Assessing the physicochemical and sensory attributes of yogurt enriched with mango and potato peel powders and their hypolipidemic effects on rats consuming a high-fat diet

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Abstract

Enhancing dairy products with bioactive functional foods and plant-derived compounds boosts their nutritional value and health benefits. The objective of the present study was to evaluate the physical, chemical, and sensory properties of yogurt that had been enriched with mango and potato peel powder at levels 1, 2, and 3%. The results demonstrated that fortifying yogurt with 3% potato and mango peel significantly enhanced its nutritional and functional qualities, as total solids increased from 13.34% in the control yogurt to 15.14 and 15.84% in the potato and mango peel-fortified versions, respectively. Protein content also rose from 3.78 to 3.94 and 4.05%, while ash levels improved from 0.78 to 0.90 and 0.98%. Additionally, fiber, which was absent in the control, reached 0.47 and 0.20% in the potato and mango peel-fortified yogurt, respectively. This fortification also led to a sharp increase in phenolic content, from 40.60 mg GAE/g in the control to 53.70 and 65.90 mg GAE/g, alongside a notable improvement in antioxidant activity, which increased from 20.60 to 33.50 and 40.80%. Together, these findings highlight the substantial positive impact of fortification on both nutritional composition and potential health benefits of yogurt. The strongest sensory features were seen in yogurt containing 2% mango and potato peel powder with a total score of 93.0 when compared to other treatments. In addition, the 2% mango and potato peel powder-fortified yogurt was tested as a hypercholesterolemia inhibitor in obese rats. Forty male Wistar rats were divided into five groups. The first group served as the healthy control group, while Groups 2 through 5 were fed a high-fat, high-cholesterol diet for the duration of the experiment and given 10 g/day of various types of yogurt: yogurt with 2% mango powder and 2% potato peel powder as a treatment. The findings revealed a considerable reduction in LDL, cholesterol, triglycerides, AST, ALT, creatinine, and urea levels as compared to the positive control group, combined with a marked rise in HDL and total protein levels. According to the findings, yogurt, mango, and potato peel powder help liver and kidney functions in hyperlipidemic rats. Collectively, these data showed that yogurt, mango, and potato peel powder shielded rats from oxidative stress and hyperlipidemia.

Keywords: hypolipidemic; mango peel; oxidative stress; potato peel; sensory characteristics; yogurt

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Introduction

The dietary behaviors of individuals alter according to their lifestyles. Nowadays, it is hard for people to control how much and what kind of food they eat. Changes may lead to increased intake of a high-fat diet (HFD) while reducing daily activity or leading a sedentary lifestyle. It causes the body to store the eaten fat, resulting in an abnormal fat buildup in adipose tissues (Nauli *et al.*, 2021). The body mass index (BMI) and waist circumference of a person who is overweight or obese are increased by this abnormal fat buildup (Febriza *et al.*, 2019; Wang *et al.*, 2013). The risk of developing metabolic syndrome is also known to rise with increased HFD consumption (Kesh *et al.*, 2016). The metabolic syndrome itself is characterized by systemic inflammation, which elevates the levels of interleukin-6 (IL-6), tumor necrosis factor-1, and other proinflammatory cytokines in the body. Adult males with central adiposity have higher levels of serum soluble tumor necrosis factor receptor (sTNFR)-2 and IL-1 (Sartika *et al.*, 2010). Oxidative stress results from an imbalance in the amounts of oxidants and antioxidants, combined with the increased levels of proinflammatiory cytokines. As a result, several molecular markers are employed to evaluate the degree of oxidative and inflammatory stress (Abdelkader *et al.*, 2022; Aboubakr *et al.*, 2023; Soliman *et al.*, 2022). The metabolic syndrome is a high-risk factor for type 2 diabetes mellitus, cardiovascular disease, stroke, nonalcoholic fatty liver disease, nonalcoholic steatohepatitis, and cancer as a result of this scenario (Kyung-Ah and Gu, 2012).

