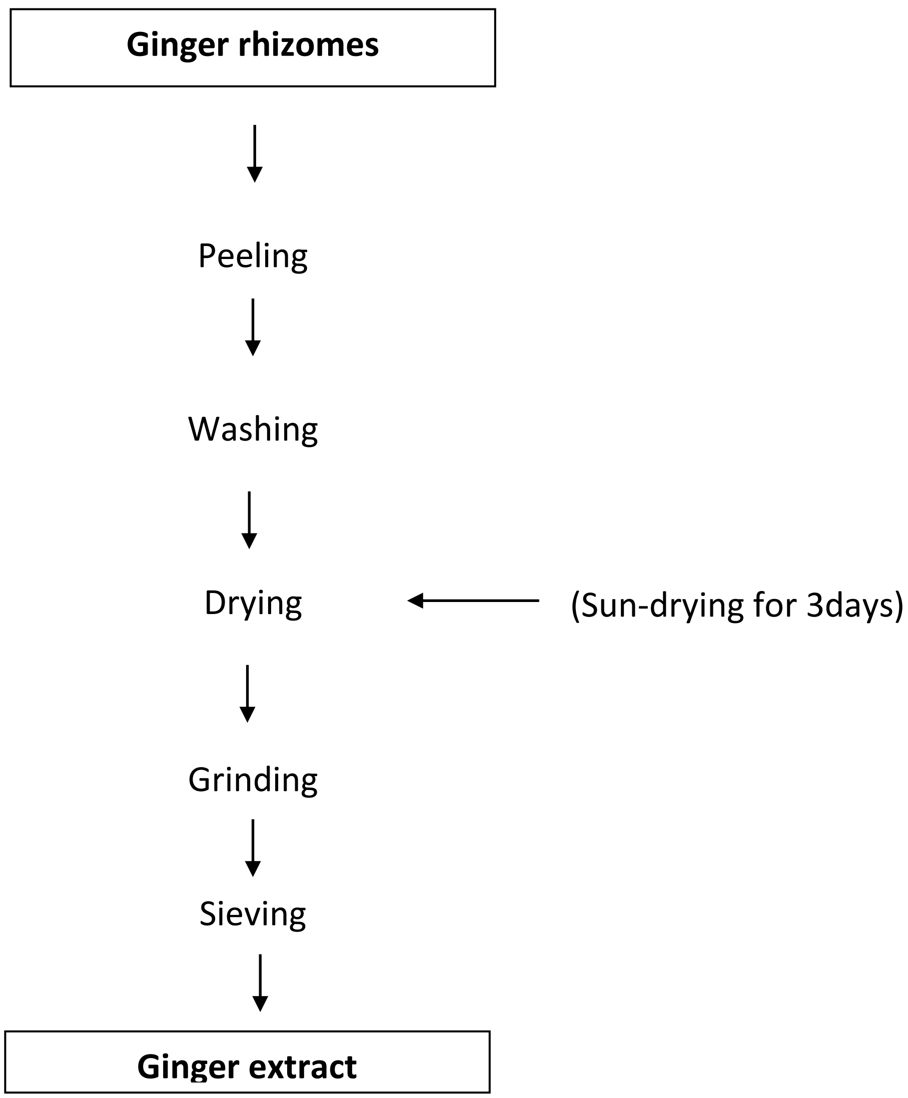

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Fig. 1: Flow chart for the production of ginger extract.

2.5.2 Preparation of Onion Powder

Fresh onion bulbs were cleaned, peeled, washed thoroughly, and sliced uniformly before sun drying for three days. The dried onion slices were milled into fine powder using the same laboratory grinder and sieved to obtain homogeneous onion powder. The powder was stored in airtight containers at ambient laboratory temperature until use.

2.5.3 Preparation of Garlic Powder

Fresh garlic bulbs were peeled, washed, and sliced before sun drying for three (3) days. The dried garlic slices were ground into powder using a laboratory grinder and sieved to obtain a fine powder. The resulting garlic powder was packaged in moisture-proof containers until incorporation into mayonnaise formulations.

