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Development and Quality Characterization of an Avocado Seed-Based Herbal Infusion Enriched with Fennel, Lemongrass and Clove

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Abstract

This study evaluated the proximate composition, mineral profile, selected phytochemicals and sensory acceptability of herbal infusion blends prepared from avocado seed (*Persea americana* Mill.) powder and enriched with fennel (*Foeniculum vulgare*), lemongrass (*Cymbopogon citratus*) and clove (*Syzygium aromaticum*). Five formulations were prepared: T0 (100% avocado seed), T1 (70:10:10:10), T2 (60:20:10:10), T3 (60:10:20:10) and T4 (50:25:15:10), representing avocado seed:fennel:lemongrass:clove, respectively. Proximate composition, selected minerals and phytochemicals were determined in triplicate. Sensory acceptability was assessed by 30 panelists using a nine-point hedonic scale. Botanical supplementation significantly ($P < 0.05$) reduced moisture from 11.30% in T0 to 8.09% in T4 and fat from 5.34% to 4.01%, while increasing protein from 3.03% to 8.06%, ash from 3.28% to 7.66% and crude fiber from 2.77% to 5.10%. T4 had the highest measured concentrations of calcium, iron, magnesium, zinc and potassium. Alkaloids increased from 2.38% in T0 to 4.93% in T4, saponins from 1.19% to 2.66%, flavonoids from 2.18% to 6.01% quercetin equivalents (QE), and total phenolics from 0.18% to 1.15% gallic acid equivalents (GAE). Tannin content peaked at 0.62% in T2 before declining to 0.38% in T4. Sensory evaluation showed that T3 received the highest scores for taste (8.20), aroma (8.40) and overall acceptability (8.00), while T2 also received high scores for these attributes. Although T4 showed the greatest enrichment for several measured compositional parameters, its lower sensory scores indicated lower preference than T2 and T3. T3 therefore provided the most favorable balance among the formulations evaluated and is a promising candidate for further product development. The compositional results refer to the dry blends; transfer of these constituents into the brewed infusion was not determined.

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Introduction

Growing interest in herbal infusions reflects a broader movement toward beverages that combine hydration with plant-derived flavor, aroma and bioactive constituents. Herbal infusions differ from conventional tea because they may be produced from seeds, leaves, flowers, fruits, roots or bark rather than Camellia sinensis. Their attractiveness as functional beverage ingredients is associated with the presence of phenolic compounds, flavonoids, volatile constituents and minerals, although the magnitude of any physiological benefit depends on composition, dose, extraction conditions and bioavailability rather than on the presence of a plant ingredient alone Ahamad, 2024; Panche *et al*., 2016; Shahidi & Ambigaipalan, 2015). Avocado (*Persea americana* Mill.) is widely consumed for its edible pulp, whereas the seed is commonly discarded during household and industrial processing. The seed can represent a substantial fraction of the fruit mass and contains fiber, minerals and secondary metabolites. This makes the seed relevant to food-waste valorization, particularly where conversion into stable powdered ingredients can reduce disposal and create additional value from an existing agricultural resource (Alsado *et al*., 2025; Anwar *et al*., 2022; Nyong, 2023). Importantly, the compositional potential of avocado seed should be interpreted alongside its sensory characteristics and the need for appropriate processing before consumption. Anwar *et al*. (2022) demonstrated that avocado seed can be processed into a tea product and that drying conditions affect moisture, ash, phenolic content, antioxidant activity and sensory quality. Their work provides a direct technological basis for the present study because it establishes that avocado seed is not

merely a waste material but can be transformed into an infusion matrix. Nevertheless, the use of avocado seed alone may be constrained by its characteristic bitterness and astringency, making flavor modification an important consideration in product development. Blending the avocado seed base with aromatic culinary spices offers two potential advantages. First, the blend can modify the flavor profile through volatile compounds contributed by the spices. Second, the compositional diversity of the finished infusion can increase because the botanical ingredients contribute different classes of nutrients and phytochemicals. Fennel is particularly relevant because it contains volatile constituents such as trans-anethole and a range of phenolic compounds and has a long history of culinary use. Recent reviews have also emphasized its functional properties and the importance of considering safety and composition when fennel is developed into food products (Noreen *et al*., 2023; Rather *et al*., 2016).

Lemongrass (*Cymbopogon citratus*) is another suitable ingredient because its characteristic lemon-like aroma can improve the sensory identity of an infusion. The plant contains terpenoids, flavonoids and phenolic acids, and recent reviews describe its applications in food and beverages as well as its broad biological activities (Du *et al*., 2024; Ekpenyong *et al*., 2015). In a beverage matrix, however, the practical value of lemongrass is determined not only by its phytochemical composition but also by the concentration required to produce an acceptable aroma and taste. Clove (*Syzygium aromaticum*) is highly aromatic and rich in phenolic constituents, particularly eugenol. It has therefore been investigated as food flavoring and as a source of antioxidant and antimicrobial compounds. Recent reviews continue to identify clove as a promising food ingredient while emphasizing that the composition and activity of clove preparations vary according to plant material, extraction procedure and formulation (Batiha *et al*., 2020; Pandey *et al*., 2024). In the present formulation, clove was maintained at a moderate proportion so that its strong flavor would complement rather than dominate the other ingredients.

The functional value of an herbal beverage cannot be assessed from nutrient or phytochemical composition alone. Consumer acceptability is equally important because bitterness, astringency, excessive spice intensity, aroma imbalance or an unpleasant mouthfeel can limit adoption even when the product has a favorable compositional profile. Sensory science therefore provides an essential product-development framework for identifying the concentration range at which a botanical ingredient improves rather than compromises acceptability (Lawless & Heymann, 2010). Although avocado seed tea has been investigated previously, there is limited information on the systematic blending of avocado seed with fennel, lemongrass and clove in a single infusion. In particular, there is a need to identify whether increasing spice inclusion produces a consistent improvement in nutritional and phytochemical composition and whether such improvement is accompanied by greater sensory acceptance. The present study was therefore designed to evaluate the proximate composition, mineral content, selected phytochemicals and sensory quality of avocado-seed-based herbal infusions containing different proportions of fennel, lemongrass and clove. This will help to identify a formulation that provides a practical balance between compositional enrichment and consumer acceptability.

Materials and Methods

The study followed a completely randomized experimental design. Ripe avocado fruits, fennel seeds, clove buds and fresh lemongrass were purchased from Relief Market, Owerri, Imo State, Nigeria. The materials were botanically identified before processing. The processing approach was based on the procedures described for avocado seed tea and herbal tea ingredients, with adjustments appropriate to the raw materials used (Anwar *et al*., 2022; Das *et al*., 2019; Tharaniya *et al*., 2023).

Sample Collection and Processing

The avocado mesocarp was removed and the testa was peeled from the seeds. The seeds were blanched at 70–80°C for 1–2 min to limit enzymatic browning, sliced to approximately 2 mm thickness and oven-dried at 50°C for 2 h. The dried slices were milled and passed through a 300-µm sieve. This drying condition is consistent with the range investigated by Anwar *et al*. (2022), who showed that drying temperature and time influence the quality characteristics of avocado seed tea. Fennel seeds were cleaned, washed and oven-dried at 50°C to constant weight before coarse milling through an 18-mesh screen. Clove buds were sorted, dried at 50°C for 30 min and milled through an 18-mesh screen. Fresh lemongrass was sorted, washed, steam-blanched for 60 s, cut into 2–3 cm pieces, dried at 60°C for 8 h and milled to pass a 250-µm sieve. These operations were selected to obtain stable powders while retaining the characteristic aroma of the ingredients; fennel, lemongrass and clove are known to contain volatile and phenolic constituents that contribute strongly to their sensory properties (Noreen *et al*., 2023; Du *et al*., 2024; Pandey *et al*., 2024). All powders were placed in airtight containers and protected from direct light, heat and moisture until formulation. The use of controlled drying and airtight storage is important for botanical ingredients because moisture and oxygen can promote quality deterioration and loss or transformation of volatile and phenolic compounds (Fellows, 2017).

Table 1. Blend ratios of avocado seed powder with fennel, lemongrass and clove powder (%)

Sample	Avocado seed powder	Fennel powder	Lemongrass powder	Clove powder
T0 (Control)	100	0	0	0
T1	70	10	10	10
T2	60	20	10	10
T3	60	10	20	10
T4	50	25	15	10

Formulation of the Herbal Infusion Blends

Table 1 presents the five formulations prepared for the study: a control made entirely from avocado seed powder (T0) and four blended samples (T1–T4). The powders were weighed at the ratios indicated, mixed thoroughly to ensure homogeneity, packed into 2 g tea bags, sealed and labeled accordingly.

Determination of Proximate Composition

Moisture, ash, crude protein, crude fat and crude fiber were each determined in triplicate using the standard procedures of AOAC (2023) on dry matter basis.