Underweight people have a BMI of less than 18.5. If your BMI is between 18.5 and 25, you are in the healthy weight zone. Overweight is defined as a BMI of 25.0 to less than 30. Obesity is defined as a BMI of 30 or greater (Jan and Weir, 2021) {Jan, 2021 #965}. The prevalence of overweight increased in the last 10 years from 11.5 to 13.6% and that of obesity from 14.8 to 21.8% (Riskesdas, 2018). Additionally, it is stated that the prevalence of dyslipidemia ranges from 9 to 25%. According to the estimates from the World Health Organization (Supply and Program, 2015), people with high levels of total cholesterol (TC) represent 2% of all Disability Adjusted Life Years (DALY) and 4.5% of all fatalities. Thus, a wide range of therapeutic strategies for treating dyslipidemia are quickly investigated. Taking statins, which are HMG-CoA reductase inhibitors, is one popular treatment to lower blood cholesterol and triglyceride levels. This class of medication is frequently used due to its favorable impact on lowering blood cholesterol levels and reasonable cost. However, this drug treatment may have several adverse consequences, including myopathy, diabetes, and hemorrhagic stroke (Pinal-Fernandez *et al.*, 2018). As a result, beneficial dietary therapies including boosting the consumption of fruits and vegetables that contain antioxidant and anti-inflammatory components are used in prevention and therapy today (Ugochukwu *et al.*, 2017). Previous research demonstrated that fruit with high antioxidant content has an antiobesity impact by lowering oxidative stress and helping to limit intestinal cholesterol absorption (Susanti and Susilowati, 2021; Utami *et al.*, 2019). Only a small portion of the byproducts produced by agroindustrial operations are reused because they do not have any commercial value (Struck and Rohm, 2020). In addition to being a source of bacteria that are damaging to the health of living beings when they are thrown, they also emit gases that influence the environment (Shirahigue and Ceccato-Antonini, 2020; Sumaya-Martínez *et al.*, 2019). Byproducts from the consumption of raw materials are a significant source of antioxidants, particularly phenolic compounds (Velderrain-Rodríguez *et al.*, 2019). According to Siacor *et al*. (2020), the demand for these compounds is rising on the global market, with an estimated 7.2% annual growth in value from 2019 to 2025.

Due to their delicious flavor, aroma, color, and nutritional value, mangoes (*Mangifera indica*) are one of the most widely produced and consumed fruits (Mwaurah *et al.*, 2020). According to the Food and Agriculture Organization (FAO), its production in 2018 was 52.08 million metric tonnes (Marcillo-Parra *et al.*, 2021), representing more than 50% in terms of tropical fruits (Alañón *et al.*, 2021). It has high antioxidant potential as it contains substances such as retinol, ascorbic acid, carotenoids, mangiferin, anthocyanins, kaempferol, quercetin, catechin, rhamnetin, gallic acid, benzoic acid, ellagic acid, tannins, flavonols, benzophenone, and their derivatives, which are primarily found in the peel and seeds (Ribeiro *et al.*, 2008). Despite its significance, high volumes of residues such as the seeds and peels are produced during processing and/or consumption, particularly in juice, concentrated pulp, jam, puree, nectar, or other related products (Rojas *et al.*, 2020), even though they contain bioactive compounds of interest (Meneses *et al.*, 2015; Sumaya-Martínez *et al.*, 2019), particularly from the phenolic group. Taken into account the aforementioned, in addition to containing the aforementioned vitamins and tocopherol (Sumaya-Martínez *et al.*, 2019), they provide the byproducts with excellent pharmacological properties such as antiatherogenic, antitumoral (Ribeiro *et al.*, 2008), anti-inflammatory, antimicrobial, and anticancer, with mangiferin, the primary compound present in the mango, being particularly representative (Castro-Vargas *et al.*, 2019; Meneses *et al.*, 2015). Due to their characteristics, they are of tremendous interest to the food industry since they may be used to produce healthier diets and avoid malnutrition by replacing synthetic chemicals with natural ones (Mwaurah *et al.*, 2020) .

After wheat, rice, and corn, the potato—a tuber originally from the Andes—is the fourth most significant

