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ORIGINAL RESEARCH ARTICLE

Formulation and Characterization of Polyphenol-Rich Functional Porridge: A Preliminary Pilot Randomized Trial in Patients with Helicobacter Pylori-Associated Peptic Ulcer Disease

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ABSTRACT

Peptic Ulcer Disease (PUD) continues to be a significant global gastrointestinal concern, being mainly caused by Helicobacter pylori infection as well as diet and lifestyle-related factors. Although proton pump inhibitors and antibiotic-based eradication regimens constitute the current standard therapeutic approach, their prolonged use can bring about undesirable outcomes, antibiotic resistance, and poor patient compliance. These necessitate the exploration of effective functional dietary strategies as complementary interventions. This present study aimed to formulate and characterize a polyphenol-rich functional porridge enriched with pomegranate peel powder and clove powder, and to evaluate its chemical composition, phytochemical profile, antioxidant activity, color characteristics, sensory screening, and a preliminary pilot assessment. Proximate analysis revealed a marked ($p < 0.05$) enhancement in fiber and ash content the optimized formulation than in the control. Phytochemical analysis showed higher levels of total phenolics and flavonoids, along with increased DPPH radical-scavenging activity, indicating strong antioxidant potential. Sensory evaluation identified formulation T5 (92:5:3) as the most optimal. A preliminary controlled pilot intervention involving f sixteen participants in four small pilot groups ($n = 4$): healthy controls (G0), diseased controls (G1), subjects receiving functional porridge (G2), and a marketed porridge (G3) was carried out at a dosage of 100 g/day for 30 days. Notably, H. pylori positivity decreased from 4/4 to 1/4 subjects in G2 g, compared with 4/4 to 3/4 subjects in G3, alongside improved hepatic enzyme profiles. These preliminary findings underscore that formulated porridge possesses significant functional dietary adjunct in PUD management, primarily attributed to its bioactive constituents, particularly polyphenols, tannins, and eugenol.

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1. INTRODUCTION

Peptic Ulcer Disease (PUD), also known as gastric or duodenal ulcer, is a chronic gastrointestinal (GI) disorder characterized by mucosa disruption due to excessive gastric acid and pepsin secretion (Shanshal et al., 2022; Magangana et al., 2020). It affects approximately 5-10% of the global population and contributes to significant morbidity, reduced quality of life, and healthcare costs (Salari et al., 2022). Despite therapeutic advancements, global prevalence increased by 27.3% between 1990 and 2019, particularly in males and low- and middle-income regions (Xie et al., 2022). PUD is a persistent global health concern due to recurrence, complications, and economic burden (Kavitt et al., 2019).

Helicobacter pylori (*H. pylori*) is the primary etiological factor responsible for over 70% of PUD cases worldwide and is classified by the World Health Organization (WHO) as a Class I carcinogen due to its potent association with gastric malignancy (Bereda, 2022; Alexander *et al.*, 2021). Approximately 4.4 billion individuals worldwide are affected with *H. pylori*, with prevalence approaching 85-95% in developing regions (Bashir & Khan, 2023; Elkhalifa et al., 2021; Hooi et al., 2017). Other contributors include prolonged non-steroidal anti-inflammatory drugs (NSAID) use (~25%), alcohol intake, smoking, and dietary irritants (Bindu et al., 2024; Thurber et al., 2023). These factors disrupt mucosal defenses, induce oxidative stress, and trigger inflammation cascades, leading to reactive oxygen species (ROS)-mediated mucosal injury (Laucirica et al., 2023; Khoder et al., 2019).

The GI tract is one of the most important aspects of an individual, not only in digestion and nutrient absorption but also as a mucosal immune barrier (Cires et al., 2017). Growing consumer interest in functional foods and nutraceuticals has increased attention toward plausible complementary approaches with antioxidant and anti-inflammatory properties (Essa et al., 2021). The global market for functional foods now exceeds US$180 billion, growing at an annual rate of approximately 8%, while polyphenol- and flavonoid-rich foods are widely accepted, accessible, and cost-effective, (Coopoosamy et al., 2023; Baker et al., 2022). According to the World Health Organization (WHO), plant-derived natural products and ethnobotanical treatments serve as primary or complementary health modalities for over 80% of the global population, particularly within traditional medicine frameworks in developing countries (Ali & Rahut, 2019).

Although Proton Pump Inhibitors (PPIs) and antibiotics remain standard therapies, their long-term effectiveness is constrained by recurrence, adverse effects, and patient non-adherence (Kandylis & Kokkinomagoulos, 2020). The need for safe, accessible, and sustainable dietary strategies to support GI integrity is important and does not need any overemphasis.

Wheat-based porridge (Dalia) is a widely consumed staple in Pakistan due to its affordability, digestibility, and nutritional value. As one of Asia's leading wheat producers (~25.5 million tons annually), wheat contributes nearly 60% of national dietary intake (Panhwar et al., 2020). Cultural preferences make Dalia an effective carrier for functional ingredients delivery (Mahgoub et al., 2020; Ajifolokun et al., 2019). Its ease of consumption and suitability for consistent dosing make it particularly attractive for dietary intervention modalities. However, incorporation of natural plant-based fortifiers necessitates careful evaluation of physicochemical and sensory attributes to ensure product quality and consumer acceptance (Kasprzak-Drozd et al., 2021; Subedi et al., 2022)).

Sustainable valorization of agro-industrial by-products aligns functional food innovation with significant environmental and economic priorities (Perler et al., 2023). Globally, ~1.13 million tons of edible food are wasted daily, equivalent to 178 g per capita per day (≈65 kg annually), with markedly higher rates in high-income countries (307 g/day) compared to upper-middle (163 g/day), lower-middle (81 g/day), and low-income regions (43 g/day) (Ge et al., 2021; Swinburn et al., 2019). Fruits (12%), vegetables (24%), and cereals (25%) are the major contributors to this waste. Beyond resource inefficiency, food waste is no longer considered a neglected by-product, as it is a substantial contributor to environmental degradation and the climate crisis burden (Chen et al., 2020).

Pomegranate (*Punica granatum* L.) peels have been traditionally used in herbal medicine since ancient times. However, they are often discarded despite constituting 30-40% of the fruit weight, accounting for nearly 1.9 million metric tons of agro-industrial by-product annually (El Barnossi et al., 2021; Batiha et al., 2020a; Batiha et al., 2020b). These peels are rich in polyphenols (Chen et al., 2021), flavonoids, vitamin C, and tannins, exhibiting strong antioxidant, anti-inflammatory, and antibacterial activities against *H. pylori* (Valero-Mendoza et al., 2023; Mo et al., 2022). Their incorporation into functional foods offers dual benefits: promoting gastroprotection by reducing oxidative stress and supporting the sustainable utilization of agro-industrial biowaste (Zamanian et al., 2024; Matsumura et al., 2023) which holds the promise of mitigating environmental pollution and re-use of hitherto classified biowastes. Clove (*Syzygium aromaticum*) is a phenolic-rich functional spice widely valued for its primary bioactive volatile constituent, eugenol, which exhibits strong antioxidant, anti-inflammatory, analgesic, and anti-microbial properties (Urooj et al., 2026; Niazi et al., 2022; Xue et al., 2022). Eugenol has been associated with enhanced gastric mucus protection and potential modulation of ulcer-related pathogens, including *H. pylori* (Adebisi et al., 2021; Gosavi et al., 2020). These attributes confer on clove a natural fortifying agent for gastroprotective and microbiota-modulating purposes through safe dietary approaches, without implying direct therapeutic "cures" or effects (Yadav et al., 2022; Longo et al., 2021).

The development of fortified wheat-based porridge enriched with pomegranate peel and clove powders necessitates thorough characterization to ensure interpretability of biological outcomes (Muthukaviya et al., 2024). Proximate composition (moisture, protein, fat, fiber, and ash) is essential for determining nutritional adequacy, the quantification of total phenolic content (TPC), total flavonoid content (TFC), and antioxidant activity (DPPH assay) is important for evaluating bioactive potential and functional quality. Sensory acceptability and color stability are critical factors for ensuring consumer compliance, palatability, and long-term translational feasibility of consumption. Despite growing interest in the gastroprotective potential of pomegranate peel and clove, evidence on combined incorporation into a standardized, nutritionally characterized, and culturally acceptable functional food matrix remains insufficient. This study aimed to develop a functional wheat-based functional porridge enriched with pomegranate peel and clove powders and to characterize its proximate composition, phytochemical profile, antioxidant activity, color properties, and sensory acceptability, as well as to conduct a pilot randomized controlled dietary intervention to evaluate preliminary changes in *H. pylori* serostatus and safety-related biomarkers in peptic ulcer patients compared with a marketed porridge and a normal-diet peptic ulcer group.

2. MATERIALS AND METHODS

2.1 Procurement of raw materials

Pomegranate fruits (*Punica granatum* L.), dried cloves (*Syzygium aromaticum* L.), and commercial wheat flour were procured from the local market of Faisalabad, Pakistan. All chemicals and reagents used in the study were of analytical grade (Merck, Germany), including methanol (CH_3OH), n-hexane (C_6H_{14}), sulfuric acid (H_2SO_4), sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3), sodium nitrite ($NaNO_2$), aluminium chloride ($AlCl_3$), Folin-Ciocalteu reagent, 2,2-diphenyl-1-picrylhydrazyl (DPPH; $C_{18}H_{12}N_5O_6$), gallic acid ($C_7H_6O_5$), and quercetin ($C_{15}H_{10}O_7$). Distilled water was used throughout the experimental procedures.

2.2 Preparation of pomegranate peel powder (PPP) and clove powder (CP)

Pomegranate fruits were thoroughly scrubbed and rinsed with tap water to remove dust and surface contaminants. The peels were manually separated from the fruits, cut, and chopped into small pieces. The pieces were then dried in a hot-air oven at 102°C for 24 h until a constant weight was achieved to ensure rapid moisture removal and to obtain a stable powder suitable for storage and incorporation. The dried peels and whole dried cloves were separately ground using a laboratory grinder and passed through an 80-mesh sieve to ensure uniform particle size. The resulting powders were separately packed in airtight polythene bags and stored at room temperature until use in the formulation of functional porridge.