Moisture Content Determination

Two grams of each of the developed sample was weighed into dried weighed crucible. The samples were put into a moisture extraction oven at 105°C and heated for 3 h. The dried samples were put into desiccators, allowed to cool and reweighed. The process was reported until constant weights were obtained. The difference in weight was calculated as a percentage of the original sample.

$$\text{Percentage of moisture (\%)} = \frac{W_2 - W_3}{W_2 - W_1} \times \frac{100}{1}$$

where:
W_1 = Initial weight of empty dish
W_2 = Weight of dish + undried sample
W_3 = Weight of dish + dried sample

Fat Content Determination

Two grams of each of the sample was loosely wrapped with a filter paper and put into the thimble which was fitted to a clean round bottom flask, which has been cleaned, dried and weighed. The flask contained 120 ml of petroleum ether. The sample was heated with a heating mantle and allowed to reflux for 5 h. The heating was then stopped and the thimbles with the spent samples kept and later weighed. The difference in weight was received as mass of fat and is expressed in percentage of the sample.

$$\text{Percentage of fat (\%)} = \frac{W_2 - W_1}{W_3} \times \frac{100}{1}$$

where:
W_1 = weight of the empty extraction flask
W_2 = weight of the flask and oil extracted
W_3 = weight of the sample

Crude Fiber Determination

Two grams (2 g) of each sample and 1g asbestos was put into 200 ml of 1.25 % of H_2SO_4 and boiled for 30 minutes. The solution and content then poured into Buchner funnel equipped with muslin cloth and secured with elastic band. This was allowed to filter and residue was then put into 200 ml boiled NaOH and boiling continued for 30 minutes, then transferred to the Buchner funnel and filtered and washed thoroughly with hot distilled water. The precipitates were then rinsed twice with alcohol and thrice with petroleum ether. The residues obtained were scrapped into a clean weighed crucible and dried in the moisture extraction oven to a constant weight. The crucibles were removed, cooled in desiccators and reweighed (Afiukwu ., 2013). Then, difference of weight (i.e. loss in ignition) is recorded as crucible fiber and expressed in percentage of crude fiber.

$$\text{Percentage of Crude Fibre (\%)} = \frac{W_1 - W_2}{W_3} \times \frac{100}{1}$$

where:
W_1 = weight of sample before incineration
W_2 = weight of sample after incineration
W_3 = weight of original sample

Crude Protein Determination

The micro kjeldahl method described by AOAC (2023) was used. Two grams of each of the samples was mixed with 10ml of concentrated H_2SO_4 in a heating tube. One tablet of selenium catalyst was added to the tube and mixture heated inside a fume cupboard. The digest was transferred into distilled water. A 10-mL portion of the digest mixed with equal volume of 45 % NaOH solution and poured into a kjeldahl distillation apparatus. The mixture was distilled and the distillate collected into 4 % boric acid solution containing 3 drops of methyl red indicator. A total of 50 ml distillate was collected and titrated as well. The sample was duplicated and the average value taken. The nitrogen content was calculated and multiplied with 6.25 to obtain the crude protein content. This is given as:

$$\text{Percentage of Nitrogen (\%)} = \frac{(100 \times N \times VF)T}{100 \times V_a}$$

where:
N = Normality of the titrate (0.1N)
VF = Total volume of the digest= 100 ml
T = Titre Value
Va = Aliquot Volume distilled

Ash Content Determination

Two grams of each of the samples was weighed into a crucible, heated in a moisture extraction oven for 3 hours at 100°C before being transferred into a muffle furnace at 55°C until it turned white and free of carbon. The sample was then removed from the furnace, cooled in a desiccator to an ambient temperature and reweighed immediately. The weight of the residual ash was then calculated as ash content.

$$Percentage\ of\ Ash\ (\%) = \frac{Weight\ of\ Ash}{Weight\ of\ original\ sample} x\ \frac{100}{1}$$

Determination of Mineral Composition

The mineral composition of the samples was determined by atomic absorption spectrophotometry (AAS) following acid digestion, using the procedure described by AOAC International (2019). Briefly, 0.5 g of each homogenized sample was accurately weighed and digested with concentrated nitric acid under controlled heating until a clear digest was obtained. The digest was cooled, filtered and made up to 50 ml with deionized water. Appropriate reagent blanks and standard solutions were prepared alongside the samples. Calcium

(Ca), iron (Fe), magnesium (Mg) and zinc (Zn) were determined using AAS at their respective analytical wavelengths, while potassium (K) was determined by flame emission/AAS. The instrument was calibrated with standard solutions of known concentrations, and the concentration of each mineral was obtained from its respective calibration curve. The mineral content was calculated on dry matter basis as:

$$Mineral\ (mg/100g) = WC\ x\ V\ x\ D\ x\ 10$$

where:
C = concentration of the mineral obtained from the calibration curve (mg/L)
V = final volume of the digested sample (L)
D = dilution factor
W = weight of sample digested (g)
100 = conversion to mg/100 g

Determination of Phytochemical Composition

The phytochemical constituents of the powdered herbal tea samples were quantitatively determined using established analytical procedures. Alkaloids and saponins were determined gravimetrically, while tannins, flavonoids and total phenolic compounds were determined using spectrophotometric methods. All determinations were performed in triplicate, and results were expressed as percentages of the dry sample.

Alkaloid Content

Alkaloid content was determined using the gravimetric method of Harborne described by Raposo, (2024), with minor modifications. Approximately 5.0 g of each powdered sample was weighed into a conical flask and extracted with 200 mL of 10% acetic acid in ethanol. The mixture was allowed to stand for approximately 4 h with intermittent shaking and was subsequently filtered. The filtrate was concentrated on a water bath to approximately one-quarter of its original volume. Concentrated ammonium hydroxide was added gradually to the concentrate until precipitation was complete. The precipitated alkaloids were allowed to settle and were recovered by filtration using a pre-weighed filter paper. The precipitate was washed with dilute ammonium hydroxide and dried to constant weight at approximately 60 °C. The increase in weight of the filter paper represented the alkaloid fraction. Alkaloid content was calculated as:

$$Alkaloid\ (\%) = \frac{Weight\ of\ sample(g)}{Weight\ of\ Dried\ alkaloid\ extract\ ?\ (g)}\ x\ 100$$

Saponin Content

Saponin content was determined using the gravimetric procedure of Obadoni and Ochuko (2001), with appropriate modification for the tea samples. Approximately 5.0 g of sample was extracted repeatedly with 20% aqueous ethanol. The combined extracts were concentrated at approximately 40–50 °C and transferred into a separating funnel. The concentrate was partitioned with diethyl ether to remove non-polar impurities. The aqueous fraction was subsequently extracted with n-butanol. The n-butanol fractions were pooled and concentrated to dryness. The dried residue was weighed and expressed as percentage saponin content.

$$Saponin\ (\%) = \frac{Weight\ of\ sample(g)}{Weight\ of\ Dried\ saponin\ fraction(g)}\ x\ 100$$

Tannin Content

Tannin content was determined using the Folin–Denis spectrophotometric method described by Makkar *et al*. (1993), with results expressed as tannic acid equivalents. Approximately 0.5 g of sample was extracted with 10 mL of 70% aqueous acetone. The mixture was shaken thoroughly and centrifuged or filtered to obtain a clear extract. An aliquot of the extract was mixed with Folin–Denis reagent and sodium carbonate solution and allowed to develop color under controlled conditions. Absorbance was measured at approximately 700–760 nm using a UV–visible spectrophotometer. A calibration curve was prepared using known concentrations of tannic acid. Tannin concentration was obtained from the calibration curve and expressed as percentage:

$$Tannin\ (\%) = m\ x\ 10C\ xV\ x\ DF$$

where:
C = concentration obtained from the calibration curve (mg/mL)
V = volume of extract (mL)
DF = dilution factor
m = mass of sample (g)
10 = conversion factor from mg/g to percentage

Flavonoid Content

Total flavonoid content was determined using the aluminium chloride colorimetric method of Chang *et al*. (2002). Approximately 1.0 g of sample was extracted with an appropriate volume of methanol or aqueous methanol. The extract was filtered and appropriately diluted. An aliquot was mixed with aluminium chloride solution, potassium acetate and distilled water. The mixture was incubated at ambient temperature for approximately 30 min, after which absorbance was measured at 415 nm. A calibration curve was prepared using known concentrations of quercetin, and flavonoid concentration was calculated from the resulting regression equation. Results were expressed as % quercetin equivalents (QE) using:

$$Flavonoid\ (\%) = m\ x\ 10C\ xV\ x\ DF$$

where:
C is the concentration obtained from the quercetin calibration curve (mg/mL), V is the extract volume (mL), DF is the dilution factor and m is the sample weight (g).

Total Phenolic Content

Total phenolic content was determined using the Folin–Ciocalteu colorimetric method of Singleton *et al*. (1999). Approximately 1.0 g of sample was extracted with an appropriate volume of methanol or aqueous

methanol. The extract was filtered and diluted as necessary. A measured aliquot of the extract was reacted with Folin–Ciocalteu reagent, followed by addition of sodium carbonate solution. The mixture was allowed to stand for approximately 30 min under dark conditions, and absorbance was measured at 765 nm using a UV–visible spectrophotometer.

A calibration curve was prepared using gallic acid as the reference standard. Total phenolic concentration was obtained from the calibration equation and expressed as % gallic acid equivalents (GAE).

$$Phenolic\ Content\ (\%) = m\ x\ 10C\ xV\ x\ DF$$

where:
C = concentration obtained from the gallic acid calibration curve (mg/mL)
V = extract volume (mL)
DF = dilution factor and m = sample weight (g).

Preparation of Herbal Infusion for Sensory Evaluation

For each formulation, 2 g of the powdered herbal blend contained in a tea bag was infused in 300 mL of freshly boiled potable water for 5 min. This procedure was adapted from Mensah *et al*. (2025), who employed a similar blend mass and infusion duration in preparing cocoa shell-based herbal infusions. The preparation and presentation of the samples for sensory evaluation were guided by the principles of standardized tea liquor preparation described in ISO 3103:2019. At the end of the infusion period, the tea bag was removed without additional filtration, and the prepared infusion was allowed to cool to approximately 45°C before serving. The samples were presented in clean, coded serving cups for sensory evaluation. A panel of thirty (30) trained panelists scored the appearance, taste, aroma, mouthfeel and overall acceptability of the five coded tea infusions, presented in random order, using a 9-point hedonic scale ranging from 1 (dislike extremely) to 9 (like extremely) according to Iwe (2002). Panelists rinsed their palate with water between samples.