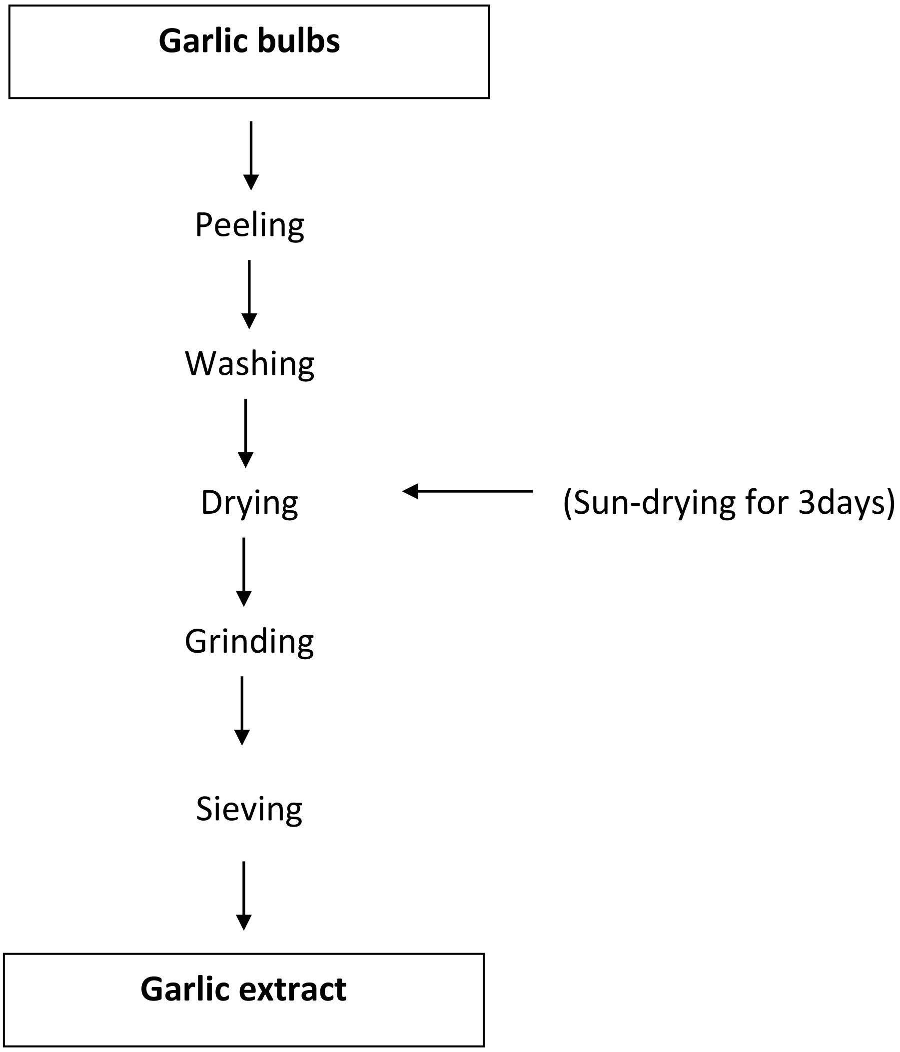

Fig. 3: Flow chart of garlic extracts production

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2.6 Production of Mayonnaise

Mayonnaise samples were prepared according to a modified laboratory-scale procedure adapted and modified from the original formulation described by Xiong et al. (2000).

Sodium chloride (0.25 g), granulated sugar (0.25 g), and white pepper (0.50 g) were blended using an electric mixer operating initially at low speed. Pasteurized egg yolk (22 mL) was gradually incorporated, followed by the slow addition of white vinegar (4 mL) and distilled water (2 mL). Continuous mixing facilitated the formation of the primary emulsion.

The mixer speed was subsequently increased while refined vegetable oil (85 mL) was added slowly in a continuous stream until a stable oil-in-water emulsion was formed. Mustard stabilizer (0.36 g) was incorporated to improve emulsion stability and texture. Finally, 6.0 g of the designated spice treatment was added according to the formulation schedule shown in Table 1. Mixing continued until a smooth, homogeneous mayonnaise was obtained.

The finished products were transferred into sterilized glass containers, sealed immediately, and stored under refrigeration (4 ± 1°C) before laboratory analyses.

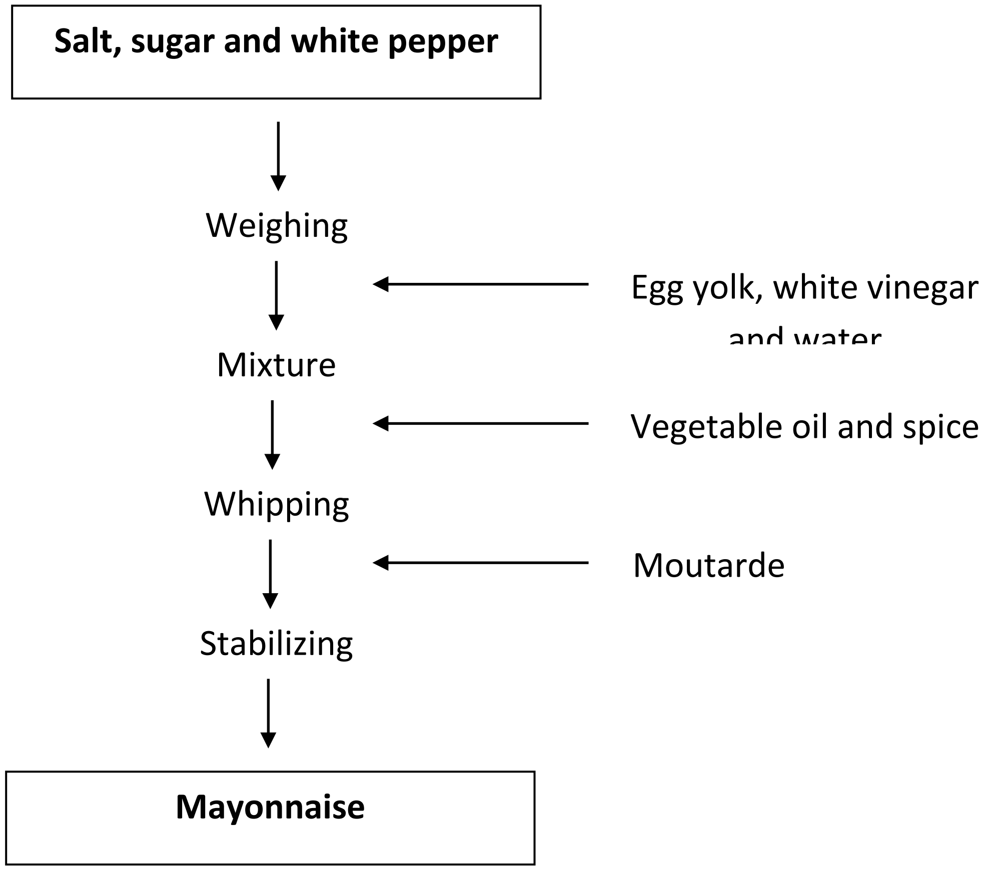

Fig 4: Flow chart for the production of mayonnaise

Table 1. Formulation of Mayonnaise Samples

Sample Code	Treatment
104	Mayonnaise containing fresh ginger
249	Mayonnaise containing fresh onion
376	Mayonnaise containing fresh garlic
461	Mayonnaise containing fresh ginger + onion + garlic
538	Mayonnaise containing ginger powder
652	Mayonnaise containing onion powder
712	Mayonnaise containing garlic powder
825	Mayonnaise containing mixed ginger, onion, and garlic powders
987	Commercial mayonnaise (Control)