2.3 Experimental Design of Functional Porridge Formulations

The experimental design consisted of 12 porridge formulations (T_0–T_{11}) prepared by varying the proportions of PPP (0, 5, 10, and 15% w/w) and CP (0, 1, 2, and 3% w/w) while maintaining a total flour weight of 100%, accurately weighed using a calibrated laboratory electronic balance, as presented in **Table 1**. The control formulation (T_0) contained 100% wheat flour without the addition of pomegranate peel or clove powder. The specific incorporation ranges for PPP (5-15%) and CP (1-3%) were established based on preliminary sensory optimization trials to strike a balance between functional efficacy and consumer palatability. During early organoleptic screening, concentrations exceeding 15% for PPP induced an intense, unpalatable astringency (attributed to high tannin levels), whereas CP additions beyond 3% imparted an overwhelming medicinal aroma and bitter note, rendering the porridge unacceptable. The remaining formulations were developed by partially replacing wheat flour with different combinations of these powders to evaluate their structural, functional, and bioactive effects.

Table 1: Composition of functional porridge formulations with varying concentrations of PPP and CP

Treatments	Wheat Flour (%)	PPP (%)	CP (%)
T_0	100	0	0
T_1	97	0	3
T_2	85	15	0
T_3	94	5	1
T_4	93	5	2
T_5	92	5	3
T_6	89	10	1

Treatments	Wheat Flour (%)	PPP (%)	CP (%)
T_7	88	10	2
T_8	87	10	3
T_9	84	15	1
T_{10}	83	15	2
T_{11}	82	15	3

Note: Formulation ratios were determined via preliminary sensory tolerance thresholds to prevent excessive plant-derived astringency and strong medicinal profiles.

2.4 Preparation of Functional Porridge

The porridge samples were prepared following traditional methods under controlled cooking conditions. In a standardized 2 L stainless steel cooking pot, 600 mL of potable water was heated to a boil (100°C at sea level) on a gas burner set to medium heat (180°C surface temperature). Once boiling, 8 g of granulated sugar (2 teapoons) was added and dissolved completely. Then, 100 g of each composite flour was gradually added while stirring constantly with a stainless-steel spatula to prevent lump formation (Emmaculate et al. 2021).

The mixture was maintained under continuous stirring for an initial cooking period of 10 min. To achieve a smooth, homogeneous consistency, the porridge was cooked for an additional 5 min of boiling under identical stirring conditions until complete water absorption. The final product was immediately transferred to sterile flat dishes and allowed to cool at ambient laboratory temperature (25 ± 2°C) for approximately 10 min before being packed into labelled food-grade plastic round food containers to retain heat and moisture. Both the optimized composite flour porridges and control samples (consisting of 100% wheat flour prepared simultaneously under identical conditions to minimize processing variability) were served to panelists while still warm 45°C within 20 min for subsequent sensory evaluation.

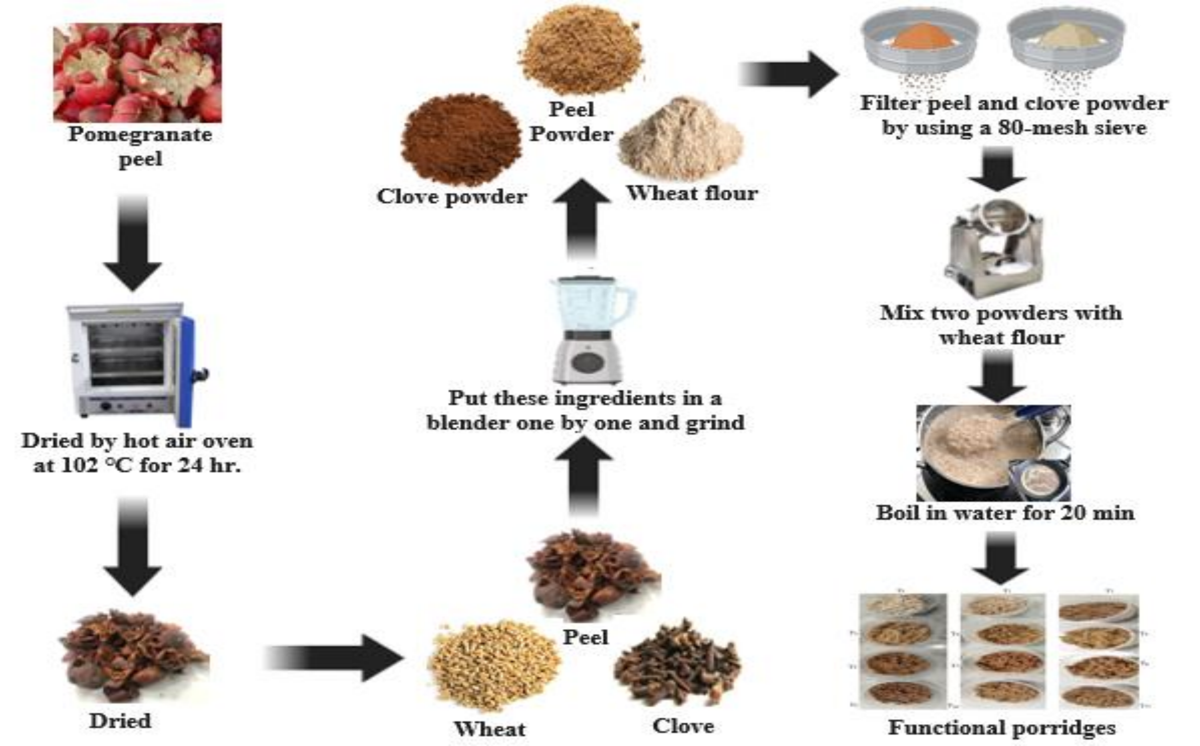


Fig. 1: Schematic representation of functional porridge formulations incorporating different concentrations of powders

2.4 Chemical composition

The proximate composition of functional porridge was determined according to AOAC (2019) standard analytical methods. Moisture content was determined using the oven-drying technique (AOAC Method 925.10). Briefly, 5 g of powdered sample was placed into a pre-weighed porcelain (China) dish and dried in a hot-air oven (UF 110, Memmert GmbH, Germany) at 100-105°C for 24 h. After drying, the sample was cooled in a desiccator (Duran, Germany) and reweighed. Moisture content was expressed as percentage (%), were determined using formula.

$$\textbf{Moisture (\%)} = \frac{\text{Loss of weight}}{\text{Sample weight}} \times 100$$
- eqn. 1

Crude fat was determined using the Soxhlet extraction method (AOAC Method 920.39). 5 g of sample were placed in a cellulose extraction thimble and extracted with n-hexane using a Soxhlet apparatus (EMX-2500, Electrothermal, UK) for 7-8 extraction cycles. The solvent was evaporated, and the extracted fat residue was dried and weighed. Following formula was used to calculate fat percentage.

$$\textbf{Crude fat (\%)} = \frac{\text{Initial weight - final weight}}{\text{Weight of sample}} \times 100$$
- eqn. 2

Crude fiber was determined according to (AOAC Method 978.10) using acid-alkali digestion procedure. A 2 g defatted sample was digested with 1.25% sulfuric acid (H_2SO_4) and 1.25% sodium hydroxide (NaOH) using a fiber digestion unit (FIWE 6, VELP Scientifica, Italy). The residue was filtered, dried, and finally ashed in a muffle furnace (L9/11/B170, Nabertherm GmbH, Germany) at 600°C. Fiber content was calculated gravimetrically.

$$\textbf{Crude fiber (\%)} = \frac{\text{W1 - W2}}{\text{W}} \times 100$$
- eqn. 3

Where,

W= Weight of the original sample

W1= Weight of the residue after digestion

W2= Weight of ash after burning the residue

Ash content was carried out according to AOAC Method 942.05. A 5 g of sample was incinerated in a porcelain crucible in a muffle furnace at 550-600°C until a light grey residue was obtained, with a formula applied for further calculations:

$$\textbf{Ash (\%)} = \frac{\text{Weight of sample before charring}}{\text{Weight of sample after charring}} \times 100$$
- eqn. 4

Protein content was analyzed using the Kjeldahl method (AOAC Method 2001.11). 5 g of sample was digested with concentrated H_2SO_4 using a Kjeldahl digestion unit (DK 20, VELP Scientifica, Italy), followed by distillation and titration to determine total nitrogen. Crude protein content was calculated by multiplying the nitrogen (N) content using the standard conversion factor of 6.25.

$$\textbf{N (\%)} = \frac{\text{V1} \times \text{V2} \times 0.0014}{\text{Weight of sample} \times \text{V3}} \times 100$$
- eqn. 5

Where,

V1= Volume of 0.1 N H_2SO_4

V2= Volume of Dilution (250 mL)

V3 = aliquot volume taken for distillation (mL)

Crude protein (%) = %N × 6.25 *- eqn. 6*

The carbohydrate content of functional porridge was calculated by subtracting the percentages of moisture,crude fat, crude fiber, and ash from 100 by using the following equation:

Carbohydrate (%) = 100− (%Moisture + %Fat + %Fiber + %Protein + %Ash) *- eqn. 7*

2.5 Bio-functional characterization

Sample preparation

For extract preparation, 2 g of porridge sample was mixed with 20 mL of methanol and maintained at room temperature for 2 h with occasional shaking. The mixture was filtered through Whatman No._1 filter paper, and the filtrate was collected in sample vials for further analysis, following the procedure described by Mayachiew *et al.* (2015).