Statistical Analysis

Data generated from the analyses were subjected to one-way analysis of variance (ANOVA) using SPSS version 20.0; where treatment means differed significantly, Least Significant Difference (LSD) test was used to separate them at P<0.05. All results are reported as mean ± standard deviation, and superscript letters that differ within the same column of a table denote a significant difference among means (P<0.05).

Results and Discussion

Proximate Composition of Avocado Seed-Based Herbal Infusion Blends

The proximate composition of the avocado seed-based herbal infusion blends is presented in Table 2. Significant differences (P<0.05) were observed among the formulations for moisture, protein, ash, fat and crude fiber, demonstrating that the incorporation of fennel, lemongrass and clove modified the nutritional composition of the avocado seed-based product. Such variation is expected in composite botanical formulations because each plant material possesses its own characteristic proportions of moisture, protein, lipid, mineral residue and structural carbohydrates. Recent studies have similarly demonstrated substantial differences in proximate composition among spices and medicinal herbs, indicating that blending different botanical materials can alter the overall nutritional characteristics of the resulting product (Mandal *et al*., 2023; Moulick *et al*., 2023).

Moisture Content

Moisture content decreased significantly from 11.30% in T0 to 8.09% in T4. The control formulation (T0), consisting entirely of avocado seed powder, therefore contained significantly more moisture than all the spice-containing formulations, whereas T4 recorded the lowest value. The reduction in moisture following incorporation of the botanical ingredients is important from a product-development perspective because moisture is one of the major factors influencing the physical, chemical and microbiological stability of dried plant products. Lower moisture generally reduces the amount of water available for microbial proliferation and can also reduce the rate of several moisture-dependent deterioration reactions. The moisture values obtained in the present study are within the range reported for several dried botanical and spice materials. Moulick *et al*. (2023) reported moisture contents ranging from 5.34% to 10.48% among nine commonly consumed spices, while Dushkova *et al*. (2023) reported 13.49% moisture in fennel fruits. These differences illustrate the importance of botanical identity, drying conditions and raw-material characteristics in determining the final moisture content of plant-based products. The relatively low moisture content of T4 may therefore be advantageous for the storage of the powdered formulation. However, moisture content alone is insufficient for predicting shelf stability. Dushkova *et al*. (2023) demonstrated that fennel fruits exhibit measurable moisture-sorption behavior that varies with temperature and relative humidity, emphasizing the importance of environmental conditions in the storage of dried botanical materials. Consequently, although the lower moisture content recorded in T4 is favorable, appropriate moisture-barrier packaging would still be necessary to prevent moisture uptake during transportation and storage. Further assessment of water activity, moisture sorption isotherms, microbial quality and chemical stability would provide stronger evidence concerning the shelf life of the developed infusion blends.

Protein Content

Protein content increased significantly from 3.03% in T0 to 8.06% in T4. T4 recorded the highest protein concentration, followed by T2 (7.46%), T3 (5.11%) and T1 (4.64%), while T0 had the lowest value. The increase indicates that replacing part of the avocado seed component with the selected botanicals changed the relative contribution of nitrogen-containing constituents in the composite formulation. The magnitude of the increase is also consistent with the known nutritional variability of spices and herbs. Moulick *et al*. (2023) reported protein values ranging from 2.70 to 15.44% across nine spices, while Dushkova *et al*. (2023)

reported a relatively high protein content of 18.25% in fennel fruits. Noreen *et al*. (2023) similarly reported 11.86% protein in fennel seeds. These findings demonstrate that botanical ingredients can make measurable contributions to the protein content of composite plant-based formulations. Nevertheless, the increase in protein observed in the present study should not be interpreted as evidence that the herbal infusion is a high-protein beverage. The values reported in Table 2 refer to the dry powdered blends, rather than the liquid infusion consumed by the consumer. During brewing, only a fraction of the nutrients present in the powder may be transferred into the aqueous phase. Furthermore, protein is generally less readily extracted into water than many low-molecular-weight soluble compounds. Therefore, the increase from 3.03% in T0 to 8.06% in T4 demonstrates improved protein concentration in the dry formulation but does not necessarily imply a proportionate increase in protein delivered by a brewed serving. This distinction is important when interpreting proximate data for herbal beverages. A study by Pușcaș *et al*. (2022) similarly demonstrated that the proximate composition of avocado seed material and that of the resulting hot drink differed substantially, illustrating the importance of distinguishing between the composition of the raw material and the composition of the final beverage.

The increase in protein may also be considered alongside the nutritional contribution of the individual botanicals. Fennel is known to contain appreciable quantities of protein and dietary fiber, although the exact composition varies according to cultivar, geographical origin, maturity and processing conditions (Noreen *et al*., 2023; Dushkova *et al*., 2023). Lemongrass also contains nutrients in addition to its characteristic volatile compounds. Manna *et al*. (2024), for example, reported 8.2% protein in lemongrass powder together with relatively high crude fiber. Therefore, the increased protein content observed in the present blends may partly reflect the replacement of avocado seed with botanicals possessing different proximate profiles.

Ash Content

Ash content increased significantly from 3.28% in T0 to 7.66% in T4. T4 had the highest ash value, followed by T2, T3, T1 and T0. Ash represents the inorganic residue remaining after the organic components of a food are combusted and is therefore commonly used as an approximate indicator of the total mineral fraction. The higher ash content of the spice-containing blends suggests that the incorporation of fennel, lemongrass and clove increased the mineral-containing fraction of the formulations. This observation is consistent with the reported mineral and ash composition of spices and herbs. Moulick *et al*. (2023) found ash contents between 2.25 % and 9.16% among nine spices, while Noreen *et al*. (2023) reported 11.39% ash in fennel seeds. Manna *et al*. (2024) also reported 4.3% ash in lemongrass powder. The relatively high ash content of T4 may therefore indicate a greater contribution of mineral-containing components to the composite formulation. This interpretation is particularly relevant because the mineral results obtained for the same formulations showed increases in several minerals with botanical incorporation. However, ash content does not identify individual minerals or establish their nutritional bioavailability. It is therefore more appropriate to interpret the increased ash as evidence of a higher total inorganic fraction and use the mineral analysis to identify the specific elements responsible for the observed difference. The variation among samples T1 to T4 further demonstrates that the response of proximate parameters was influenced by the specific ratio of the botanical ingredients, rather than simply by the presence or absence of spices. T2, for example, had a higher protein and ash content than T1 and T3, whereas T4 recorded the highest values for both parameters. Such formulation-dependent responses are expected because each treatment contained different proportions of avocado seed, fennel, lemongrass and clove. Botanical ingredients differ in their protein, fiber, lipid, mineral and carbohydrate composition, and their relative proportions determine the final proximate profile of a composite product (Mandal *et al*., 2023; Moulick *et al*., 2023).

Crude Fiber Content

Crude fiber increased significantly from 2.77% in T0 to 5.10% in T4. The progressive increase across the formulations, although not perfectly linear, indicates that incorporation of the selected botanicals increased the fiber fraction of the dry blends. T4 had the highest crude fiber content (5.10%), followed by T3 (4.87%), T1 (4.34%) and T2 (4.01%), whereas T0 had the lowest value (2.77%). This finding is nutritionally relevant because plant structural materials contribute to dietary fiber, which is associated with several physiological functions. The relatively high fiber content reported for fennel and lemongrass provides a plausible explanation for the increase observed after botanical incorporation. Noreen *et al*. (2023) reported high fiber content in fennel seed, while Manna *et al*. (2024) reported 16.7% crude fiber in lemongrass powder. The increased fiber content also supports the valorisation of avocado seed and other underutilized plant materials in functional food development. Avocado seed has been reported to contain fiber and other bioactive constituents and has been investigated as an ingredient in beverage development. Pușcaș *et al*. (2022) demonstrated the feasibility of using roasted avocado seed powder in the preparation of a hot drink, while Nyakang'i *et al*. (2023) investigated avocado seed powder in model beverages and baked products. These studies support the potential of avocado seed as a food ingredient rather than merely an agro-industrial waste material. However, the fiber result requires careful interpretation because the product is intended for infusion. Crude fiber measured in the dry blend does not necessarily represent the quantity of fiber that will be consumed in a cup of the beverage. Insoluble fiber is likely to remain largely in the plant residue after brewing, whereas some soluble fiber-associated components may enter the aqueous phase. Consequently, the observed increase from 2.77% to 5.10% indicates an improvement in the fiber content of the powdered product, but the physiological contribution of this fiber cannot be determined without evaluating the composition of the brewed infusion. Future studies should therefore determine extraction efficiency and quantify soluble and insoluble fractions in both the dry

Table 2. Proximate composition (%) of the avocado seed-based herbal infusion blends

Sample	Moisture	Protein	Ash	Fat	Crude fibre
T0	$11.30^{a} \pm 0.04$	$3.03^{e} \pm 0.01$	$3.28^{e} \pm 0.01$	$5.34^{a} \pm 0.01$	$2.77^{e} \pm 0.01$
T1	$9.02^{c} \pm 0.01$	$4.64^{d} \pm 0.02$	$6.01^{d} \pm 0.01$	$4.57^{b} \pm 0.02$	$4.34^{c} \pm 0.01$
T2	$10.20^{b} \pm 0.02$	$7.46^{b} \pm 0.02$	$7.47^{b} \pm 0.03$	$4.20^{d} \pm 0.03$	$4.01^{d} \pm 0.01$
T3	$10.37^{b} \pm 0.01$	$5.11^{c} \pm 0.01$	$6.84^{c} \pm 0.02$	$4.28^{c} \pm 0.02$	$4.87^{b} \pm 0.01$
T4	$8.09^{d} \pm 0.00$	$8.06^{a} \pm 0.00$	$7.66^{a} \pm 0.00$	$4.01^{e} \pm 0.00$	$5.10^{a} \pm 0.01$

Values are mean ± SD of triplicate determinations. Different superscript letters within a column indicate significant differences ($P<0.05$. Keys: T0 = Control (100% avocado seed powder); T1 = 70% avocado seed powder, 10% fennel powder, 10% lemongrass powder and 10% clove powder; T2 = 60% avocado seed powder, 20% fennel powder, 10% lemongrass powder and 10% clove powder; T3 = 60% avocado seed powder, 10% fennel powder, 20% lemongrass powder and 10% clove powder; T4 = 50% avocado seed powder, 25% fennel powder, 15% lemongrass powder and 10% clove powder.

product and prepared beverage.