Table 2. Ingredient Composition of Experimental Mayonnaise

Ingredient	Quantity
Vegetable oil	85 mL
Egg yolk	22 mL
White vinegar	4 mL
Water	2 mL
Spice	6.0 g
Salt	0.25 g
Sugar	0.25 g
White pepper	0.50 g
Mustard stabilizer	0.36g

2.8 Determination of Functional Properties

The functional properties of the mayonnaise samples were evaluated to determine their physicochemical behavior, structural stability, and suitability for commercial application. These properties influence product quality, shelf stability, consumer acceptability, and processing characteristics. All analyses were carried out in triplicate, and results were expressed as mean ± standard deviation.

2.8.1 Determination of pH

The pH of the mayonnaise samples was determined using a calibrated digital pH meter following the procedure described by AOAC International (2023**)**. Approximately 10g of each mayonnaise sample was dispersed in 50 mL of distilled water and homogenized thoroughly. The pH meter was calibrated using standard buffer solutions of pH 4.00 and 7.00 before analysis. The electrode was immersed in the homogenized sample, and the pH reading was recorded after stabilization.

The pH of mayonnaise is an important quality parameter because it influences microbial stability, product safety, flavour, and shelf life. Commercial mayonnaise generally possesses a pH below 4.6, which inhibits the growth of pathogenic microorganisms such as *Salmonella* spp. and *Clostridium botulinum* (AOAC International, 2023; McClements, 2020).

2.8.2 Determination of Water Absorption Capacity (WAC)

Water absorption capacity was determined using the centrifugation method of Beuchat (1977) with slight modifications. One (1) gram of each sample was mixed with 10 mL of distilled water in a centrifuge tube and allowed to stand for 30 minutes at room temperature with intermittent stirring. The mixture was centrifuged at 3,000 rpm for 20 minutes, and the supernatant was carefully decanted. The amount of water retained by the sample was calculated and expressed as grams of water absorbed per gram of sample.

Water absorption capacity measures the ability of food components, particularly proteins and dietary fibres, to bind and retain water. High water absorption contributes to improved viscosity, texture, consistency, and emulsion stability in mayonnaise and other semisolid food systems (Beuchat, 1977; Damodaran, 2021).

2.8.3 Determination of Oil Absorption Capacity (OAC)

Oil absorption capacity was determined according to the procedure described by Beuchat (1977)**.** One gram of sample was mixed thoroughly with 10 mL of refined vegetable oil and allowed to stand for 30 minutes. The mixture was centrifuged at 3,000 rpm for 20 minutes, and the unbound oil was decanted. The retained oil was quantified and expressed as grams of oil absorbed per gram of sample.

Oil absorption capacity reflects the ability of proteins and other food constituents to physically bind lipids. This property contributes to flavour retention, mouthfeel, and the overall stability of oil-in-water emulsions such as mayonnaise (McClements, 2020; Dickinson, 2021).

2.8.4 Determination of Bulk Density

Bulk density was determined using the tapped-cylinder method described by Onwulata (2022). A known weight (10 g) of each sample was transferred into a clean, dry 25 mL graduated cylinder. The cylinder was gently tapped several times until a constant volume was attained. Bulk density was calculated using the equation:

Bulk Density (g/mL) = Weight of Sample (g) / Volume Occupied (mL)

Bulk density indicates the degree of compactness of a material and influences packaging, transportation, mixing efficiency, and storage characteristics of powdered food ingredients incorporated into mayonnaise formulations (Onwulata, 2022).

2.8.5 Determination of Emulsion Stability

Emulsion stability was evaluated according to the method described by McClements (2020). Approximately 20 g of mayonnaise was transferred into centrifuge tubes and centrifuged at 3,000 rpm for 15 minutes. The samples were subsequently heated in a water bath at 80°C for 30 minutes and centrifuged again. The percentage of emulsion remaining stable after treatment was calculated.

Emulsion stability (%) was calculated as:

Emulsion Stability (%) = (Weight of Stable Emulsion / Initial Sample Weight) × 100

Emulsion stability represents the resistance of the oil-in-water emulsion to phase separation during processing and storage. Stable emulsions improve product appearance, texture, and shelf life (McClements, 2020; Dickinson, 2021).

2.8.6 Determination of Foam Stability

Foam stability was determined using the procedure reported by Damodaran (2021). Approximately 50 mL of each sample was whipped using a laboratory mixer for 5 minutes. The initial foam volume was recorded immediately after whipping, while the final foam volume was measured after standing for 30 minutes at room temperature.

Foam stability was calculated using the equation:

Foam Stability (%) = (Foam Volume after 30 min / Initial Foam Volume) × 100

Foam stability evaluates the ability of proteins and other surface-active compounds to maintain incorporated air bubbles over time. Although foaming is not a principal quality attribute of mayonnaise, it provides useful information regarding protein functionality and interfacial properties (Damodaran, 2021).

2.8.7 Determination of Peroxide Value

Peroxide value was determined according to the iodometric titration method described in AOAC International (2023). Oil extracted from each mayonnaise sample was reacted with acetic acid–

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chloroform solution and potassium iodide, followed by titration with standardized sodium thiosulphate using starch as an indicator.