2.5.1 Total phenolic contents (TPC)

Total phenolic content was measured using the Folin-Ciocalteu (FC) colorimetric assay as outlined by Mayachiew *et al.* (2015). 200 µL of extract was mixed with 1 mL of 10-fold freshly diluted FC reagent and incubated to react for 5 min. After that 1.5 mL of sodium carbonate solution (60 g/L) was added, and the reaction mixture was incubated at room temperature for 90 min. Absorbance of solution was measured at 750 nm using a UV-Vis spectrophotometer. A standard calibration curve was prepared using gallic acid, and results were shown as milligrams of gallic acid equivalents per 100 g of sample (mg GAE/100 g).

$$\textbf{TPC (mg GAE/100 g)} = \text{C} \times \frac{\text{V} \times 100}{\text{W}}$$
- eqn. 8

Where:

C = concentration of gallic acid from calibration curve (mg/mL)

V = total volume of extract (mL)

M = weight of sample extracted (g)

2.5.2 Total flavonoid content (TFC)

Total flavonoid content was determined using the aluminum chloride colorimetric method described by Oniszczuk *et al.* (2019). 0.5 mL of extract was mixed with 4 mL distilled water, followed by the addition of 0.3 mL of 5% sodium nitrate ($NaNO_2$) solution. After 5 min, 0.3 mL of 10% aluminium chloride ($AlCl_3$) solution was added, stirred, and then allowed to stand for 6 min. After that, 2 mL of 1 M Sodium hydroxide (NaOH) solution was added, and the final volume was adjusted to 10 mL with distilled water. The mixture was thoroughly mixed and left for 10 min before measuring the absorbance at 510 nm using a UV-Vis spectrophotometer. A standard calibration curve was prepared using quercetin, and the results were presented as milligrams of quercetin equivalents per 100 g of sample (mg QE/100 g).

$$\textbf{TFC (mg QE/100 g)} = C \times \frac{V \times 100}{W} \quad \text{- eqn. 9}$$

Where:

C = concentration of quercetin from calibration curve (mg/mL)

V = total volume of extract (mL)

M = weight of sample extracted (g)

2.5.3 Anti-oxidative potential (DPPH)

Antioxidant activity of extracts was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay according to Mayachiew *et al.* (2015). An aliquot of 1 mL of the sample extract was mixed with 2 mL of 0.5 mM DPPH solution prepared in methanol. The reaction mixture was incubated for 30 min at room temperature in the absence of light. Absorbance was measured at 517 nm using a UV-Vis spectrophotometer. The percentage radical scavenging activity was calculated as follows:

$$\textbf{Radical scavenging activity (\%)} = \frac{A_{control} - A_{sample}}{A_{control}} \times 100 \quad \text{- eqn. 10}$$

Where:

$A_{control}$ = absorbance of the control sample

A_{sample} = absorbance of the sample extract

2.6 Color analysis

Color characteristics of the functional porridge samples were analyzed using a Hunter lab colorimeter, following the method as mentioned by Khan *et al.* (2020). The color parameters were recorded as L*, a*, and b* values. The following equations were used to calculate color difference (ΔE), chroma (C*) and whitening index (WI).

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad \text{- eqn. 11}$$

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \quad \text{- eqn. 12}$$

$$WI = \sqrt{(100 - L^*)^2 + (a^*)^2 + (b^*)^2} \quad \text{- eqn. 13}$$

2.7 Sensory evaluation

A preliminary sensory evaluation of functional porridge formulations (T_0–T_{11}) was conducted using five semi-trained postgraduate panelists (2 males and 3 females; aged 25-30 years), following the procedure described by Katunzi-Kilewela and Fortunatus (2022), with minor modifications. Prior to the evaluation, the panelists were briefed on the purpose of the study, sensory attributes to be assessed, and the use of 9-point hedonic scale where 1 = dislike extremely and 9 = like extremely. Participation in the sensory evaluation was entirely voluntary, and all responses were recorded anonymously. The control porridge (T_0), prepared from 100% wheat flour without pomegranate peel or clove powder. Freshly prepared porridge samples with 10 g per serving were served at a consumption temperature of 45 °C in identical disposable boxes labeled with random three-digit codes. To minimize bias, the panelists were blinded to the formulation and composition of the samples throughout evaluation. The sensory attributes assessed included color, aroma, taste, and overall acceptability. Drinking water was provided for rinsing the mouth between successive samples to minimize flavor carryover.

2.8 Human trial

2.8.1 Selection of subjects and Ethical Approval

For research purpose, a total of 16 participants were enrolled in the study, 12 patients diagnosed with PUD and 4 healthy individuals. Participants were recruited from Tehsil Headquarter (THQ), Shujaabad, District Multan, Pakistan. The inclusion criteria for PUD patients were 25-36 years, confirmed diagnosis of PUD by blood examination, and willingness to participate in the study. The exclusion criteria included pregnancy or lactation, severe systemic illness, gastric malignancy, previous gastric surgery, known allergy to any ingredient of the porridge, and any other condition considered unsuitable by the investigator. Information regarding the use of antibiotics, proton pump inhibitors (PPIs), non-steroidal anti-inflammatory drugs (NSAIDs), antacids, bismuth-containing compounds, and other ulcer-related medications was recorded before enrolment.

After getting ethical approval for the study from the Directorate Office of Research, Innovation & Commercialization (ORIC) at the University of Agriculture, Faisalabad. Written informed consent was obtained from all participants prior to enrolment. The participants were randomly distributed into four groups (n=4 per group): a healthy control (G_0), PUD patients receiving only their normal diet (G_1), PUD patients receiving the functional porridge (G_2), and PUD patients receiving the commercially available marketed porridge (G_3). Each participant in G_2 and G_3 consumed 100 g of assigned porridge daily at breakfast for 30 days.

Baseline demographic characteristics, including age and sex, were recorded before the intervention. Compliance with porridge consumption was monitored by weekly telephonic follow-up, and participants were instructed to report any adverse events experienced during the intervention period. Biochemical analyses were performed before and after the 30-day intervention to evaluate the efficacy of the treatments by comparing pre- and post-intervention biochemical parameters among the study groups.

Table 2: Treatment plan for the human efficacy trial

Groups	Conditions	Treatments
G_0	Control group	Normal diet
G_1	Peptic ulcer	Normal diet
G_2	Peptic ulcer	Functional porridge (100g)
G_3	Peptic ulcer	Marketed porridge (100g)

2.9 Biochemical analysis

2.9.1 Blood examination for H. pylori

H. pylori status was determined blood examination following the protocol as mentioned by Godbole et al. (2020). The presence or absence of anti-*H. pylori* antibodies was recorded qualitatively as either positive or negative.

2.9.2 Hematology test

Venous blood samples were collected into EDTA-containing tubes for complete blood count (CBC) analysis. Hematological parameters, including hemoglobin (Hb), red blood cells (RBCs), white blood cells (WBCs), and platelets (PLTs), were quantified as described by Elkhalifa et al. (2021).

2.9.3 Liver function tests

Liver function was evaluated following the protocol described by Kumar et al. (2023). Serum alanine aminotransferase (ALT; also known as serum glutamic-pyruvic transaminase, SGPT) was measured to assess hepatic function. Serum aspartate aminotransferase (AST) levels were determined after an overnight fast of at least 10 hours. Venous blood (5 mL) was collected into plain vacutainer tubes, and serum was separated and stored at –80 °C until subsequent enzymatic activity analysis.

2.10 Statistical analysis

All laboratory experiments were carried out in triplicate, and the results are presented as mean ± standard deviation (SD). To characterize functional porridge properties, data were analyzed using one-way analysis of variance (ANOVA), with Tukey's Honest Significant Difference (HSD) test for post hoc comparisons to determine statistically significant differences among treatment means ($p < 0.05$) (Montgomery, 2020). For the human efficacy trial, an exploratory descriptive pilo-analysis approach was adopted due to the small sample size (n = 4 per group). Biochemical and hematological outcomes were summarized using descriptive statistics (mean ± standard deviation) and evaluated at the individual-participant level to examine trends between baseline (Day 0) and Day 30. The binary outcome of *H. pylori* status was evaluated via proportions (n/N) and analyzed using Fisher's exact test. All analyses were performed using Statistix 10 (Analytical Software, Tallahassee, FL, USA), following the data-reporting and exact testing procedures described by Analytical Software (n.d.) and the National Institute of Standards and Technology (2023).

3. RESULTS AND DISCUSSIONS

3.1 Chemical composition

The chemical composition of functional porridges were significantly ($p < 0.05$) influenced as shown in **Figure 2A–F.** The moisture content ranged from 65.27% to 77.70%. The highest moisture content was observed in control treatment (T_0), whereas the lowest in was recorded in T_{10} containing

15% PPP and 2% CP. The variation in moisture content was due to the different raw material composition, especially the addition of PPP to porridge, which may have affected the moisture content due to the powder's hygroscopic nature, which enables it to attract and retain water molecules (Amwoma *et al.*, 2023). These findings are in line with prior reported literature (Singh et al., 2019; Singh et al., 2023).

Crude fat content varied significantly ($p < 0.05$) among the treatments, ranging from 1.09% to 2.68%. The results revealed that the highest fat content was observed in T_3, whereas the lowest value was recorded in T_5. Conversely, T_2 had a fat content of 1.70%, representing a decrease of 0.5 times compared to T_0. Similarly, T_{11}, containing higher concentrations of powders, had a fat content of 1.31%, which is 0.44 times decreased compared to T_0, 1 time as compared to T_1, and 0.39 times as compared to T_2. This may be attributed to the varying concentrations of PPP and CP incorporated into the formulations. Although both ingredients contain relatively low lipid contents, formulation-dependent interactions among ingredients may influence the measured crude fat content (Kumar *et al.*, 2022). These findings are related to Muhammad et al. (2023a), which found that adding PPP significantly increased the fat content of fortified wheat flour.