Fat Content

Fat content exhibited an opposite trend, decreasing significantly from 5.34% in T0 to 4.01% in T4. T0 had the highest fat content, whereas T4 had the lowest. The reductions observed in the spice-containing formulations suggest that replacement of a portion of the avocado seed powder with the botanical ingredients resulted in a lower overall lipid concentration. This is plausible because the proximate composition of spices varies considerably and several of the ingredients used in the present formulation contain relatively modest amounts of fat compared with the avocado seed material. Moulick *et al*. (2023) reported fat contents ranging from 4.33 to 19.04% among the spices examined, while Manna *et al*. (2024) reported only 3.1% crude fat in lemongrass powder. The reduction in fat may have technological relevance for the storage of the dry herbal blend because unsaturated lipids can undergo oxidation, leading to the formation of undesirable volatile compounds and off-flavors. Avocado seed itself contains lipid, and its concentration may influence the oxidative behavior of avocado-seed-based products. Nyakang'i *et al*. (2023) investigated the storage stability of phenolic compounds in avocado seed powder and demonstrated the importance of storage conditions in maintaining the quality of avocado-seed-based ingredients. Nevertheless, the present fat data alone cannot establish that T4 will have a longer shelf life than T0. Such a conclusion would require direct measurement of oxidative deterioration indicators, including peroxide value, p-anisidine value and free fatty acids, together with water activity and microbiological quality during storage.

The decrease in fat should also be considered from the perspective of the intended use of the product. Herbal infusions are generally consumed primarily for their flavor, aroma and phytochemical characteristics rather than as major dietary sources of macronutrients. Consequently, the relatively low fat contents observed in T1–T4 may be technologically appropriate for a powdered beverage. The aromatic and bioactive characteristics of fennel, lemongrass and clove may be more important to the functional identity and sensory quality of the product than their contribution to macronutrient intake. Recent reviews have highlighted the diverse bioactive constituents of fennel, lemongrass and clove, including volatile compounds and phenolic constituents that are relevant to their use in food and beverage applications (Abdul Aziz *et al*., 2023; Du *et al*., 2024; Tazi *et al*., 2024).

Mineral Composition of Avocado Seed-Based Herbal Infusion Blends

The mineral composition of the avocado seed-based herbal infusion blends is presented in Table 3. Significant differences ($P < 0.05$) were observed among the formulations for calcium, iron, magnesium, zinc and potassium. Overall, incorporation of fennel, lemongrass and clove substantially modified the mineral profile of the avocado seed-based blends. T4, consisting of 50% avocado seed, 25% fennel, 15% lemongrass and 10% clove, recorded the highest concentrations of all the minerals evaluated, with values of 37.44 mg/100 g calcium, 1.46 mg/100 g iron, 113.99 mg/100 g magnesium, 1.12 mg/100 g zinc and 136.52 mg/100 g potassium. In contrast, T0, containing 100% avocado seed powder, had the lowest values of 18.11, 0.86, 41.93, 0.39 and 66.21 mg/100 g, respectively. The consistent increase in mineral concentrations following incorporation of the botanical ingredients suggests that blending avocado seed with fennel, lemongrass and clove improved the mineral density of the resulting formulations.

Calcium Content

The calcium concentration increased significantly from 18.11 mg/100 g in T0 to 25.21, 33.90, 30.26 and 37.44 mg/100 g in T1, T2, T3 and T4, respectively. The concentration in T4 was approximately 106.7% higher than that of the control. This increase may be associated with the relatively high calcium contribution of the incorporated botanicals, particularly fennel and clove. Noreen *et al*. (2023) reported a calcium concentration of approximately 588.93 mg/100 g in fennel seeds, demonstrating that fennel can constitute an important dietary source of calcium. Similarly, clove has been reported to contain appreciable amounts of calcium, together with potassium, magnesium, iron and zinc (Xue *et al*., 2022; Niazi *et al*., 2024). Thus, replacement of part of the avocado seed powder with mineral-containing botanical ingredients could reasonably account for the increased calcium concentration observed in the formulated blends. The substantial variation between T2 and T3 also suggests that the mineral response was influenced not merely by total spice incorporation but by the identity and relative proportions of the individual ingredients.

Table 3. Mineral composition (mg/100 g) of the avocado seed-based herbal infusion blends

Sample	Calcium	Iron	Magnesium	Zinc	Potassium
T0	$18.11^{e} \pm 0.01$	$0.86^{e} \pm 0.03$	$41.93^{e} \pm 0.04$	$0.39^{e} \pm 0.03$	$66.21^{e} \pm 0.01$
T1	$25.21^{d} \pm 0.01$	$1.06^{d} \pm 0.02$	$78.64^{d} \pm 0.03$	$0.64^{d} \pm 0.01$	$80.91^{d} \pm 0.03$
T2	$33.90^{b} \pm 0.03$	$1.28^{c} \pm 0.04$	$106.03^{b} \pm 0.04$	$0.97^{c} \pm 0.01$	$130.27^{b} \pm 0.03$
T3	$30.26^{c} \pm 0.01$	$1.31^{b} \pm 0.02$	$98.55^{c} \pm 0.05$	$1.01^{b} \pm 0.04$	$118.00^{c} \pm 0.01$
T4	$37.44^{a} \pm 0.02$	$1.46^{a} \pm 0.03$	$113.99^{a} \pm 0.13$	$1.12^{a} \pm 0.03$	$136.52^{a} \pm 0.04$

Values are mean ± SD of triplicate determinations. Different superscript letters indicate significant differences within a column ($P<0.05$). Keys: T0 = Control (100% avocado seed powder); T1 = 70% avocado seed powder, 10% fennel powder, 10% lemongrass powder and 10% clove powder; T2 = 60% avocado seed powder, 20% fennel powder, 10% lemongrass powder and 10% clove powder; T3 = 60% avocado seed powder, 10% fennel powder, 20% lemongrass powder and 10% clove powder; T4 = 50% avocado seed powder, 25% fennel powder, 15% lemongrass powder and 10% clove powder.

Magnesium Content

Magnesium exhibited a particularly pronounced increase, rising from 41.93 mg/100 g in T0 to 113.99 mg/100 g in T4. The value obtained for T4 represented an approximately 171.9% increase relative to the control. Magnesium is an essential mineral involved in energy metabolism, enzymatic reactions, neuromuscular activity and maintenance of normal cellular function. The increase observed in the present study is consistent with the established occurrence of magnesium in the botanical ingredients used for the formulations. Fennel seeds, for example, have been reported to contain substantial magnesium, while clove also contains considerable quantities of the mineral (Noreen *et al*., 2023; Xue *et al*., 2022). Lemongrass likewise contains magnesium together with calcium, potassium, iron and zinc, further supporting its potential contribution to the mineral enrichment of the blends (Sambo *et al*., 2024; Liu *et al*., 2025). The higher magnesium content of T4 may therefore reflect the combined contribution of fennel, lemongrass and clove, together with the specific proportions used in that formulation.

Potassium Content

Potassium also increased considerably following incorporation of the spice ingredients. The concentration increased from 66.21 mg/100 g in T0 to 80.91, 130.27, 118.00 and 136.52 mg/100 g in T1, T2, T3 and T4, respectively. Consequently, T4 contained approximately 106.2% more potassium than T0. Potassium is an important intracellular electrolyte involved in fluid and electrolyte balance, nerve transmission, muscle function and maintenance of membrane potential. The high potassium concentrations in the spice-containing formulations are consistent with the mineral composition reported for the component botanicals. Fennel seeds have been reported to contain approximately 409.64 mg/100 g potassium, while clove has been characterized as particularly rich in potassium (Noreen *et al*., 2023; Niazi *et al*., 2024). Lemongrass has also been identified as a source of potassium and other essential mineral elements (Liu *et al*., 2025). Therefore, the increasing proportion of these ingredients in the blends provides a plausible explanation for the marked increase in potassium, particularly in T2 and T4.

Iron Content

Iron concentration increased progressively from 0.86 mg/100 g in T0 to 1.06, 1.28, 1.31 and 1.46 mg/100 g in T1, T2, T3 and T4, respectively. The concentration in T4 represented an increase of approximately 69.8% relative to T0. Although the absolute iron concentrations were considerably lower than those of calcium, magnesium and potassium, the increase contributes positively to the micronutrient profile of the formulated product. Iron is essential for oxygen transport, cellular respiration and several enzymatic processes. Previous studies have demonstrated that fennel, lemongrass and clove contain iron in varying concentrations (Noreen *et al*., 2023; Xue *et al*., 2022; Liu *et al*., 2025). Interestingly, T3 contained slightly more iron than T2 (1.31 versus 1.28 mg/100 g), despite T2 having higher calcium, magnesium and potassium concentrations. This further demonstrates that individual minerals respond differently to formulation composition and that total botanical inclusion alone cannot be used to predict the concentration of every mineral.