Peroxide value (mEq O_2/kg oil) was calculated as:

PV = (S × N × 1000) / W

Where:

S = volume of sodium thiosulphate (mL)

N = normality of sodium thiosulphate

W = weight of oil sample (g)

Peroxide value is a measure of primary lipid oxidation and serves as an important indicator of oxidative deterioration in mayonnaise. Lower peroxide values indicate greater oxidative stability and better product quality during storage (Shahidi & Zhong, 2020).

Proximate composition was determined according to the standard methods of the AOAC International (2023).

All analyses were performed in triplicate.

2.9 Sensory Evaluation

Sensory evaluation was conducted using twenty (20) semi-trained panelists recruited from staff and postgraduate students familiar with mayonnaise products. Ethical approval for sensory participation was obtained according to institutional guidelines, and informed consent was obtained from all participants before evaluation.

Samples were coded using random three-digit numbers and presented in randomized order to minimize bias.

Panelists evaluated the samples for:

- Colour
- Taste
- Flavour
- Consistency
- Mouthfeel
- Overall acceptability

Evaluation was performed using a 9-point hedonic scale, where:

- 9 = Like extremely
- 5 = Neither like nor dislike
- 1 = Dislike extremely

Potable water was provided between samples to minimize flavour carry-over.

2.10 Statistical Analysis

All experimental determinations were carried out in triplicate, and results were expressed as mean ± standard deviation (SD). Data were subjected to one-way analysis of variance (ANOVA) using IBM SPSS Statistics (Version 26.0, IBM Corp., Armonk, NY, USA). Significant differences among treatment means were separated using Duncan's Multiple Range Test at a significance level of $p < 0.05$.

Results and Discussion

3.1 Proximate Composition of Spice-Enriched Mayonnaise

3.1.1 Moisture Content

The moisture content of the mayonnaise formulations ranged from 41.85% to 54.10%**,** with the formulation containing the combined fresh spices (Sample 461) exhibiting the highest value, whereas the commercial control recorded the lowest moisture content. The higher moisture observed in samples prepared with fresh ginger, garlic, and onion is expected because fresh spices naturally contain substantial amounts of water, which become incorporated into the continuous aqueous phase of the mayonnaise emulsion. Conversely, formulations containing dehydrated spices and the commercial control contained comparatively lower moisture levels because of the reduced water contribution from these ingredients.

Moisture content is one of the most important quality parameters influencing the physicochemical stability and microbial shelf life of mayonnaise. Increased moisture generally enhances water activity

and may increase susceptibility to microbial spoilage if storage conditions are inadequate. Nevertheless, the acidic environment of mayonnaise (pH below 4.6) substantially inhibits the growth of most pathogenic microorganisms, thereby improving product safety (McClements, 2020; Liu et al., 2022; Rather et al., 2023).
Similar observations have been reported for mayonnaise enriched with natural plant ingredients, where moisture variation was primarily dependent on the composition of the added botanical materials rather than product deterioration (Kumar et al., 2021; Yegin & Yildiz, 2024).

3.1.2 Dry Matter
Dry matter values ranged from 45.90% to 58.15%**,** showing an inverse relationship with moisture content.The commercial mayonnaise exhibited the highest dry matter due to its comparatively lower moisture level, while formulations containing fresh spice combinations recorded lower dry matter values.
Dry matter reflects the concentration of solids within food systems and contributes significantly to viscosity, body, texture, and storage stability. Products with higher dry matter generally exhibit greater emulsion stability because the dispersed oil droplets are more effectively immobilized within the continuous phase (McClements, 2020; Dickinson, 2021).
Comparable inverse relationships between moisture and dry matter have been reported in mayonnaise formulations enriched with vegetable powders and plant extracts (Rahmani et al., 2024).

3.1.3 Ash Content
Ash content ranged from 1.15% to 2.21%**,** with the mixed spice powder formulation (Sample 825) exhibiting the highest mineral content.
The observed increase in ash content following spice incorporation is indicative of an improvement in the mineral composition of the mayonnaise formulations. Ginger, garlic, and onion are recognized as valuable sources of essential minerals including potassium, calcium, phosphorus, magnesium, iron, and zinc (USDA, 2023; Nile et al., 2023).
The higher ash content observed in spice-fortified mayonnaise therefore reflects the contribution of these minerals to the finished product. Similar increases in mineral composition following incorporation of spice powders into food emulsions have been reported by Salehi et al. (2021) and Rahmani et al. (2024).

3.1.4 Fat Content
Fat content differed significantly ($p < 0.05$) among formulations, ranging from 30.23% to 42.42%**.** The onion-containing formulation (Sample 249) exhibited the highest fat content, whereas the commercial control recorded the lowest value.
Mayonnaise is a high-fat oil-in-water emulsion in which lipid content strongly influences creaminess, viscosity, lubrication, flavour release, and consumer acceptability. Variations in fat content among formulations may have resulted from differences in oil retention capacity and interactions between the incorporated spice particles and the oil droplets during emulsification (McClements, 2020; Dickinson, 2021).
Dietary fibres, proteins, and polysaccharides naturally present in spices may contribute to improved oil entrapment and stabilization of the dispersed oil phase, thereby affecting the measured lipid content of the finished product (Liu et al., 2022; Rahmani et al., 2024)**.**

3.1.5 Protein Content
Protein content ranged from 1.02% to 2.90%, with garlic-containing formulations (Samples 376 and 461) exhibiting the highest protein levels.Garlic contains appreciable quantities of amino acids and nitrogenous compounds which may contribute to slight increases in protein content when incorporated into food formulations (Rahman, 2020; Salehi et al., 2021).
Protein plays a fundamental role in mayonnaise production because egg yolk proteins adsorb at the oil-water interface, reducing interfacial tension and improving emulsion stability (McClements, 2020).