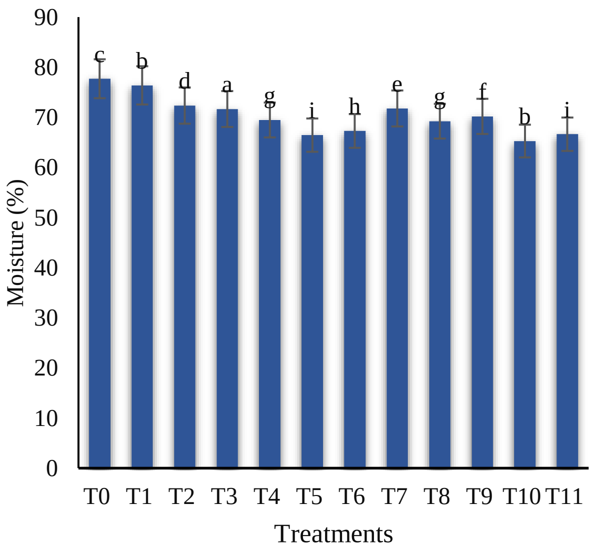
Crude fiber was highest in T_8 which is 1.87, 0.82, and 2.78, and 1.11 times higher than in T_0, T_1, T_2, and T_3, respectively, containing 10% PPP and 3% CP, while the lowest value was observed in T_2, which contained 15% PPP without CP. Although T_1 (6.11%) showed a slightly higher fiber content than the control (T_0, 5.06%), which was 1.05 times that of the control sample as summarized in **Figure 2C**. Similarly, T_2 had 4.15%, which lower than 0.91 and 1.96 times to T_0 and T_1, respectively. Likewise, T_3 had 5.82% crude fiber, which 0.76 times more and 0.29 times less than T_1, respectively. The addition of various powders concentrations resulted in changes in the values. This could be attributed to the high fiber content of the powders, which increased the crude fiber content of the functional porridge. The results are consistent with the study of García *et al.* (2023), which explored the development of fiber-enriched bread using PPP at various ratios.

Protein content showed a gradual decline as the substitution level of wheat flour increased as represented in **Figure 2D**. The highest value observed in the T_0 and the lowest value in T_{11}. This could be attributed to the PPP and CP, which have lower protein contents than the other raw materials used in the porridge. The total protein contents ranged from 11.40% to 13.20%, which is similar to the findings of Ranjitha *et al.* (2018a) and Ranjitha *et al.* (2018b).

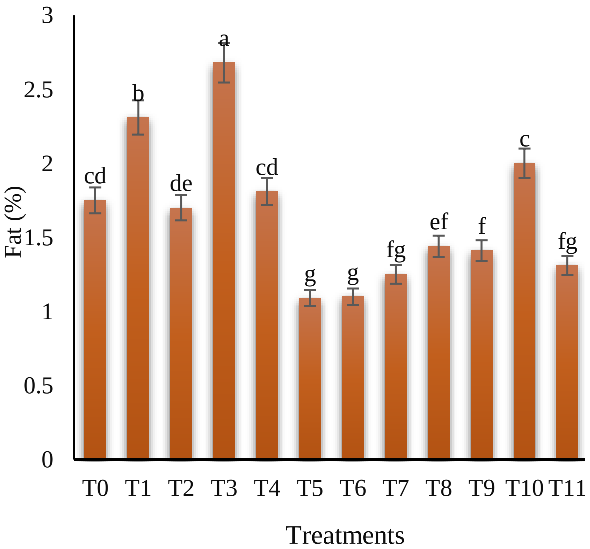
Ash content, an indicator of the total mineral content of foods, increased progressively with increasing incorporation of pomegranate peel and clove powders. Ash values ranged from 1.75% to 2.16%, shown in **Figure 2E**. The minimum ash contents were found in T_0, while the maximum ash contents were observed in T_{11}, showing a consistent trend with increasing powder concentrations, indicating that higher levels of PPP contributed to higher ash content. These outcomes have been comparable to the earlier study conducted by Khadka (2023), which incorporated PPP into a mixture of wheat flour, pearl millet flour, and chickpea flour and revealed that varying powder proportions increased the ash content, ranging from 2.09% to 2.91%.

Nitrogen-free extract (NFE), representing the available carbohydrate fraction, ranged from 0.49% to 12.22% as shown in **Figure 2F**. The lowest carbohydrate values were observed in T_1 (0.49%) and the control (T_0, 0.54%), whereas T_{10} showed the highest carbohydrate value (12.22%), followed by T_5 (11.93%) and T_{11} (11.59%). The observed variation shows changes in the relative proportions of moisture, protein, fat, fiber, and ash resulting from the replacement of wheat flour with PPP and CP. Since carbohydrate was calculated by difference, differences among treatments correspond to the compositional changes introduced by the varying formulation ratios.

(A)



(B)



(C) **(D)**

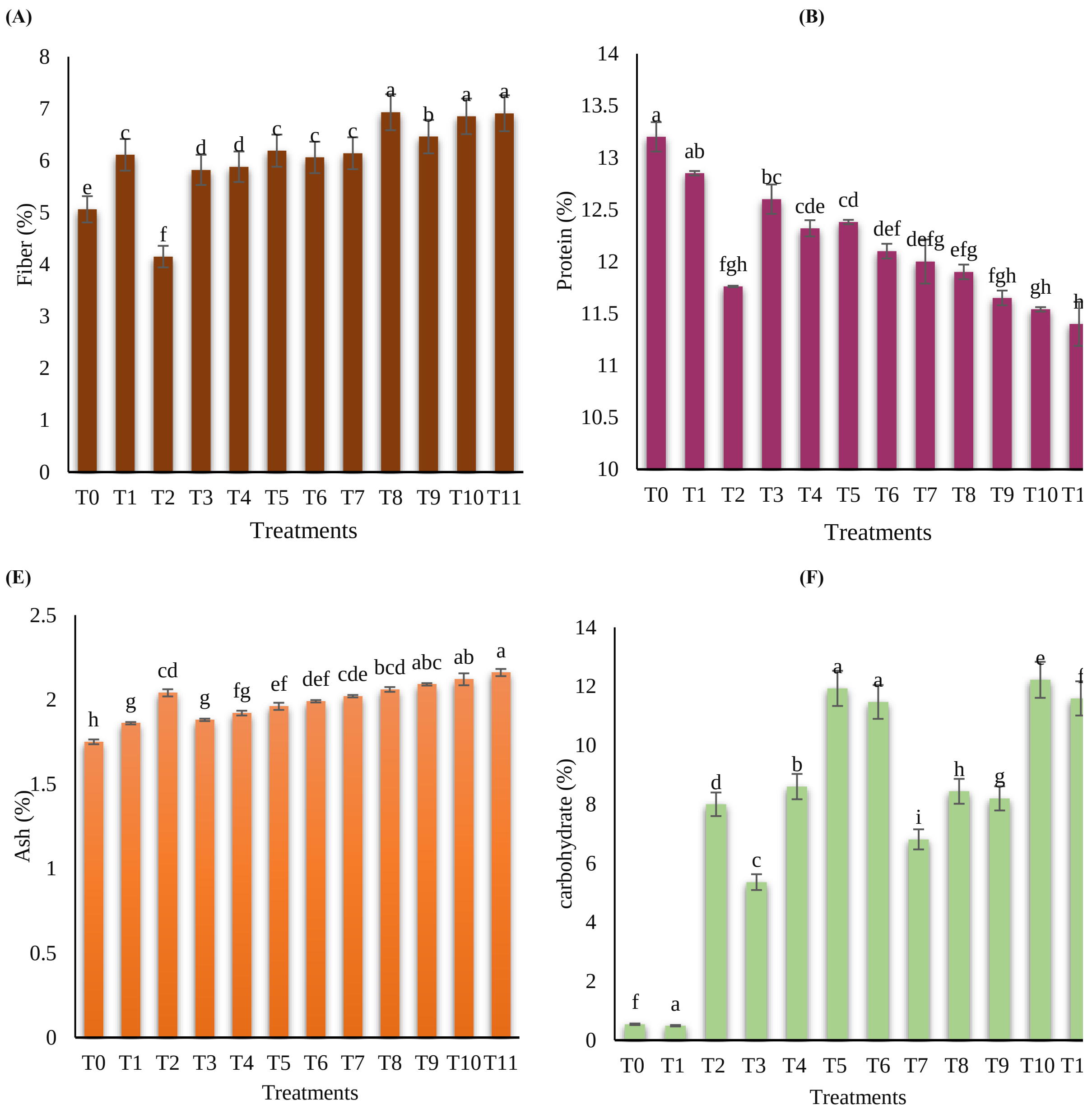
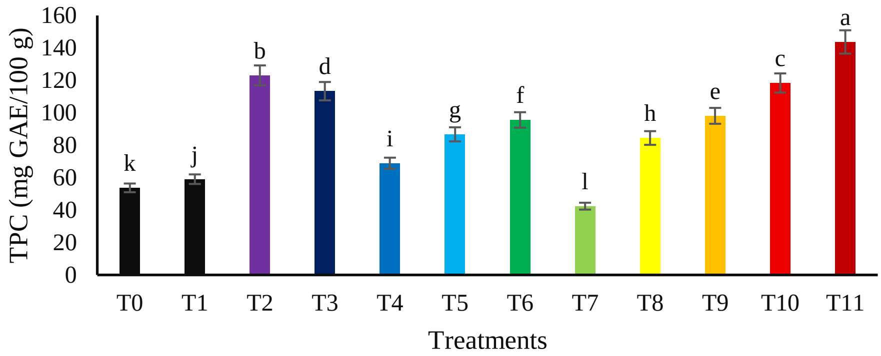


Fig. 2. Chemical composition (%) of functional porridge. (A) Moisture content (%); (B) Crude fat (%); (C) Crude fiber (%); (D) Crude protein (%); (E) Ash content (%); and (F) NFE (%). Values are presented as mean ± SD (n = 3). Different lowercase letters above the bars indicate statistically significant differences among treatments ($p < 0.05$).