Zinc Content

Zinc showed the greatest relative increase among the five minerals evaluated. Its concentration increased from 0.39 mg/100 g in T0 to 0.64, 0.97, 1.01 and 1.12 mg/100 g in T1, T2, T3 and T4, respectively. The zinc concentration of T4 was approximately 187.2% higher than that of T0. Zinc is required for numerous biological functions, including enzyme activity, protein synthesis, cell division, immune function and maintenance of normal growth and development. The increase observed in the blends is consistent with the occurrence of zinc in fennel, lemongrass and clove. Noreen *et al*. (2023) reported zinc in fennel seeds, while Xue *et al*. (2022) documented zinc among the mineral constituents of S. aromaticum. Lemongrass has similarly been reported to contain zinc together with several macro- and micro-minerals (Liu *et al*., 2025). The progressive increase in zinc across the formulations therefore indicates that the botanical ingredients made a measurable contribution to the trace-mineral profile of the developed blends.

Phytochemical Composition of Avocado Seed-Based Herbal Infusion Blends

The phytochemical composition of the avocado seed-based herbal infusion blends (Table 4) differed significantly among the formulations, indicating that incorporation of fennel, lemongrass and clove substantially modified the phytochemical profile of the avocado seed base. Alkaloids, saponins, flavonoids and phenolic compounds generally increased with increasing incorporation of the herbal ingredients, whereas tannin

exhibited a different pattern. This overall increase is consistent with the known phytochemical diversity of herbal materials and supports the potential of combining underutilized plant materials with herbs and spices to produce phytochemical-rich beverages. Shaik *et al*. (2023) reported that herbal beverages can contain several classes of phytochemicals, including flavonoids, tannins, phenolic acids and terpenoids, and emphasized that the botanical composition and processing conditions strongly influence their final phytochemical characteristics.

Alkaloid Content

The alkaloid content increased progressively from 2.38% in T0 to 4.93% in T4. T4 therefore recorded the highest alkaloid concentration, followed by T2 (4.28%), T3 (3.84%) and T1 (3.16%), while T0 had the lowest value. The progressive increase suggests that the incorporated herbs and spice contributed additional alkaloid-containing constituents to the formulations. This interpretation is supported by the recent review of Wan and Xing (2025), which identified alkaloids among the chemical constituents of lemongrass, together with flavonoids, polysaccharides and volatile compounds. Fennel also contains a diverse range of secondary metabolites, and its phytochemical composition varies according to the plant part and extraction conditions (Rafieian *et al*., 2024). The increasing alkaloid content in the present blends may therefore reflect the cumulative contribution of phytochemicals from the different botanical ingredients.

Saponin Content

The saponin content increased consistently across the formulations, from 1.19% in T0 to 2.66% in T4. T4 recorded the highest value, followed by T3 (2.33%), T2 (2.08%) and T1 (1.65%). The progressive increase suggests that increasing the proportion of the herbal components resulted in greater recovery of saponin-related constituents in the final formulations. Saponins are widely distributed secondary metabolites in plants and are characterized by their amphiphilic chemical structure and surface-active properties. Their occurrence in plant-based foods and beverages contributes to the broad phytochemical diversity of these products. The comprehensive review of herbal beverages by Shaik *et al*. (2023) similarly identified saponins among the phytochemical constituents reported in several traditional herbal drinks. Consequently, the higher saponin values observed in T2–T4 demonstrate that herbal supplementation substantially altered the phytochemical composition of the avocado seed infusion (Arsov *et al*., 2025).

Flavonoid Content

The flavonoid content exhibited a pronounced increase, rising from 2.18% in T0 to 6.01% in T4. T4 had the highest value, followed by T2 (5.76%) QE, T3 (5.22%) QE and T1 (4.15%) QE. The approximately three-fold increase from T0 to T4 indicates substantial enrichment of the infusion with measured flavonoid compounds. This result is consistent with the documented flavonoid-rich nature of several of the ingredients used. Wan and Xing (2025) reported that flavonoids are among the major groups of phenylpropanoid compounds identified in lemongrass, including compounds such as luteolin, rutin and isoquercitrin. Similarly, Rafieian *et al*. (2024) described fennel as a source of phenolic acids and flavonoids, while recent characterization of fennel materials has identified numerous flavonoid and phenolic constituents. The contribution of clove may also have been important to the increased flavonoid and phenolic values. Clove contains a chemically diverse group of bioactive compounds, including eugenol, eugenyl acetate, flavonoids and phenolic acids. Pandey *et al*. (2024) highlighted the abundance of bioactive constituents in clove and its essential oil, while a recent review of clove essential oil and eugenol also emphasized its complex phenolic and volatile composition. Thus, the increasing flavonoid concentration across samples T1 to T4 is chemically plausible and likely reflects contributions from more than one of the incorporated botanical materials.

Phenolic Content

The phenolic content also increased markedly, from 0.18% GAE in T0 to 1.15% GAE in T4. T4 recorded the highest value, followed by T2 (0.92%) GAE, T3 (0.64%) GAE and T1 (0.29%) GAE. This pattern indicates that increasing herbal supplementation enhanced the total measured phenolic constituents of the infusion. Fennel has been characterized as a valuable source of phenolic acids and flavonoids, including caffeoylquinic acids and other phenolic constituents (Rafieian *et al*., 2024; Santoro *et al*., 2024). Lemongrass also contains several phenolic and flavonoid constituents, and Wan and Xing (2025) reported that its chemical composition includes phenyl-propanoids and numerous flavonoid compounds. The increase in phenolic content may additionally be related to the contribution of avocado seed itself. Recent research on *Persea americana* seed oil identified measurable total phenolic and flavonoid constituents and demonstrated the phytochemical richness of avocado seed-derived materials (Onyedikachi *et al*., 2024). Therefore, the high phenolic values in the supplemented formulations may represent the combined contribution of avocado seed and the incorporated herbs and spice rather than the effect of a single ingredient. The progressive increase in flavonoids and phenolics is particularly relevant because these compounds constitute major groups of plant polyphenols. Rudrapal *et al*. (2024) described dietary polyphenols as structurally diverse plant constituents that include flavonoids and phenolic acids and noted their importance in food and nutritional research. Similarly, El-Saadony *et al*. (2024) reviewed the chemistry, bioactivity and nutritional relevance of polyphenols and emphasized their occurrence in plant-derived foods and beverages. The present increase in total flavonoids and phenolics therefore indicates meaningful phytochemical enrichment of the herbal infusion formulations.

Tannin Content

The tannin content showed a different pattern from the other phytochemicals. Tannin increased from 0.01% in T0 to a maximum of 0.62% in T2, followed by decreases to 0.53% in T3 and 0.38% in T4. Thus, T2

Table 4. Phytochemical composition of the avocado seed-based herbal infusion blends

Sample	Alkaloids	Saponin	Tannin	Flavonoid (% QE)	Phenol (% GAE)
T0	2.38^{e}± 0.01	1.19^{e} ± 0.01	0.01^{e} ± 0.01	2.18^{e} ± 0.02	0.18^{e} ± 0.01
T1	3.16^{d}± 0.01	1.65^{d} ± 0.01	0.18^{d} ± 0.02	4.15^{d} ± 0.04	0.29^{d} ± 0.01
T2	4.28^{b}± 0.02	2.08^{c} ± 0.03	0.62^{a} ± 0.01	5.76^{b} ± 0.01	0.92^{b} ± 0.03
T3	3.84^{c}± 0.06	2.33^{b} ± 0.02	0.53^{b} ± 0.02	5.22^{c} ± 0.01	0.64^{c} ± 0.01
T4	4.93^{a} ± 0.03	2.66^{a} ± 0.03	0.38^{c} ± 0.01	6.01^{a} ± 0.01	1.15^{a} ± 0.03

Values are mean ± SD of triplicate determinations. Different letters within a column indicate significant differences ($P<0.05$). Keys: T0 = Control (100% avocado seed powder); T1 = 70% avocado seed powder, 10% fennel powder, 10% lemongrass powder and 10% clove powder; T2 = 60% avocado seed powder, 20% fennel powder, 10% lemongrass powder and 10% clove powder; T3 = 60% avocado seed powder, 10% fennel powder, 20% lemongrass powder and 10% clove powder; T4 = 50% avocado seed powder, 25% fennel powder, 15% lemongrass powder and 10% clove powder.

rather than T4 recorded the highest tannin concentration. The absence of a simple dose-dependent relationship suggests that tannin concentration was influenced by the specific proportions of the individual botanical ingredients and possibly by differences in the extractability of tannin compounds during infusion preparation. Shaik *et al*. (2023) noted that the phytochemical composition of herbal drinks is affected by both the herbs employed and the processing conditions used during preparation. The reduction in tannin concentration from T2 to T4 is also noteworthy because T4 had the highest values for alkaloids, saponins, flavonoids and phenolics. This demonstrates that increasing total herbal incorporation does not necessarily produce a proportional increase in every phytochemical class. Instead, the phytochemical profile of a composite infusion is determined by the relative contribution of each ingredient and the compounds that are preferentially extracted under the preparation conditions. Sejbuk *et al*. (2024) emphasized that food processing can alter the quantity, bioactivity and bioavailability of plant polyphenols, reinforcing the importance of processing conditions when interpreting phytochemical measurements.

Sensory Evaluation of Avocado Seed-Based Herbal Infusion Blends

The sensory evaluation revealed clear differences among the avocado seed-based herbal infusion formulations, indicating that the incorporation and relative proportions of fennel, lemongrass and clove substantially influenced the sensory quality of the products. In general, T2 and T3 were the most favorably rated formulations, while T0 and T1 received lower scores for most attributes. This finding supports the view that blending underutilized plant materials with complementary herbs and spices can improve beverage acceptability, provided that the ingredients are used at appropriate levels. Recent research on plant-based beverages similarly reported that blending different plant materials can enhance acceptance, although excessive incorporation may introduce undesirable sensory characteristics and reduce liking (Bayudan *et al*., 2026).