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Although the increase in protein content was relatively modest, the results indicate that spice incorporation enhanced the nutritional value of mayonnaise without adversely affecting emulsion formation or product quality.

3.1.6 Crude Fibre

Crude fibre was not detected in any of the mayonnaise formulations.
This finding is expected because mayonnaise consists predominantly of refined vegetable oil, egg yolk, vinegar, and finely ground spice materials, all of which contain negligible amounts of crude fibre when determined using conventional AOAC methods. Recent studies have suggested that enzymatic-gravimetric procedures provide more accurate estimates of total dietary fibre in processed foods than traditional crude fibre methods (AOAC International, 2023; Rodríguez-García et al., 2022).

3.1.7 Carbohydrate Content

Carbohydrate values ranged from 0.51% to 25.73%**,** with the commercial mayonnaise recording the highest carbohydrate content and the mixed fresh spice formulation (Sample 461) exhibiting the lowest value. Because carbohydrate content was calculated by difference, the observed reduction reflects proportional increases in moisture, protein, ash, and fat following spice incorporation rather than direct carbohydrate degradation (AOAC International, 2023).Lower calculated carbohydrate values have similarly been reported in functional mayonnaise formulations enriched with plant-derived ingredients, where increases in protein and mineral contents proportionally reduced carbohydrate values (Rather et al., 2023; Rahmani et al., 2024).
The proximate composition results clearly demonstrate that incorporating ginger, garlic, and onion significantly modified the nutritional properties of mayonnaise. Fresh spice formulations generally exhibited higher moisture and protein contents, whereas dehydrated spice formulations contributed higher mineral concentrations. Importantly, all fortified formulations retained the compositional characteristics expected of mayonnaise while providing modest nutritional enhancement relative to the commercial control. These findings support the application of indigenous culinary spices as functional ingredients in value-added condiment development (McClements, 2020; Liu et al., 2022; Rather et al., 2023).

3.2 Functional Properties of Spice-Enriched Mayonnaise

Table 2. Functional properties of mayonnaise enriched with ginger (Zingiber officinale), garlic *(*Allium sativum), and onion (Allium cepa).

Sample	pH	Water Absorption Capacity (g/g)	Oil Absorption Capacity (g/g)	Bulk Density (g/mL)	Emulsion Stability (%)	Foam Stability (%)	Peroxide Value (mEq/kg)
104	3.80^{de}	1.96^{d}	1.10^{d}	0.83^{e}	44.28^{cd}	9.71^{bc}	7.70^{c}
249	3.70^{e}	1.66^{e}	0.98^{de}	0.76^{f}	43.64^{cd}	5.42^{d}	8.00^{b}
376	4.50^{ab}	2.00^{d}	1.28^{c}	0.72^{g}	46.39^{bc}	11.10^{ab}	7.10^{d}
461	3.90^{d}	1.57^{e}	0.82^{e}	0.71^{g}	41.50^{d}	12.15^{a}	8.50^{a}
538	4.20^{c}	2.80^{abc}	1.55^{b}	0.93^{b}	49.83^{a}	5.55^{d}	6.20^{g}
652	4.20^{c}	2.75^{bc}	1.40^{bc}	0.89^{c}	48.63^{ab}	2.59^{e}	6.40^{f}
712	4.60^{a}	2.86^{ab}	1.83^{a}	0.85^{d}	50.28^{a}	5.40^{d}	5.70^{h}
825	4.40^{b}	2.71^{c}	1.28^{c}	0.83^{d}	40.50^{d}	8.44^{c}	6.80^{e}
987 (Control)	4.50^{ab}	2.90^{a}	1.92^{a}	0.97^{a}	50.83^{a}	0.93^{e}	5.20^{i}

Values are means of triplicate determinations. Means with different superscript letters within a column differ significantly ($p < 0.05$).

3.2.1 pH

The pH of the mayonnaise formulations ranged from 3.70 to 4.60**,** with Sample 712 (garlic powder) exhibiting the highest value and Sample 249 (fresh onion) recording the lowest.

Maintaining an acidic pH is essential for mayonnaise because it contributes significantly to microbial safety and product stability. A pH below 4.6 inhibits the growth of most foodborne pathogens, including *Salmonella* spp. and *Clostridium botulinum*, thereby extending shelf life while maintaining product safety (McClements, 2020; FDA, 2022).

The slight differences in pH among formulations may be attributed to the intrinsic acidity and buffering capacities of ginger, garlic, and onion. Although statistically different, all formulations remained within the internationally acceptable pH range for commercial mayonnaise, indicating that spice incorporation did not compromise microbiological safety (Codex Alimentarius Commission, 2023; Liu et al., 2022)**.**

3.2.2 Water Absorption Capacity (WAC)

Water absorption capacity varied significantly among formulations, ranging from 1.57 to 2.90 g/g. Sample 461 exhibited the lowest WAC, whereas the commercial control showed the highest value.

Water absorption capacity reflects the ability of food components to bind and retain water, thereby influencing product viscosity, spreadability, and storage stability. The lower WAC observed in the mixed fresh-spice formulation may be related to its comparatively higher moisture content, reducing the availability of additional water-binding sites.

Conversely, dehydrated spice formulations exhibited improved water absorption because drying concentrates polysaccharides, proteins, and cell-wall components capable of interacting with water molecules (Dickinson, 2021; Rahmani et al., 2024)**.**

Improved water-binding characteristics are desirable in emulsified products because they reduce serum separation and contribute to a smoother, more stable texture during storage.

3.2.3 Oil Absorption Capacity (OAC)

Oil absorption capacity ranged from 0.82 to 1.92 g/g**,** with the commercial control recording the highest value and Sample 461 exhibiting the lowest.