3.2 Biofunctional Characterization

Biofunctional properties of functional porridges were measured by determining total phenolic content (TPC) and total flavonoid content (TFC), and antioxidant activity as depicted in **Figure 3A-C**. Significant differences ($p < 0.05$) were observed among formulations, demonstrated that incorporation of PPP and CP enhances bioactive composition of porridges. TPC and TFC of functional porridges increased significantly ($p < 0.05$) with increasing levels of PPP and CP (**Figure 3A** and **3B**). TPC ranged from 42.4 to 143. 67 mg GAE/100 g, while TFC varied from 44.11 to 146.08 mg QE/100 g. The enrichment in polyphenols in PPP (gallic acid, ellagic acid, hydrolysable tannins, punicalagins) and eugenol in clove significantly enhance its antioxidant properties. Similar improvements in TPC and TFC outlined by Mottan (2024), results elucidated the fortification of PPP in wheat bread significantly enhanced the bioactive composition. Antioxidant activity was also significantly influenced ($p < 0.05$) by increasing incorporation of PPP and CP (**Figure 3C**). The lowest antioxidant activity (4.0%) was observed in the control sample (100% wheat), whereas the highest activity was observed in T_{11} containing 15% PPP and 3% CP. The results indicated that enhanced antioxidant capacity can be attributed to synergistic effects of polyphenolic compounds derived from both functional ingredients. Phenolic acids from pomegranate peel, effectively scavenge reactive oxygen species through hydrogen atom donation and electron transfer mechanisms, while eugenol, the major phenolic constituent of clove, further enhances antioxidant



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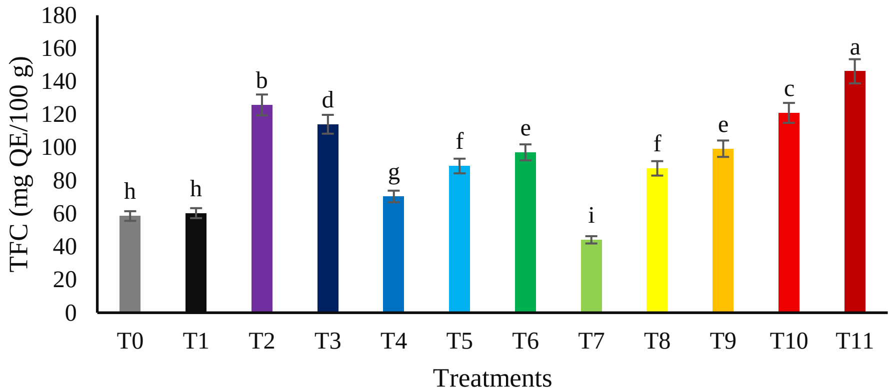

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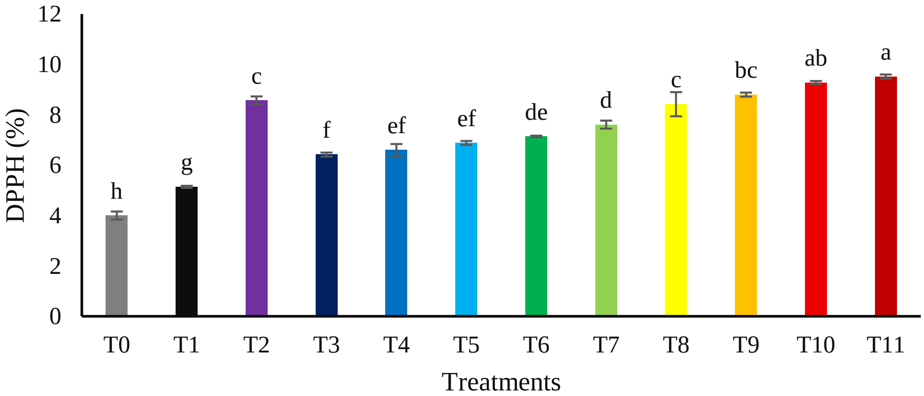

Fig. 3. Biofunctional characterization of functional porridges. (A) TPC, (B) TFC, and (C) DPPH. Data are presented as mean ± standard deviation (SD) (n = 3). Bars with different lowercase letters indicate statistically significant differences among treatments ($p < 0.05$)

capacity by stabilizing free radicals and inhibiting lipid peroxidation

(Saeed et al., 2018). Moreover, increasing inclusion of PPP and CP resulted in a proportional increase in the radical-scavenging capacity of the porridges. Clove is considered one of the richest natural spices in terms of antioxidant source, and even small quantities can significantly improve antioxidant activity (Sharma et al., 2016). These results are consistent with previous findings reported by Niveditha et al. (2023)

3.3 Color characteristics

Color is an important quality attribute in food influencing the visual appeal and initial preferences and choices of food products. The color characteristics of functional porridges were evaluated using the CIE L*a*b* color system, from which the total change in color (ΔE), chroma (C*), and whiteness index (WI), as shown in **Figure 4a-4c**. Significant differences (p < 0.05) were observed among formulations markedly affected with the addition of PPP and CP. ΔE can be considered a physical indicator of cooking intensity and commonly associated as an indicator of processing-induced physicochemical modifications. As shown in **Figure 4a**, the highest ΔE value (18.02) was observed in T_3, whereas the lowest value (1.73) was noted in T_1. The color changes are mainly attributed to the combined effects of intrinsic pigments in PPP and CP observed in functional porridges during cooking. Polyphenol oxidation, Maillard reactions among reducing sugars and amino acids, caramelization, and degradation of native pigments collectively contributed to the formation of darker-colored compounds, resulting in greater color deviation from the control (Urgancı and Isık, 2021). Similar observations have been consistent with Essa and Mohamed (2018). C* value indicates color saturation and intensity, was also significantly influenced (p < 0.05) by increasing incorporation of PPP and CP (**Figure 4b**). The lowest C* value was recorded for T_2, containing 15% PPP. T, whereas the highest value was observed for T_3 (5% PPP and 1% CP). Moderate incorporation levels enhanced color vividness, whereas higher concentrations reduced C* because the dark phenolic pigments and tannins of PPP masked the natural cream color of wheat flour. Similar trend have been reported by Borbi *et al.* (2020), following incorporation of polyphenol-rich plant materials into banana rice slightly change C* value of banana rice. Whiteness index (WI) also decreased significantly (p < 0.05) with increasing levels of PPP and CP (**Figure 4c**). T_3 showed the highest WI value (28.35), whereas the lowest value (12.88) was observed in $T_{10,}$ indicating a progressive loss of whiteness as wheat flour was increasingly replaced with the functional ingredients. This reduction primarily attributable to naturally dark color of PPP and CP, greater incorporation of these ingredients produced porridges with lower brightness and whiteness. These results are consistent with previously findings reported by Rasool Khan (2021).

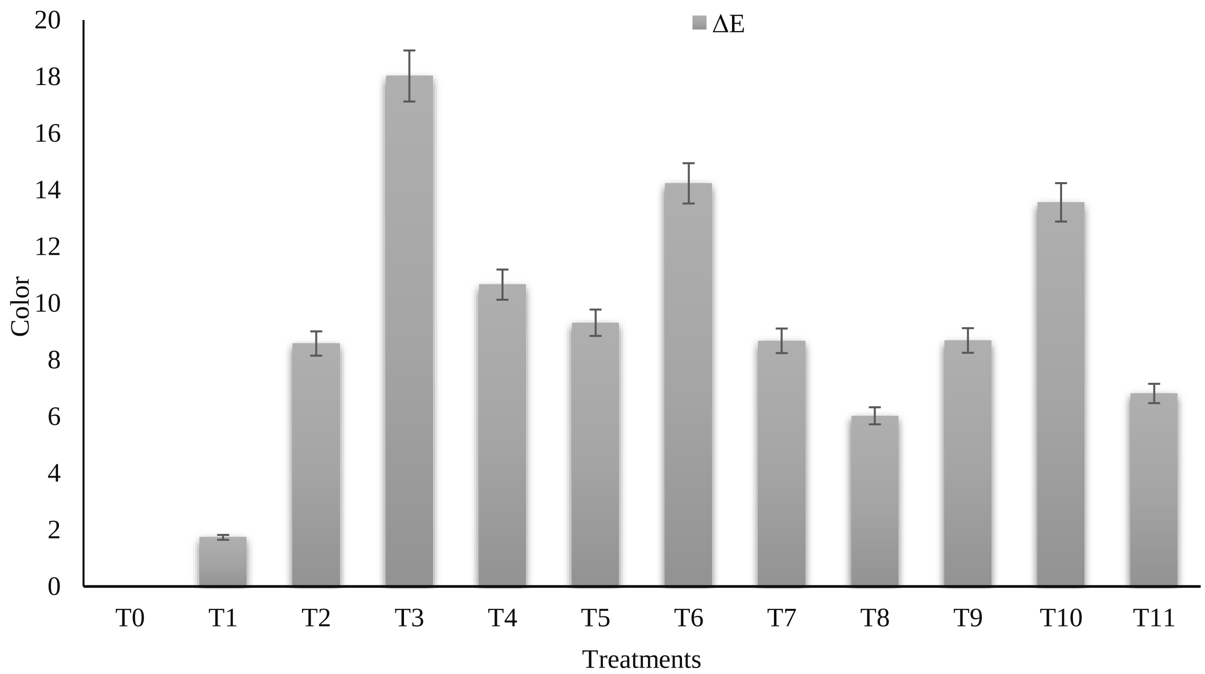

Fig. 4a. Effect of various concentrations of PPP and CP on ΔE in functional porridges