Appearance

As regards appearance, T3 and T4 recorded the highest scores (8.00 each), followed by T2 (7.50), whereas T0 and T1 recorded lower scores of 6.40 and 5.60, respectively. The higher appearance scores of the supplemented formulations suggest that the incorporation of the herbal ingredients produced a more attractive visual character than avocado seed alone. This may be associated with differences in color intensity and the visual contribution of the dried herbs and spices used in the blends. Mensah *et al*. (2025) similarly observed that the type and proportion of ingredients in herbal infusions affected color and consumer preference, with differences in the visual characteristics of the blends influencing their sensory acceptance.

Taste

The taste scores showed a pronounced improvement in the supplemented formulations. T3 had the highest taste score (8.20), closely followed by T2 (8.00), while T4 recorded 7.10. T0 and T1 had substantially lower scores of 5.80 and 6.00, respectively. The high taste scores of T2 and T3 indicate that the combinations of avocado seed, fennel, lemongrass and clove produced a more desirable flavor profile than avocado seed alone. Taste is particularly important in determining beverage acceptability. Szymandera-Buszka *et al*. (2025) reported that taste characteristics were a key determinant of sensory desirability among consumers evaluating different plant-based beverages. The reduction in taste score from T3 to T4 suggests that increasing the proportion of the herbal ingredients beyond the optimum level did not result in a further sensory advantage. Instead, the stronger contribution of the herbs and spices in T4 may have altered the flavor balance. This interpretation agrees with findings from spice-based beverages, where formulations containing fewer or lower levels of certain spices were preferred over formulations with greater spice intensity. In particular, a 2025 study of ready-to-drink reported greater preference for formulations containing fewer spices, demonstrating that excessive spice intensity can negatively affect sensory acceptance (Mensah *et al*., 2025).

Aroma

The aroma scores further demonstrated the superiority of T2 and T3. T3 recorded the highest aroma score (8.40), followed by T2 (7.80), whereas T4 scored 6.40. T0 and T1 had considerably lower scores of 4.70 and 4.80, respectively. The high aroma score of T3 suggests that its particular combination of herbal ingredients generated a desirable aromatic profile. This is important for herbal infusions because aroma

Table 5. Sensory evaluation of mixed herbal tea samples

Sample	Appearance	Taste	Aroma	Mouthfeel	Overall Acceptability
T0	6.40±0.70^{b}	5.80±0.79^{c}	4.70±0.67^{c}	4.80±0.79^{c}	5.00±0.67^{c}
T1	5.60±0.52^{b}	6.00±0.82^{c}	4.80±0.63^{c}	5.80±0.79^{b}	5.70±0.67^{bc}
T2	7.50±0.53^{a}	8.00±0.67^{a}	7.80±0.79^{a}	8.10±0.74^{a}	7.80±0.79^{a}
T3	8.00±0.82^{a}	8.20±0.42^{a}	8.40±0.52^{a}	7.80±0.42^{a}	8.00±0.67^{a}
T4	8.00±0.67^{a}	7.10±0.57^{b}	6.40±0.70^{b}	5.60±0.52^{d}	6.30±0.48^{b}

Values are mean ± SD (n = 30). Means within a column bearing different superscripts differ significantly (P<0.05). Keys: T0 = Control (100% avocado seed powder); T1 = 70% avocado seed powder, 10% fennel powder, 10% lemongrass powder and 10% clove powder; T2 = 60% avocado seed powder, 20% fennel powder, 10% lemongrass powder and 10% clove powder; T3 = 60% avocado seed powder, 10% fennel powder, 20% lemongrass powder and 10% clove powder; T4 = 50% avocado seed powder, 25% fennel powder, 15% lemongrass powder and 10% clove powder.

contributes strongly to the overall sensory impression of the beverage. Mensah *et al*. (2025) noted that aroma can provide an indication of the origin and quality of an herbal infusion and demonstrated significant differences in aroma preference among differently formulated herbal beverages. The strong aroma response observed in T3 may also be related to the complementary volatile compounds contributed by lemongrass, fennel and clove. Clove, in particular, contains aromatic compounds such as eugenol, while lemongrass contributes characteristic citrus-like volatile compounds. Recent research on tea aroma has demonstrated a strong relationship between volatile compounds and sensory aroma perception, showing that changes in volatile composition can produce substantial differences in consumer sensory responses. Thus, the high aroma score of T3 may reflect a favorable balance of the volatile constituents contributed by the different plant materials.

Mouthfeel

With respect to mouthfeel, T2 recorded the highest score (8.10), followed by T3 (7.80), while T1, T4 and T0 recorded 5.80, 5.60 and 4.80, respectively. The high scores obtained by T2 and T3 indicate that these formulations produced the most desirable oral sensation. Conversely, the lower score recorded by T4 suggests that increasing the proportion of the herbal ingredients may have adversely affected mouthfeel. This observation is consistent with recent research showing that changes in plant-based beverage formulation can influence thickness, grittiness, smoothness and other textural characteristics, which subsequently affect consumer liking (Sharma *et al*., 2025). The relatively poor sensory performance of T0, particularly in aroma, mouthfeel and overall acceptability, indicates that avocado seed alone produced a less attractive infusion. This is important because although avocado seed has considerable potential as a source of bioactive compounds, its incorporation into food products must be carefully managed to obtain desirable sensory characteristics. Nyakang'i *et al*. (2023) reported that avocado seed incorporation could influence sensory properties and acceptability of food products, supporting the need for appropriate formulation when avocado seed is used as a functional ingredient.

Overall Acceptability

The overall acceptability scores clearly identified T3 as the most preferred formulation. T3 recorded an overall acceptability score of 8.00, followed by T2 (7.80). T4 recorded 6.30, while T1 and T0 recorded 5.70 and 5.00, respectively. The superior performance of T3 can be attributed to its consistently high scores for appearance, taste, aroma and mouthfeel. Thus, T3 appears to have achieved the best sensory balance among the formulations. Sahu *et al*. (2025) similarly demonstrated that optimizing the relative proportions of botanical ingredients in a functional beverage was important for achieving high scores across color, aroma, mouthfeel, taste and overall acceptability. The lower overall acceptability of T4, despite its high appearance score, is particularly noteworthy. Its taste score decreased from 8.20 in T3 to 7.10, aroma decreased from 8.40 to 6.40, and mouthfeel decreased from 7.80 to 5.60. This suggests that the increased proportion of the herbal ingredients in T4 may have produced a sensory intensity that was less desirable. Similar findings have been reported in herbal functional beverages, where increasing the concentration of functional plant materials may improve certain nutritional or bioactive characteristics while simultaneously increasing bitterness, astringency or excessive herbal/spicy notes (Awlqadr *et al*., 2026).

Conclusion

The incorporation of fennel, lemongrass and clove into avocado seed powder resulted in variations in the proximate composition, mineral profile and selected phytochemical constituents of the dry herbal infusion blends. Among the formulations, T4 (50% avocado seed, 25% fennel, 15% lemongrass and 10% clove) recorded higher values for several of the measured compositional parameters, including protein, ash, crude fiber and selected minerals. However, the phytochemical response varied among the formulations, indicating that the inclusion of different botanical ingredients did not produce uniform changes across all measured constituents. Sensory evaluation showed that T3 (60% avocado seed, 10% fennel, 20% lemongrass and 10% clove) recorded the highest scores for taste, aroma and overall acceptability. Consequently, T3 was the most sensory-acceptable formulation among those evaluated, although this does not establish it as an optimised formulation. These findings demonstrate that differences in the measured compositional characteristics of the dry blends do not necessarily correspond to differences in sensory preference.

The study establishes the potential of avocado seed powder as an ingredient for developing herbal infusion blends with fennel, lemongrass and clove.

However, the proximate, mineral and phytochemical results represent measurements obtained from the powdered dry blends and cannot be directly interpreted as the composition or nutritional contribution of the brewed infusions. The extent to which the measured constituents are extracted into the beverage during brewing was not established. Further studies should therefore determine the proximate and phytochemical composition of the brewed infusions, evaluate the extraction of relevant constituents under defined brewing conditions, and investigate antioxidant activity, microbial quality, storage stability and shelf life. Additional research on product safety, bioavailability and consumer acceptability is also necessary before wider application or commercial development.

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Authors Contributions

Adedokun, I.I.: Conceptualization, methodology, investigation, data curation, formal analysis, writing – original draft, and visualization; Nwokeke, B.C.: Methodology, investigation, laboratory analysis. Ogugua, E.C.: Data curation, and writing – review and editing. Ezeikpe, U.J.: Investigation, laboratory analysis, validation, and writing – review and editing, validation, data analysis. Okoronkwo, K.A.: writing – review and editing. Ogbedeagu, C.O.: Supervision, validation. Wason, I.B.: project administration, interpretation of results. Nwachukwu, C.A.: writing – review and editing. All authors contributed to the interpretation of the findings, critically reviewed and approved the final manuscript, and agreed to be accountable for all aspects of the work.

Ethics Approval

The study was conducted in accordance with the ethical principles for research involving human participants. Ethical approval for the sensory evaluation was obtained from the appropriate institutional ethics committee of the University of Agriculture and Environmental Sciences, Umuagwo, Imo State, Nigeria, before commencement of the study.

Consent to Participate

All participants in the sensory evaluation were informed about the purpose and procedures of the study before participation. Participation was voluntary, and informed consent was obtained from all participants prior to the sensory assessment. Participants were also informed of their right to withdraw from the study at any time without any consequences.