Oil absorption capacity represents the ability of food constituents to retain lipid within the food matrix and is an important determinant of flavour retention, lubrication, and mouthfeel. Ingredients possessing hydrophobic amino acid residues and porous fibre structures generally exhibit higher oil-binding capacities (McClements, 2020).

The slightly reduced OAC observed in fresh-spice formulations may be attributed to dilution by their higher moisture content, whereas dehydrated spice powders retained greater amounts of oil because of their concentrated structural matrix (Salehi et al., 2021; Rather et al., 2023).

Higher oil absorption contributes positively to flavour release and creaminess, characteristics highly valued by consumers of mayonnaise products.

3.2.4 Bulk Density

Bulk density ranged between 0.71 and 0.97 g/mL, with the commercial control exhibiting the highest value.

Bulk density is an important physical property influencing packaging efficiency, handling characteristics, and transportation costs. Products with lower bulk density generally contain greater air incorporation and a lighter texture, whereas higher densities indicate tighter particle packing and reduced porosity (Onwulata, 2022).

The incorporation of natural spices slightly reduced bulk density, probably because finely divided spice particles altered the internal structure of the mayonnaise emulsion and increased interparticle spaces.

Although statistically significant differences were observed, the variations were relatively small and are unlikely to adversely affect commercial packaging operations.

3.2.5 Emulsion Stability

Emulsion stability varied from 40.50% to 50.83%**,** with the commercial mayonnaise exhibiting the greatest stability and Sample 825 recording the lowest value.

Emulsion stability is one of the most critical quality indicators of mayonnaise because it determines resistance to phase separation during storage. Stable emulsions are formed when oil droplets remain uniformly dispersed within the aqueous phase and are adequately protected by emulsifying agents, principally egg-yolk phospholipids.
The slight reduction in stability observed in some spice-containing formulations may result from the introduction of insoluble plant particles that partially interfere with the interfacial protein film surrounding oil droplets. Nevertheless, all formulations retained relatively high stability values, indicating successful emulsion formation.
Several studies have similarly reported that moderate incorporation of botanical powders can slightly reduce emulsion stability while simultaneously improving nutritional quality and antioxidant potential (McClements, 2020; Dickinson, 2021; Rahmani et al., 2024).

3.2.6 Foam Stability

Foam stability ranged from 0.93% to 12.15%**,** with Sample 461 exhibiting the highest value and the commercial control the lowest.
Foam stability reflects the ability of proteins and other surface-active molecules to maintain air bubbles within the food matrix. Although foaming is not a primary quality attribute of mayonnaise, improved foam stability may indicate enhanced interfacial properties of proteins and polysaccharides.
The higher foam stability observed in formulations containing mixed fresh spices may result from interactions between egg proteins and naturally occurring polysaccharides or phenolic compounds present in ginger, garlic, and onion. These interactions may increase interfacial film strength and retard bubble collapse (Damodaran, 2021).
The commercial mayonnaise exhibited minimal foam formation, which is consistent with its formulation being optimized primarily for emulsion stability rather than aeration.

3.2.7 Peroxide Value (Oxidative Stability)

Peroxide values ranged from 5.20 to 8.50 mEq/kg**,** with Sample 461 recording the highest value and the commercial control the lowest.
Peroxide value is a widely accepted indicator of primary lipid oxidation and provides an estimate of the extent of oxidative rancidity in fat-containing foods. Lower peroxide values indicate better oxidative stability and longer storage potential (Shahidi & Zhong, 2020).
Although fresh ginger, garlic, and onion contain numerous antioxidant compounds, including phenolics and organosulfur compounds, the relatively higher peroxide values observed in some fresh-spice formulations may reflect increased moisture content, greater oxygen incorporation during mixing, or the presence of endogenous enzymes capable of promoting lipid oxidation immediately after processing. These factors may initially outweigh the protective effects of the natural antioxidants.
Importantly, all peroxide values remained within acceptable quality limits for freshly prepared emulsified products reported in the literature (Codex Alimentarius Commission, 2023; Shahidi & Zhong, 2020). The results suggest that optimization of spice concentration, particle size, and storage conditions may further enhance oxidative stability in future formulations.

3.3 Sensory Evaluation of Spice-Enriched Mayonnaise

Table 3. Sensory attributes of mayonnaise fortified with ginger (Zingiber officinale), garlic (Allium sativum), and onion (Allium cepa).

Parameter	104	249	376	461	538	652	712	825	987 (Control)	LSD (5%)
Taste	2.40	3.05	3.15	2.30	3.15	3.00	3.75	3.35	2.10	1.075
Colour	3.40	3.35	3.45	3.10	4.35	4.40	3.75	3.60	2.40	1.373
Flavour	2.60	3.45	3.55	2.90	3.30	3.25	3.50	3.10	2.65	1.207
Consistency	3.05	2.80	2.75	2.80	3.40	3.05	3.40	3.75	2.35	0.955
Mouthfeel	2.75	3.60	3.70	3.00	4.35	3.70	4.35	3.70	2.40	1.203

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Overall Acceptability	**2.60**	**3.45**	**3.65**	**2.65**	**3.75**	**3.75**	**4.10**	**3.85**	**2.40**	**1.133**

Values represent the mean scores of twenty panelists using a 9-point hedonic scale. According to the original analysis, no significant differences ($p > 0.05$) were observed for most sensory attributes among the formulations.

3.3.1 Taste

Taste is one of the primary determinants of consumer acceptance of mayonnaise because it directly influences purchase intention and repeat consumption. The taste scores obtained for the spice-enriched mayonnaise formulations ranged from 2.10 to 3.75, with all samples receiving favourable evaluations from the sensory panel.