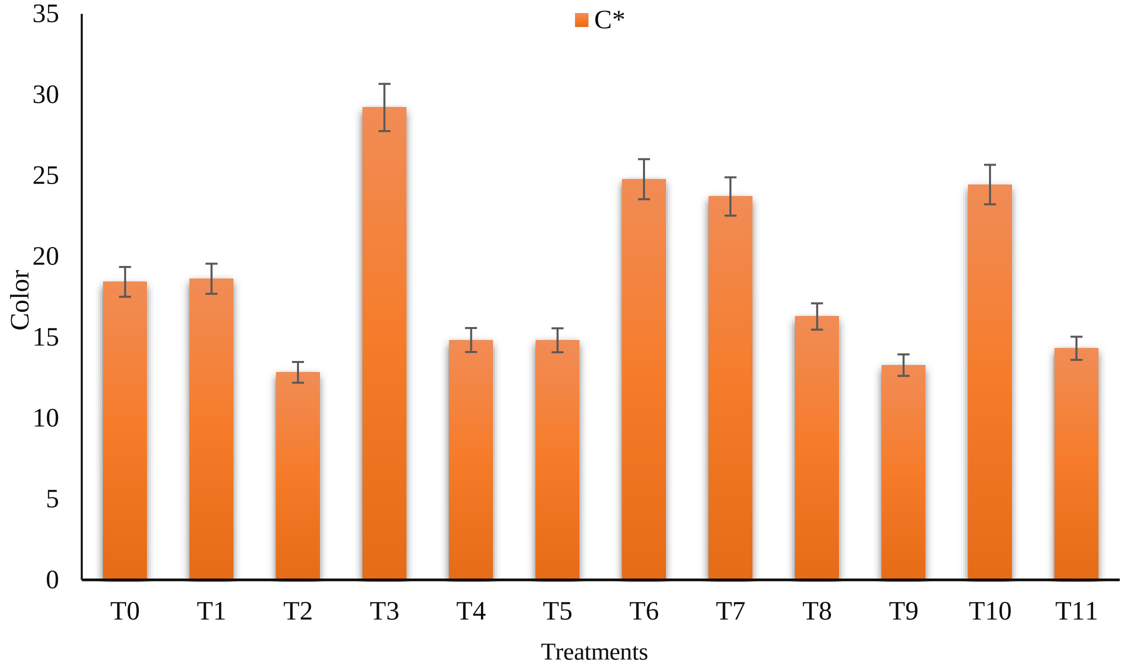

Fig. 4b. Effect of various concentrations of PPP and CP on C* in functional porridges

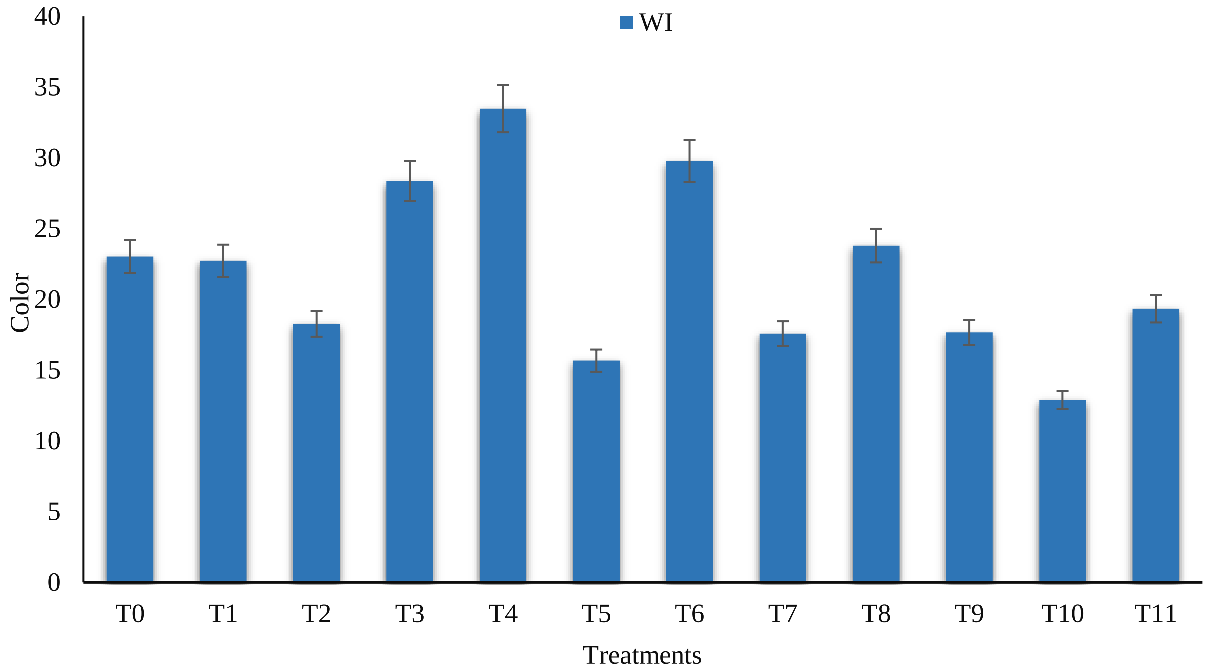

Fig. 4c. Effect of various concentrations of PPP and CP on WI in functional porridges

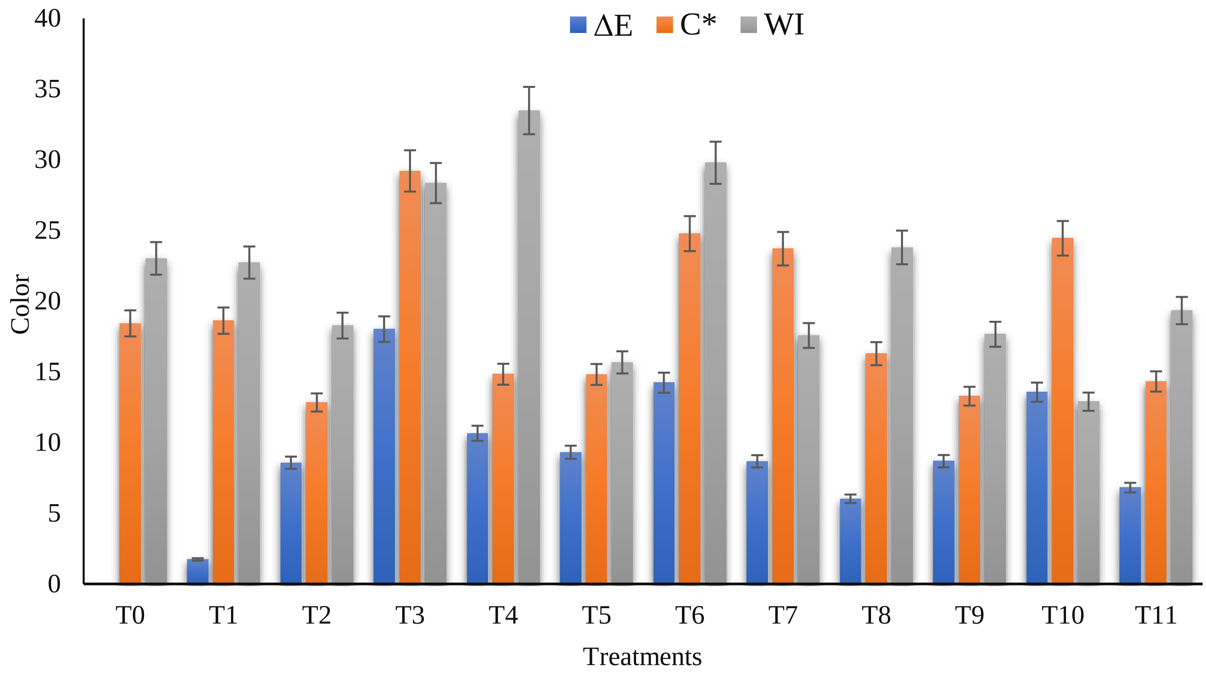

Fig. 4d. Effect of various concentrations of PPP and CP on color characteristics in functional porridges

3.4 Sensory evaluation

The organoleptic properties of twelve functional porridge formulations were evaluated using a 9-point hedonic scale as a preliminary sensory screening conducted by a semi-trained panel to determine the influence of progressive incorporation of PPP and CP on sensory acceptability. Significant differences ($p < 0.05$) were assessed among formulations for appearance, aroma, taste, and overall acceptability as presented in **Figure 5A-D**, indicating that concentration of functional ingredients markedly influenced sensory perception.

Appearance scores progressively declined with increasing substitution of wheat flour with PPP and CP (**Figure 5A**). Formulations containing 5% PPP 3% CP (T_5) maintained visual characteristics comparable to control, whereas higher incorporation levels (10–15% PPP) produced significantly darker porridges as shown in **Figure 6**, with T_{11} receiving the lowest appearance score. The reduction in visual acceptability can be attributed to the intrinsic dark pigmentation of PPP, which enriched in polyphenols and tannins, together with the naturally brown color of CP. Thermal processing further promoted non-enzymatic browning reactions and polyphenol oxidation, further contributing to the darker appearance of porridges (Muhammad *et al.*, 2023a). These findings are consistent with those of Ijaz et al. (2022) of cereal-based porridges fortified with PPP, which significantly reduced the visual appearance.

Aroma acceptability also decreased significantly ($p < 0.05$) as the concentration of PPP and CP increased (**Figure 5B**). The highest aroma scores were recorded for control (T_0) and the formulation containing only 3% CP (T_1) whereas the lowest was observed in T_{11}. Moderate incorporation of CP contributed pleasant spicy notes primarily associated with eugenol, its major volatile constituent. However, higher levels of PPP and CP produced a more intense effects of thermal processing and interactions between phenolic compounds and volatile constituents during porridge preparation may be responsible for roasted and cereal-like aromas thereby reducing sensory preferences. Similar results were observed by Muhammad *et al.* (2023b), who evaluated the aroma of cookies fortified with high concentrations of PPP.

Taste, a sensory attribute most affected by incorporation of PPP and CP significantly ($p < 0.05$) (**Figure 5C**). The maximum taste score was observed a control sample (T_0), whereas the minimum score was recorded in T_{11}. As increasing concentrations of added powders resulted in a progressive decline in taste scores. This may be primarily due to the high tannin content of PPP, which imparts bitterness and astringency, together with the pungent phenolic compounds present in clove.

Overall acceptability, highest scores were observed in treatments T_0, T_1, and T_5 (**Figure 5D**). However, the lowest overall acceptability was found in T_{11}, likely due to its bitter taste and darker color resulting from higher concentrations of added powders. These finding agree with those studied by Folakemi *et al.* (2019). These findings validate the formulation strategy during the preliminary optimization trials, in which PPP concentrations above 15% and CP concentrations exceeding 3% were excluded due to unacceptable sensory characteristics. Consequently, T_5 (5% PPP and 3% CP) was selected as the optimized formulation because it provided the most appropriate balance between enhanced functional ingredient incorporation, favourable sensory acceptability, and practical suitability for regular consumption. Similar trends have been reported in functional cereal products enriched with plant polyphenols, where moderate fortification improves nutritional functionality while preserving desirable sensory attributes (Gadallah et al., 2022; Giri et al., 2024).