References

Abdul Aziz, A. H., Rizkiyah, D. N., Qomariyah, L., Irianto, I., Che Yunus, M. A., & Putra, N. R. (2023). Unlocking the full potential of clove (*Syzygium aromaticum*) spice: An overview of extraction techniques, bioactivity, and future opportunities in the food and beverage industry. *Processes*, *11*(8), 2453. https://doi.org/10.3390/pr11082453

Afiukwa, C. A., Ugwu, O. P., Okechukwu, P. C., Ebenyi, L. N., Oketa, H. A., Idenyi, J. N., & Ossai, E. C. (2013). Phytochemical analysis of two wild edible mushrooms, *Auricularia polytricha* and *Pleurotus ostreatus*, common in Ohaukwu area of Ebonyi State, Nigeria. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, *4*(2), 1065–1070.

Ahamad, J. (2024). Ethnomedicinal and pharmacological significance of *Syzygium aromaticum* (clove): A review. *Journal of Angiotherapy*, *8*(10), 1–9. https://doi.org/10.25163/angiotherapy.8109864

Alsado, C., Chen, L., & Wismer, W. (2025). Are plant-based milks unique products or dairy milk substitutes? A study of consumer perceptions, uses, and consumption motivations of plant-based and dairy milks. *Food Quality and Preference*, *134*, 105681. https://doi.org/10.1016/j.foodqual.2025.105681

Anwar, C., Irhami, & Aprita, I. R. (2022). The potency of avocado seeds (*Persea americana* Mill.) as a source of antioxidant tea. *Bulletin of the Transilvania University of Braşov, Series II: Forestry, Wood Industry, Agricultural Food Engineering*, *15*(64)(1), 131–144. https://doi.org/10.31926/but.fwiafe.2022.15.64.1.10

AOAC International. (2019). *Official methods of analysis of AOAC International* (21st ed.). AOAC International.

AOAC International. (2023). *Official methods of analysis of AOAC INTERNATIONAL* (22nd ed.). Oxford University Press. https://doi.org/10.1093/9780197610145.001.0001

Arsov, A., Tsigoriyna, L., Batovska, D., Armenova, N., Mu, W., Zhang, W., Petrov, K., & Petrova, P. (2024). Bacterial degradation of antinutrients in foods: The genomic insight. *Foods*, *13*(15), 2408. https://doi.org/10.3390/foods13152408

Awlqadr, F. H., Qadir, S. A., Altemimi, A. B., Tlay, R. H., Saeed, M. N., Mohammed, O. A., & Abedelmaksoud, T. G. (2026). Innovations in herbal functional beverages: From green formulation and bioactivity preservation to sensory optimization and regulatory safety. *Food Science & Nutrition*, *14*(5), e71776. https://doi.org/10.1002/fsn3.71776

Batiha, G. E. S., Beshbishy, A. M., Wasef, L. G., Elewa, Y. H. A., Al-Sagan, A. A., Abd El-Hack, M. E., Taha, A. E., Abd-Elhakim, Y. M., & Prasad, M. N. V. (2020). Chemical constituents and pharmacological activities of *Syzygium aromaticum* (clove): A review. *Food and Chemical Toxicology*, *142*, 111609. https://doi.org/10.1016/j.fct.2020.111609

Bayudan, S., Laureati, M., Proserpio, C., Cattaneo, C., Guerrero, L., Badia-Olmos, C., Claret, A., Dapčević-

Hadnađev, T., Pestorić, M., Škrobot, D., Ubiparip, D., Pojić, M., De Steur, H., & Schouteten, J. J. (2026). Exploring consumer perceptions of composite plant-based beverages formulated with neglected and underutilized crops. *Food Research International*, *233*, 118985. https://doi.org/10.1016/j.foodres.2026.118985

Chang, C. C., Yang, M. H., Wen, H. M., & Chern, J. C. (2002). Estimation of total flavonoid content in propolis by two complementary colorimetric methods. *Journal of Food and Drug Analysis*, *10*(3), 178–182.

Du, X., Zhang, M., Wang, S., Li, J., Zhang, J., & Liu, D. (2024). Ethnopharmacology, chemical composition and functions of *Cymbopogon citratus*. *Chinese Herbal Medicines*, *16*(3), 358–374. https://doi.org/10.1016/j.chmed.2023.07.002

Dushkova, M., Dimov, M., Lazarov, L., & Pencheva, M. (2023). Physical, chemical, sorption and microbiological characteristics of fennel fruits. *Heliyon*, *9*(9), e19127. https://doi.org/10.1016/j.heliyon.2023.e19127

Ekpenyong, C. E., Akpan, E., & Nyoh, A. (2015). Ethnopharmacology, phytochemistry and biological activities of *Cymbopogon citratus* (lemongrass): A review. *Chinese Journal of Natural Medicines*, *13*(5), 321–337.

El-Saadony, M. T., Yang, T., Saad, A. M., Alkafaas, S. S., Elkafas, S. S., Eldeeb, G. S., Mohammed, D. M., Salem, H. M., Korma, S. A., Loutfy, S. A., Alshahran, M. Y., Ahmed, A. E., Mosa, W. F. A., Abd El-Mageed, T. A., Ahmed, A. F., Fahmy, M. A., El-Tarabily, M. K., Mahmoud, R. M., AbuQamar, S. F., El-Tarabily, K. A., & Lorenzo, J. M. (2024). Polyphenols: Chemistry, bioavailability, bioactivity, nutritional aspects and human health benefits: A review. *International Journal of Biological Macromolecules*, *277*(3), 134223. https://doi.org/10.1016/j.ijbiomac.2024.134223

Fellows, P. J. (2017). *Food processing technology: Principles and practice* (4th ed.). Woodhead Publishing.

Francis, G., Kerem, Z., Makkar, H. P. S., & Becker, K. (2002). The biological action of saponins in animal systems: A review. *British Journal of Nutrition*, *88*(6), 587–605. https://doi.org/10.1079/BJN2002725

Fufa, D. D., Bekele, T., Tamene, A., & Bultosa, G. (2025). Drying kinetic models, thermodynamics, physicochemical qualities, and bioactive compounds of avocado (*Persea americana* Mill. Hass variety) seeds dried using various drying methods. *Heliyon*, *11*(1), e41058. https://doi.org/10.1016/j.heliyon.2024.e41058

International Organization for Standardization. (2019). *Tea—Preparation of liquor for use in sensory tests* (ISO Standard No. 3103:2019). ISO.

Iwe, M. O. (2002). *Handbook of sensory methods and analysis*. Rejoint Communication Services.

Jain, A., Jangid, T., Bhardwaj, G. S., & Jangir, R. N. (2026). *Syzygium aromaticum*: A systematic review of its phytochemistry and pharmacological applications. *Letters in Functional Foods*, *3*, e26669390425078. https://doi.org/10.2174/0126669390425078260205113815

Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food: Principles and practices* (2nd ed.). Springer. https://doi.org/10.1007/978-1-4419-6488-5

Makkar, H. P. S., Blümmel, M., Borowy, N. K., & Becker, K. (1993). Gravimetric determination of tannins and their correlations with chemical and protein precipitation methods. *Journal of the Science of Food and Agriculture*, *61*(2), 161–165. https://doi.org/10.1002/jsfa.2740610205

Mandal, D., Sarkar, T., & Chakraborty, R. (2023). Critical review on nutritional, bioactive, and medicinal potential of spices and herbs and their application in food fortification and nanotechnology. *Applied Biochemistry and Biotechnology*, *195*(2), 1319–1513. https://doi.org/10.1007/s12010-022-04132-y

Manna, S., Boxi, K., Chanda, S. K., & Khalua, R. K. (2024). Proximate analysis of lemongrass powder (*Cymbopogon citratus*). *The Bioscan*, *19*(Special Issue 1), 495–496. https://doi.org/10.63001/tbs.2024.v19.i02.S.I(1).pp495-496

Marafon, K., Prestes, A. A., Carvalho, A. C. F., de Souza, C. K., & Prudencio, E. S. (2025). Bioactive compounds' importance in plant-based beverages: A review. *Current Opinion in Food Science*, *63*, 101304. https://doi.org/10.1016/j.cofs.2025.101304

Masyita, A., Sari, R. M., Astuti, A. D., Yasir, B., Rahmawati, S., Sugiyanto, H., & Ilyas, S. (2022). Terpenes and terpenoids from clove (*Syzygium aromaticum*): A review. *Phytotherapy Research*, *36*(7), 2640–2657. https://doi.org/10.1002/ptr.7495

Mensah, G. A., Aryeetey, E., & Lutterodt, H. E. (2025). Nutritional and nutraceutical properties of cocoa shell–based herbal infusion. *Journal of Food Quality*, *2025*, 6696124. https://doi.org/10.1155/jfq/6696124

Moulick, S. P., Jahan, F., Al Mamun, M. Z. U., Hossain, M. I. S., Waliullah, M., & Sathee, R. A. (2023). Analysis of indigenous spices widely consumed in Bangladesh: An assessment to explore its proximate contents, minerals, phytochemical compositions, and antioxidant activities. *Journal of Agriculture and Food Research*, *14*, 100720. https://doi.org/10.1016/j.jafr.2023.100720

Musa, N., & Nahar, D. M. (2025). Sensory evaluation of bidara leaves (tea) infusion (*Ziziphus mauritiana*). *Junior Science Communication*, *53*.