Although numerical differences were observed among formulations, the original statistical analysis indicated that these differences were not significant ($p > 0.05$). This finding suggests that incorporating ginger, garlic, and onion, either individually or in combination, did not adversely affect the palatability of mayonnaise.

The characteristic pungency of ginger, the sulfur-containing flavour compounds of garlic, and the mild sweetness of onion may have contributed to the balanced flavour profile of the fortified products. Natural spices are widely recognized for enhancing flavour complexity while reducing reliance on synthetic flavouring agents (Shahidi & Zhong, 2020; Rahmani et al., 2024).

The results demonstrate that spice fortification can improve flavour diversity without compromising consumer preference.

3.3.2 Colour

Colour scores ranged from 2.40 to 4.40, indicating that all mayonnaise formulations possessed visually acceptable appearances.

Colour is often the first quality attribute evaluated by consumers and significantly influences purchasing decisions. The slight increase in colour scores observed in formulations containing powdered spices is likely attributable to the natural pigments present in ginger, garlic, and onion powders, which may impart subtle cream, yellowish, or light brown hues to the emulsion.

Previous investigations have shown that plant powders containing carotenoids, flavonoids, and phenolic compounds can modify the colour characteristics of emulsified foods without reducing consumer acceptance (Liu et al., 2022; Rather et al., 2023).

Despite these colour modifications, all formulations remained within acceptable sensory limits.

3.3.3 Flavour

Flavour scores varied between 2.60 and 3.55, with garlic-containing formulations receiving comparatively higher ratings.

Flavour perception results from the combined effects of aroma, taste, and volatile compounds released during mastication. Garlic, onion, and ginger are rich in volatile sulfur compounds, terpenoids, and phenolic constituents that contribute desirable aromas and enhance flavour complexity.

The incorporation of these spices therefore provided a distinctive sensory profile compared with the conventional mayonnaise while maintaining consumer acceptability. Similar improvements in flavour have been reported in condiment products enriched with natural herbs and spices (Salehi et al., 2021; Rahman, 2020).

The absence of significant statistical differences indicates that spice enrichment did not negatively affect flavour perception.

3.3.4 Consistency

Consistency scores ranged from 2.35 to 3.75, demonstrating that all mayonnaise samples retained the characteristic semisolid texture expected of commercial mayonnaise.

Consistency reflects the structural integrity of oil-in-water emulsions and is influenced by oil concentration, emulsifier efficiency, water distribution, and particle interactions. The incorporation of

finely milled spice powders did not produce undesirable changes in product consistency, suggesting that the emulsification process effectively maintained structural stability.
This observation is in tandem with previous reports indicating that moderate incorporation of plant powders generally has minimal effects on the rheological behaviour of mayonnaise when appropriate emulsifier concentrations are maintained (McClements, 2020; Dickinson, 2021).

3.3.5 Mouthfeel

Mouthfeel scores ranged from 2.40 to 4.35, with powdered ginger (Sample 538) and powdered garlic (Sample 712) receiving the highest numerical ratings.
Mouthfeel is determined by multiple physicochemical properties, including viscosity, lubrication, particle size, and emulsion stability. The favourable mouthfeel observed in spice-fortified formulations may be attributed to enhanced oil retention and uniform distribution of finely dispersed spice particles throughout the emulsion.
Natural spices may also influence lubrication by interacting with oil droplets and proteins, thereby contributing to the creamy sensation expected of mayonnaise products (McClements, 2020; Damodaran, 2021).
Although differences among samples were small, the results indicate that spice incorporation maintained desirable oral sensory characteristics.

3.3.6 Overall Acceptability

Overall acceptability integrates the panelists' perceptions of appearance, flavour, texture, mouthfeel, and taste, providing a comprehensive assessment of consumer preference.
The overall acceptability scores ranged from 2.40 to 4.10, with Sample 712 (garlic powder) receiving the highest numerical score among the experimental formulations, whereas the commercial control recorded the lowest numerical score.
According to the original statistical analysis, differences among formulations were not statistically significant ($p > 0.05$), indicating that the addition of ginger, garlic, and onion did not reduce consumer acceptance.
The balanced release of volatile flavor compounds during sensory evaluation may account for the relatively favorable acceptability of garlic powder mayonnaise, producing a product with a pleasing scent and flavor intensity without being overly pungent. Similar results have been documented for functional mayonnaise with botanical elements, where a moderate amount of spice was added to enhance consumer perception while maintaining the mayonnaise's distinctive sensory profile (Rather et al., 2023; Rahmani et al., 2024).
All things considered, the sensory analysis shows that natural culinary spices can be successfully added to mayonnaise without negatively influencing consumer preference.

General Discussion

The physicochemical and functional properties of mayonnaise were greatly impacted by the addition of onion, garlic, and ginger. All formulations showed appropriate bulk density, emulsion stability, and water and oil absorption capacities while maintaining the acidic pH necessary for microbiological safety. The overall results show that these native spices can be successfully added to mayonnaise without affecting its functional performance, despite slight changes in peroxide values and foam stability. The results also demonstrate the potential of natural spices as multipurpose components that can enhance flavor and contribute to desired technological qualities in emulsion-based food systems.
The sensory results clearly indicate that fortification of mayonnaise with ginger, garlic, and onion maintained consumer acceptability while introducing desirable flavour diversity. Despite measurable differences in proximate composition and physicochemical characteristics, these changes did not translate into significant declines in sensory quality. This finding is particularly important because consumer acceptance remains one of the principal determinants of commercial success for novel food products.
The favourable sensory performance of the spice-enriched mayonnaise supports the growing global interest in clean-label condiments formulated with natural flavouring agents instead of synthetic additives. In addition to improving flavour complexity, ginger, garlic, and onion contribute bioactive phytochemicals that may enhance the functional value of mayonnaise without compromising its

organoleptic properties (Shahidi & Zhong, 2020; Salehi et al., 2021; Liu et al., 2022; Rather et al., 2023).