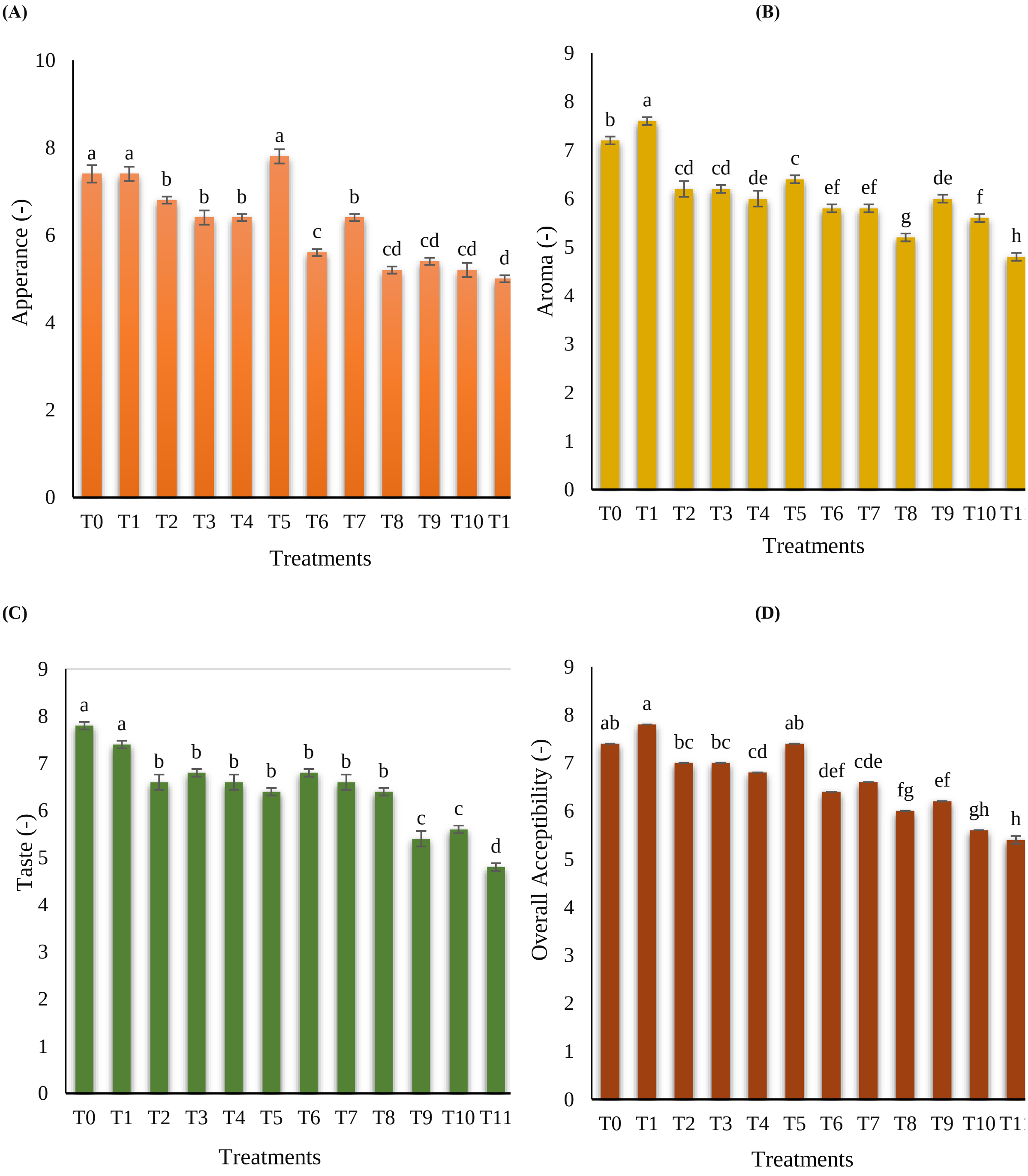

Fig. 5. Organoleptic properties of functional porridges. (A) Appearance, (B) Aroma, (C) Taste, and (D) Overall acceptability. Values are expressed as mean ± SD (n = 3). Error bars with different lowercase letters indicate significant differences among treatments (p < 0.05).

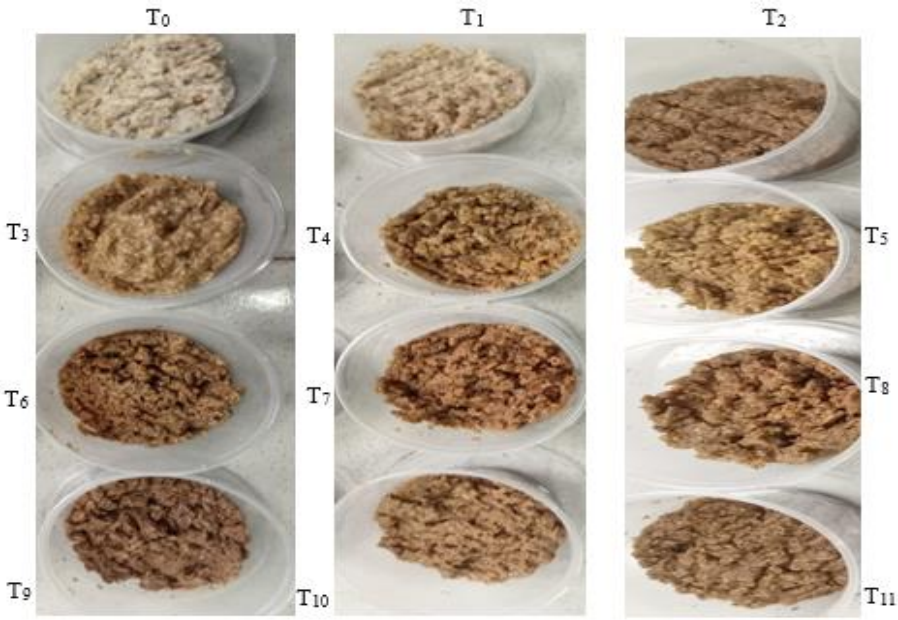

Fig. 6. Pictorial representation of functional porridge treatments

3.5 Efficacy study

3.5.1 Effect of functional porridge on H. pylori status and its impact on PUD

Participants were assessed for *H. pylori* positivity at baseline (day 0) and after 30 days of intervention, as presented in **Table 3**. At baseline, all participants in the diseased groups (G_1–G_3) were positive for *H. pylori (4/4),* whereas no participant in the healthy control group (G_0) was positive (0/4). After 30 days of intervention, *H. pylori* positivity remained unchanged in the diseased control group (G_1; 4/4), whereas the number of positive participants decreased to 1/4 in functional porridge group (G_2) and to 3/4 in the marketed porridge group (G_3). These preliminary findings suggest that consumption of functional porridge was associated with greater reduction *H.* in the number of participants remaining seropositive than the marketed porridge. The pronounced reduction in *H. pylori* positivity observed in G_2 may be attributed to the incorporation of PPP and CP, which contain bioactive polyphenolic compounds, such as tannins and eugenol (Al-Badry, 2019). Previous experimental studies have outlined that phytochemicals possess antimicrobial activity against *H. pylori* and may inhibitory effects with bacterial growth and adhesion to gastric mucosa (Guerra-Valle *et al.*, 2022; Piazza, 2021). In contrast, the marketed porridge (G_3) showed a smaller reduction in the number of positive participants (3/4). Although it was not specifically formulated to exert antimicrobial effects, its dietary fibers, prebiotics, or other nutritional components may support GIT health (Alazzouni et al 2021). Nevertheless, any observed difference between the two porridge formulations should be interpreted with caution because of the limited sample size and the exploratory nature of this pilot study. These findings are consistent with Ahmed et al. (2020) and Muhialdin et al. (2023), who reported that dietary supplementation with PPP significantly reduced *H. pylori* infection in rabbits and gastro-protective and therapeutic effect of *Punica granatum* against stomach ulcer caused by *H. pylori*. Similarly, Uhuo et al. (2022) and Hobani et al. (2022) observed marked amelioration of *H. pylori* infection and gastroprotective effect of low dose eugenol in albino rats following experimental treatment with clove buds.

Table 3. H. pylori status in different treatment groups at baseline (Day 0) and after 30 days of intervention

Groups	Day 0 n/N	Day 30 n/N
G_0 (Healthy control)	0/4	0/4
G_1 (Diseased control)	4/4	4/4
G_2 (Functional porridge)	4/4	1/4
G_3 (Marketed porridge)	4/4	3/4

n = number of participants positive for *H. pylori*; N = total number of participants in each group

3.5.2 Effect of functional and marketed porridge on ALT

Serum ALT is predominantly localized in hepatocytes and is therefore considered a sensitive biomarker of liver injury. In healthy adults, serum ALT concentrations are generally below 40 IU/L, whereas elevated levels may indicate metabolic disturbances and hepatic stress (Martin & Friedman, 2018). As summarized in **Table 4**, G_0 (healthy control group) maintained ALT concentrations within the normal reference range throughout the intervention, with only a slight reduction observed between baseline and day 30. G_1 (diseased control group) showed ALT level further increased from 68.00 ± 0.816 to 72.25 ± 0.081 IU/L during study period, suggesting worsening liver enzyme levels and persistent hepatic stress due to the absence of dietary interventions. Participants receiving functional porridge (G_2) showed significantly ($p < 0.05$) greatest reduction in ALT levels from 73.75 ± 0.081 to 69.38 ± 0.081 IU/L as presented in **Table 4**, whereas only minimal changes were observed in the marketed porridge group (G_3). from 69.75 ± 0.032 to 70.12 ± 0.048 IU/L during the study period. This suggests that the marketed porridge had minimal effect on liver enzyme levels. The reduction in ALT observed following consumption of the functional porridge is consistent with previous studies reporting hepatoprotective effects of pomegranate-derived polyphenols. Baghdadi et al. (2025) reported that PPP supplementation significantly reduced ALT levels in individuals with non-alcoholic fatty liver disease. Similar results have been reported by Jafarirad et al. (2023), pomegranate extract supplementation improved liver biomarkers and reduced ALT levels in patients with metabolic liver disorders.