Niazi, M. K., Badr ul Ain, H., Noreen, S., Tufail, T., Hassan, F., & Ismail, M. A. (2024). Characterization of muffins prepared with clove (*Syzygium aromaticum*) extract and its effect on hyperlipidemic adult patients. *Natural Product Communications*, *19*(9). https://doi.org/10.1177/1934578X241283188

Noreen, S., Tufail, T., Bader Ul Ain, H., Ali, A., Aadil, R. M., Nemat, A., & Manzoor, M. F. (2023). Antioxidant activity and phytochemical analysis of fennel seeds and flaxseed. *Food Science & Nutrition*, *11*(3), 1309–1317. https://doi.org/10.1002/fsn3.3165

Noreen, S., Tufail, T., Bader Ul Ain, H., & Awuchi, C. G. (2023). Pharmacological, nutraceutical, functional and therapeutic properties of fennel (*Foeniculum*

vulgare). *International Journal of Food Properties*, *26*(1), 915–927. https://doi.org/10.1080/10942912.2023.2192436

Nyakang'i, C. O., Marete, E., Ebere, R., & Arimi, J. M. (2023). Physicochemical properties of avocado seed extract model beverages and baked products incorporated with avocado seed powder. *International Journal of Food Science*, *2023*, 6860806. https://doi.org/10.1155/2023/6860806

Nyong, B. E. (2023). Nutritional composition of flour from avocado pear (*Persea americana*) peels and seeds. *International Journal of Recent Research in Life Sciences*, *10*(2), 29–32.

Obadoni, B. O., & Ochuko, P. O. (2002). Phytochemical studies and comparative efficacy of the crude extracts of some haemostatic plants in Edo and Delta States of Nigeria. *Global Journal of Pure and Applied Sciences*, *8*(2), 203–208. https://doi.org/10.4314/gjpas.v8i2.16033

Oboh, G., Ademosun, A. O., & Akinleye, M. O. (2020). Nutritional quality and antioxidant properties of herbal beverage formulations. *Heliyon*, *6*(11), e05458.

Okibe, F. G., Hwok, D. J., Saidu, A., Ogah, E., Echioda, S., Ogbeh, E., Adagayi, M. A., Burbwa, V. O., Itodo, D. A., & Adoga, S. O. (2023). Proximate, mineral and antinutrient composition of avocado (*Persea americana*) seeds and peel. *Nigerian Annals of Pure and Applied Sciences*, *6*(1), 102–111. https://doi.org/10.5281/zenodo.7338397

Panche, A. N., Diwan, A. D., & Chandra, S. R. (2016). Flavonoids: An overview. *Journal of Nutritional Science*, *5*, e47. https://doi.org/10.1017/jns.2016.41

Pandey, V. K., Srivastava, S., Ashish, Dash, K. K., Singh, R., Dar, A. H., Singh, T., Farooqui, A., Shaikh, A. M., & Kovacs, B. (2024). Bioactive properties of clove (*Syzygium aromaticum*) essential oil nanoemulsion: A comprehensive review. *Heliyon*, *10*(1), e22437. https://doi.org/10.1016/j.heliyon.2023.e22437

Pușcaș, A., Tanislav, A. E., Marc, R. A., Mureșan, V., Mureșan, A. E., Pall, E., & Cerbu, C. (2022). Cytotoxicity evaluation and antioxidant activity of a novel drink based on roasted avocado seed powder. *Plants*, *11*(8), 1083. https://doi.org/10.3390/plants11081083

Rafieian, F., Amani, R., Rezaei, A., Karaça, A. C., & Jafari, S. M. (2024). Exploring fennel (*Foeniculum vulgare*): Composition, functional properties, potential health benefits, and safety. *Critical Reviews in Food Science and Nutrition*, *64*(20), 6924–6941. https://doi.org/10.1080/10408398.2023.2176817

Raposo, F., Borja, R., & Gutiérrez-González, J. A. (2024). A comprehensive and critical review of the unstandardized Folin–Ciocalteu assay to determine the total content of polyphenols: The conundrum of the experimental factors and method validation. *Talanta*, *272*, 125771. https://doi.org/10.1016/j.talanta.2024.125771

Rather, M. A., Dar, B. A., Sofi, S. N., Bhat, B. A., & Qurishi, M. A. (2016). *Foeniculum vulgare*: A comprehensive review of its traditional use, phytochemistry, pharmacology, and safety. *Arabian Journal of Chemistry*, *9*(Suppl. 2), S1574–S1583. https://doi.org/10.1016/j.arabjc.2012.04.011

Sahu, R. K., Khokhar, D., Mishra, N., & Sahu, C. (2025). Assessing sensory acceptability of ginger-turmeric based functional beverage by fuzzy logic approach. *European Journal of Nutrition & Food Safety*, *17*(6), 158–178. https://doi.org/10.9734/ejnfs/2025/v17i61747

Santoro, V., Rosa, E., Donadio, G., Polito, F., De Feo, V., & De Tommasi, N. (2024). *Foeniculum vulgare* Miller bracts, revalorization of a local food waste. *Scientific Reports*, *14*, 31287. https://doi.org/10.1038/s41598-024-82779-9

Sari, P., Rumaisha-Zuhriansyah, R., & Faridah, D. N. (2025). Functional antioxidative and sensory characteristics of ready-to-drink (RTD) blue wedang uwuh, a traditional beverage from Indonesia. *Food Chemistry Advances*, *7*, 101025. https://doi.org/10.1016/j.focha.2025.101025

Sejbuk, M., Mirończuk-Chodakowska, I., Karav, S., & Witkowska, A. M. (2024). Dietary polyphenols, food processing and gut microbiome: Recent findings on bioavailability, bioactivity, and gut microbiome interplay. *Antioxidants*, *13*(10), 1220. https://doi.org/10.3390/antiox13101220

Shahidi, F., & Ambigaipalan, P. (2015). Phenolics and polyphenolics in foods, beverages and spices: Antioxidant activity and health effects—A review. *Journal of Functional Foods*, *18*, 820–897. https://doi.org/10.1016/j.jff.2015.06.018

Shaik, M. I., Hamdi, I. H., & Sarbon, N. M. (2023). A comprehensive review on traditional herbal drinks: Physicochemical, phytochemicals and pharmacology properties. *Food Chemistry Advances*, *3*, 100460. https://doi.org/10.1016/j.focha.2023.100460

Shan, B., Cai, Y. Z., Sun, M., & Corke, H. (2005). Antioxidant capacity of 26 spice extracts and characterization of their phenolic constituents. *Journal of Agricultural and Food Chemistry*, *53*(20), 7749–7759. https://doi.org/10.1021/jf051513y

Sharma, B., Keast, R., Liem, D. G., Nolvachai, Y., & Costanzo, A. (2025). Impact of protein on sensory attributes and liking of plant-based milk alternatives. *Food Quality and Preference*, *133*, 105617. https://doi.org/10.1016/j.foodqual.2025.105617

Singh, P., & Prasad, S. (2023). A review on iron, zinc and calcium biological significance and factors affecting their absorption and bioavailability. *Journal of Food Composition and Analysis*, *123*, 105529. https://doi.org/10.1016/j.jfca.2023.105529

Singleton, V. L., Orthofer, R., & Lamuela-Raventós, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin–Ciocalteu reagent. *Methods in Enzymology*, *299*, 152–178. https://doi.org/10.1016/S0076-6879(99)99017-1

Soares, S., Brandão, E., Mateus, N., & de Freitas, V. (2020). Sensorial properties of red wine polyphenols: Astringency and bitterness. *Critical Reviews in Food Science and Nutrition*, *60*(6), 937–948.

Sultanbawa, F., & Sultanbawa, Y. (2023). Mineral nutrient-rich plants – Do they occur? *Applied Food*

Research, *3*(2), 100347. https://doi.org/10.1016/j.afres.2023.100347

Szymandera-Buszka, K., Jankowska, A., Jędrusek-Golińska, A., Jarzębski, M., Karwik, A., Anioła, J., Wieruszewski, M., Lasota, A., & Pawlicz, J. (2025). Analysis of sensory attributes and purchasing decisions of plant-based beverages of young consumers in Poland on a vegan and traditional diet. *Foods*, *14*(21), 3672. https://doi.org/10.3390/foods14213672

Tazi, A., Zinedine, A., Rocha, J. M., & Errachidi, F. (2024). Review on the pharmacological properties of lemongrass (*Cymbopogon citratus*) as a promising source of bioactive compounds. *Pharmacological Research—Natural Products*, *3*, 100046. https://doi.org/10.1016/j.prenap.2024.100046

Tharaniya, M., Karthikeyan, K., Sandhiya, S., Shalini, K., & Rabiya, S. (2023). Evaluating nutritional values for lemongrass (*Cymbopogon citratus*) herb tea formulation used in tea bags. *Innovations in Agriculture*, *6*, 1–5. https://doi.org/10.25081/ia.2023-090

Tomas, M., Wen, Y., Liao, W., Zhang, L., Zhao, C., McClements, D. J., Nemli, E., Bener, M., Apak, R., & Capanoglu, E. (2025). Recent progress in promoting the bioavailability of polyphenols in plant-based foods. *Critical Reviews in Food Science and Nutrition*, *65*(12), 2343–2364. https://doi.org/10.1080/10408398.2024.2336051

Umeh, O. E., Agu, H. O., Mba, J. C., & Nwankwegu, R. O. (2025). Phytochemical and sensory evaluation of functional tea produced from lemongrass, turmeric bud and moringa leaf. *Agriculture, Food and Natural Resources Journal*, *4*(1), 35–41.

Wan, S., & Xing, B. (2025). Research progress on chemical composition, biological activity and application of lemongrass and its essential oils. *Journal of Functional Foods*, *135*, 107083. https://doi.org/10.1016/j.jff.2025.107083

Williamson, G. (2025). Bioavailability of food polyphenols: Current state of knowledge. *Annual Review of Food Science and Technology*, *16*, 315–332. https://doi.org/10.1146/annurev-food-060721-023817

Xue, Q., Xiang, Z., Wang, S., Cong, Z., Gao, P., & Liu, X. (2022). Recent advances in nutritional composition, phytochemistry, bioactive, and potential applications of *Syzygium aromaticum* L. (Myrtaceae). *Frontiers in Nutrition*, *9*, 1002147. https://doi.org/10.3389/fnut.2022.1002147