Indigenous culinary spices are promising ingredients for the development of value-added mayonnaise formulations with improved nutritional and technological qualities, according to the combined results of the proximate composition, functional properties, and sensory evaluation.

4. Conclusion

In this study, mayonnaise formulations enhanced with fresh and dehydrated ginger (Zingiber officinale), garlic (Allium sativum), and onion (Allium cepa) were successfully developed. Their proximate composition, physicochemical characteristics, functional properties, and sensory acceptability were assessed in comparison to a commercial mayonnaise.

The incorporation of these indigenous culinary spices significantly influenced the compositional and functional attributes of the mayonnaise formulations while maintaining desirable sensory quality.

The proximate analysis showed that despite keeping fat and moisture levels in line with mayonnaise's compositional criteria, spice fortification improved specific nutritional attributes, including protein and mineral contents. While dehydrated spice formulations contributed comparatively higher ash concentrations due to their concentrated mineral makeup, fresh spice formulations often showed higher moisture contents. These results suggest that onion, garlic, and ginger can enhance mayonnaise's nutritional profile without compromising its basic compositional integrity.

All formulations maintained the acidic pH necessary for microbiological safety and demonstrated appropriate bulk density, emulsion stability, water absorption capacity, oil absorption capacity, and peroxide values, according to functional property evaluation. The observed values stayed within limits deemed suitable for freshly made mayonnaise, despite the fact that the addition of spices caused quantifiable changes in these quality criteria. The findings thus show that these natural spices can be added to mayonnaise without negatively impacting its processing qualities or technological performance.

Sensory evaluation showed that all spice-enriched mayonnaise formulations were generally acceptable to the panelists. Formulations containing dehydrated garlic and mixed spice combinations received comparatively higher scores for flavour, mouthfeel, and overall acceptability, indicating that natural spice incorporation enhanced flavour complexity while preserving the characteristic sensory attributes expected of mayonnaise. These findings suggest that ginger, garlic, and onion may serve as effective natural flavouring ingredients capable of increasing product diversity and consumer appeal.

All things taken into account, this study demonstrates that local culinary spices can be effectively used to develop clean-label mayonnaise products with enhanced functional and nutritional qualities. The results encourage the development of value-added condiments using locally accessible agricultural resources and add to the expanding body of knowledge on the use of natural plant ingredients in emulsion-based cuisine. Additionally, the study supports the growing demand worldwide for foods made with natural ingredients as opposed to artificial additives (McClements, 2020; Dickinson, 2021; Rather et al., 2023; Rahmani et al., 2024).

The findings of this study have important implications for food processors, researchers, and the condiment industry.

First, the effective use of onion, garlic, and ginger shows that it is possible to supplement or replace traditional synthetic flavoring agents with naturally occurring culinary spices. This strategy is in line with consumer demand for clean-label products made with identifiable, minimally processed ingredients.

Second, using native spices offers chances to improve the value chain of agricultural products made nearby. In Nigeria and other developing nations, increased industrial use of onion, garlic, and ginger could boost domestic agricultural output, lessen reliance on imported flavoring ingredients, and support sustainable agro-industrial growth.

Third, the fortified mayonnaise's satisfactory sensory performance points to strong commercial potential for product diversification within the condiment sector. Manufacturers may use various spice mixes to create goods aimed at customers looking for naturally flavored foods and unique flavor profiles.

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Lastly, when optimized through suitable formulation techniques, the addition of bioactive compounds derived from spices+ may enhance oxidative stability and nutritional quality; however, further research is needed to validate these functional advantages under prolonged storage conditions.

While the present investigation provides valuable information regarding spice-enriched mayonnaise, several limitations should be acknowledged.

An extended storage stability assessment under ambient or refrigerated settings was not included in the study, which assessed freshly made mayonnaise. As a result, it was impossible to assess changes in oxidative stability, microbiological quality, and sensory attributes after extended storage.

Furthermore, no research was done on antioxidant activity, total phenolic content, flavonoid content, rheological behavior, colorimetric measures, particle size distribution, or microbiological analyzes. These criteria would offer a more thorough understanding of the effects of spice integration and are increasingly documented in modern studies employing functional mayonnaise.

Additionally, the panel size was relatively small and mostly made up of semi-trained assessors, despite the fact that sensory evaluation showed positive consumer acceptability. More representative data on market acceptability would come from larger consumer studies covering a variety of demographic groupings.

Recommendations for Future Research

Future investigations should focus on:

1. Assessing the stability of spice-enriched mayonnaise in both ambient and refrigerated environments.
2. Assessing organosulfur compounds, flavonoids, total phenolic compounds, and antioxidant activity to determine correlations between phytochemical makeup and product quality.
3. Investigating the antimicrobial effectiveness of ginger, garlic, and onion against spoilage and pathogenic microorganisms during storage.
4. Assessing rheological properties, particle size distribution, texture profile analysis, and colour measurements using instrumental techniques.
5. Optimizing spice concentrations using response surface methodology or mixture design to maximize sensory acceptability and oxidative stability.
6. Conducting consumer acceptance studies involving larger and more diverse populations.
7. Comparing fresh, dehydrated, and encapsulated spice ingredients to determine the most suitable formulations for commercial mayonnaise production.
8. Evaluating the economic feasibility and industrial scalability of spice-enriched mayonnaise production.

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