3.5.3 Effect of functional and marketed porridge on AST

AST is another important biomarker used to assess liver function, although it is also present in cardiac muscle, skeletal muscle, kidneys, and brain tissue. Elevated serum AST concentrations (generally >40 IU/L) may indicate hepatocellular injury, muscle damage, or metabolic disturbances (Kalas *et al.*, 2021). As shown in Table 4, G_0 showed only a slight reduction (0.60 times) in AST from 33.40 ± 0.163 to 33.20 ± 0.163 during the study period, indicating stable liver function, whereas G_1 demonstrated only a marginal (1.51-fold) decrease in AST from 61.75 ± 0.163 to 60.83 ± 0.0163 during study period. Among the intervention groups, participants consuming the functional porridge (G_2) showed a largest decrease (3.33 times) from 69.50 ± 0.244 to 67.26 ± 0.081 ($p < 0.05$; **Table 4**), whereas the G_3 (marketed porridge group) showed only a modest reduction (0.68 times) from 66.00 ± 1.632 to 65.55 ± 0.032. G_3 showed a 0.68 times reduction, from 66.00 ± 1.632 to 65.55 ± 0.032. The greatest reduction in observed in G_2, likely due to the hepatoprotective effects of tannin an active component of PPP and clove phytochemical eugenol. The outcomes agree with those of Baghdadi et al. (2025) demonstrated significant lowered levels of AST following PPP supplementation in individuals with liver disorders. Similarly, Ali et al. (2021) showed that PPP possesses hepatoprotective properties capable of reducing serum liver enzyme levels by alleviating oxidative stress and inflammatory responses.

3.5.4 Effect of functional and marketed porridge on hemoglobin concentration

Hemoglobin is oxygen carrying protein present in red blood cells responsible for transporting oxygen from lungs to tissues and carrying carbon dioxide back to the lungs. Maintaining hemoglobin within the normal range is critical for proper physiological function. Reference ranges generally between 13.5–17.5 g/dL (2.09–2.71 mmol/L) for adult males and 12.0–16.0 g/dL (1.86–2.48 mmol/L) for adult females (Ciaccio et al., 2022). As presented in **Table 4**, G_0 showed only a negligible increase (0.22 times) in hemoglobin levels, from 13.55 ± 0.081 to 13.58 ± 0.008 g/dL, whereas G_1, exhibited a slight decline (0.49 times) from 12.12 ± 0.016 to 12.06 ± 0.024 g/dL over the intervention period. In contrast, the increase observed in G_2 was statistically significant ($p < 0.05$) 1.59 times in hemoglobin concentrations from 13.6 ± 0.244 to 13.82 ± 0.081 g/dL an absolute increase of 0.22 g/dL. A slight increase of 0.07-fold was observed in marketed porridge group (G_3) from 13.87 ± 0.008 to 13.88 ± 0.008 g/dL. Polyphenolic compounds in PPP may help reduced oxidative stress, thereby protecting erythrocytes from oxidative damage and supporting normal erythropoiesis. Clove contains manganese and other micronutrients that contribute to normal hematopoietic processes and hemoglobin synthesis. Similar findings from Bahari et al. (2024) suggested that increase in hemoglobin levels observed in the functional porridge group may be associated with polyphenolic compounds in PPP, which possess strong antioxidant properties and support erythropoiesis and overall hematological health.

Table 4. Effect of functional porridge on ALT (IU/L) in humans

Groups	0^{th} Day	30^{th} Day
G_0	35.30 ± 0.244^{e}	34.60 ± 0.163^{e}
G_1	68.00 ± 0.816^{d}	72.25 ± 0.081^{b}
G_2	73.75 ± 0.081^{a}	69.38 ± 0.081^{c}
G_3	69.75 ± 0.032^{c}	70.12± 0.048^{c}

Table 4. Effect of functional porridge on ALT (IU/L) in humans

Groups	0th Day	30th Day
Effect of functional porridge on AST (IU/L) in humans		
G_0	33.40 ± 0.163^d	33.20 ± 0.163^d
G_1	61.75 ± 0.163^c	60.83 ± 0.016^c
G_2	69.50 ± 0.244^b	67.26 ± 0.081^c
G_3	66.00 ± 1.632^b	65.55 ± 0.032^b
Effect of functional porridge on hemoglobin (g/dL) in humans		
G_0	13.55 ± 0.081^a	13.58 ± 0.008^a
G_1	12.12 ± 0.016^b	12.06 ± 0.024^b
G_2	13.6 ± 0.244^a	13.82 ± 0.081^a
G_3	13.87 ± 0.008^a	13.88 ± 0.008^a

3.5.5 Effect of functional and marketed porridge on total red blood cell count

Total red blood cell (RBC) count, also known as total erythrocyte count, represents the number of circulating RBCs in a given volume of blood. RBC count is crucial hematological parameter for evaluating oxygen-carrying capacity and detecting abnormalities such as anemia. Normal reference ranges from 4.5–5.9 × 10^{12}/L for adult males and 3.5-5.5 ×10^{12}/L for adult females (Pretini *et al.*, 2019). During the 30-day pilot intervention, RBC count remained relatively stable in the healthy control (G_0) and diseased control (G_1) groups as summarized in **Table 5**. Participants administrating functional porridge (G_2) showed a significant increase in RBC count compared with baseline ($p < 0.05$). The reason is that PPP contains minerals, including iron, which carries oxygen throughout the body, supporting RBCs production and function. Consistent with a prior human study by Manthou et al. (2017), pomegranate juice supplementation significantly increased RBCs count and hemoglobin levels in healthy individuals, likely due to enhanced erythropoiesis and antioxidant protection of RBCs.

3.5.6 Effect of functional and marketed porridge on white blood cell count

White blood cells (WBCs), are an essential component of the immune system and play a vital role in protecting the body against infectious agents and inflammatory conditions. The normal reference range of adults is 4.5-11.0 x 10^9/L (Glenn and Armstrong, 2019). As represented in **Table 5**, WBC values at 0 day were observed in G_0 (6.67 ± 0.009×10^9), G_1 (6.20 ± 0.163×10^9), G_2 (9.85 ± 0.081×10^9), and G_3 (8.82 ± 0.081×10^9). After 30 days intervention period, the values for control and treated groups (G_0. G_1, G_2, G_3) were 9.35 ± 0.008×10^9/L 10.66 ± 0.008, 6.13 ± 0.020, and 6.61 ± 0.008, respectively. G_2 fed on functional porridge provided better results from control and other treated groups for the same duration. The difference for G_2 was recorded as 9.85 ± 0.081 at 0 days and 10.66 ± 0.008 at 30th days. Whereas G_3 treated fed on marketed porridge showed a slight increase in WBCs during the 30th day of treatment, starting from 8.82 ± 0.081 and ending at 9.35 ± 0.008. It was observed that, after being treated with functional porridge, the WBC count of G_2 at 30th days increased, which had a positive effect on humans due to clove powder containing the compound eugenol, which has strong antimicrobial properties that help fight infections and enhance immune-boosting effects, potentially improving WBC function. Experimental studies have shown that clove and its principal bioactive constituent, eugenol, can influence leukocyte activity and modulate immune function (Vicidomini et al., 2021). Similarly, complementary evidence from Nawar (2025) further indicated that clove extract can potentiate WBC-mediated immune responses in experimental models.

Table 5. Effect of functional porridge on RBCs (1012/L) in humans

Groups	0th Day	30th Day
G_0	8.76±0.081[a]	8.86 ± 0.081[a]
G_1	7.23±0.0163[de]	7.31± 0.024[cd]
G_2	7.10±0.081[e]	7.86± 0.-024[b]
G_3	7. 26±0.0163[cde]	7.44± 0.032[c]
Effect of functional porridge on WBCs (10^9/L) in humans		
G_0	6.67 ± 0.009[e]	6.61 ± 0.008[e]
G_1	6.20 ± 0.163[f]	6.13 ± 0.020[f]
G_2	9.85 ± 0.081[b]	10.66 ± 0.008[a]
G_3	8.82 ± 0.081[d]	9.35 ± 0.008[c]

CONCLUSION

By utilizing pomegranate peel, an underutilized agro-industrial by-product, this study successfully developed and characterized a polyphenol-rich functional porridge enriched with PPP and CP. Although increasing levels of PPP and CP reduced sensory acceptability, the optimized formulation (T_5; 5% PPP and 3% CP) provided the most appropriate balance between improved biofunctional properties and acceptable sensory quality during the preliminary sensory screening. The findings suggest that this porridge may aid in the treatment of peptic ulcers caused by *H. pylori*, as evidenced by significant improvement in ulcer conditions along with favorable effects on liver enzymes (ALT and AST), supporting its inclusion in a regular diet for PU management. Furthermore, functional porridge shows potential benefits in managing lifestyle-related disorders, particularly peptic ulcers, due to its rich content of bioactive compounds such as tannins and eugenol derived from pomegranate peel and clove, which contribute to reduced *H. pylori* risk. From a commercial perspective, it represents a simple, cost-effective, and nutrient-dense breakfast option with a soft texture and high nutritional value, making it a preferable alternative to conventional breakfast foods. In addition, its functional properties can be further enhanced through the use of citrus peel wastes (lemon, orange, and grapefruit) to support digestive health, as well as by incorporating bioactive components such as dietary fibers, polyphenols, and probiotics, thereby extending its potential in the management of other chronic diseases, including diabetes and cardiovascular diseases.

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DATA AVAILABILITY STATEMENT

Datasets analyzed during the current study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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