agricultural crop produced worldwide (Benkeblia, 2020). Global potato output has generally climbed in recent years, reaching 370,436,581 tonnes in 2019, according to data from the Food and Agriculture Organization of the United Nations (FAO(. There are currently more than 4000 kinds of potatoes recognized, with the *Solanum tuberosum* L. being the most extensively cultivated variety (Burlingame *et al.*, 2009). Large volumes of waste are produced by the potato processing sector, primarily peel, fried goods, screen solids, and wastewater (Pathak *et al.*, 2018). Depending on the chosen peeling method, the potato peel byproduct can account for up to 10% of the total potato waste and between 15 and 40% of the fruit (Sepelev and Galoburda, 2015). This waste product, which has no use in the feed industry, would provide an attractive raw material for the recycling sector because after being processed using green technologies, the molecules it produces have excellent qualities for human health and a variety of industrial applications (Galhano dos Santos *et al.*, 2016). As this portion makes up between 40 and 45% of the dry weight (dw) of the potato, potato peel has recently been recognized as a novel and significant source of dietary fiber (Singh *et al.*, 2005). The significant components that should be noticed in terms of its chemical makeup include carbohydrates (63%, of which starch accounts for 34%), protein (17%), lignin (10%), ash (9%), and lipids (1%) in addition to the high percentage of moisture observed (Liang and McDonald, 2014; Martinez-Fernandez *et al.*, 2021). It is noteworthy that this byproduct has also been reported to be a source of phenolic chemicals, with the peel having a larger concentration than the flesh does (Wu *et al.*, 2012). According to Banarjee *et al*. (2017) and Gullón *et al*. (2020), phenolic compounds exhibit a variety of biological properties, including those that are antioxidant, antibacterial, antimicrobial, apoptotic, anticarcinogenic, chemopreventive, and anti-inflammatory. Consequently, it is anticipated that the recovery of bioactive compounds from potato peel would aid in the creation of new, nutritious functional foods (Al-Weshahy and Rao, 2009). However, it could lead to a wide range of applications if used as a sustainable feedstock in integrated biorefineries (Galhano dos Santos *et al.*, 2016).

Production of functional foods through fortification of dairy products with plant byproducts or natural substances has gained increasing attention in the last few decades (Atwaa *et al.*, 2022a, 2022b; Shahein *et al.*, 2022a–f, 2023; Swelam *et al.*, 2021; Zommara *et al.*, 2022). One of the most popular dairy products, yogurt, uses both a prebiotic growth substrate and a starter culture of probiotic bacteria. Synbiotic yogurt, so named because it combines probiotics and prebiotics, aims to enhance the yogurt quality (Pandey *et al.*, 2015). Many fruit and vegetable products can be utilized as a source of prebiotics to create synbiotic yogurt by combining them with lactic acid bacteria (Bostan *et al.*, 2017). Consuming yogurt had positive effects on lowering blood cholesterol levels, boosting intestinal protection, and enhancing the overall health (Wu *et al.*, 2015). The effects of potato peel-based yogurt (SPPY) and mango peel-based yogurt (MPPY) products still need to be elucidated. Mango and potato peels were chosen for this study because they are readily available in many countries and offer a pleasant taste that enhances the flavor and nutritional profile of the product. The primary objective of this study is to investigate the physicochemical and sensory properties of yogurt fortified with mango or potato peels, as well as to evaluate the health effects of this fortified yogurt on rats with hyperlipidemia and obesity induced by an unhealthy diet.

Materials and Methods

Ethical approval

This study was carried out following the final approval from the Institutional Animal Care and Research Unit of Zagazig University (Approval Number: ZU-IACUC/2/F/109/2023).

Materials and reagents

Fresh standardized buffalo milk (3% fat) was provided by the Dairy Technology Unit, Food Science Department, Faculty of Agriculture, Zigzag University, Egypt. The ripe Mango (*Mangifera indica*) zebda variety and potatoes (*Solanum tuberosum*) were obtained from the local market. Gallic acid and 1,1-diphenyl-2-picrylhydrazyl (DPPH) were purchased from Sigma company (St. Louis, MO, USA). The biochemical analysis kits were bought from Gamma Trade Company (Cairo, Egypt). Chr. Hansen (Hrsholm, Denmark) provided the lyophilized starter culture ABT-5, which contains *Lactobacillus acidophilus*, *Streptococcus thermophiles*, and *Bifidobacterium bifidum*.

Animals

Male adult albino Sprague Dawley rats were obtained from the Agricultural Research Center in Giza (Egypt). The main animal house at the National Research Center in Dokki, Giza, Egypt supplied the components for the basic pellet diet, including 15% casein, 5% cellulose, 10% fat, 4% salt mixture, 1% vitamins mixture, and 65% corn starch. This formulation was prepared according to the guidelines of the Association of Official Agricultural Chemists (AOAC, 2016). The rats had unrestricted access to water throughout the study.

Preparation of mango and potato peel powders

Mango and potato fruits were washed with distilled water then peeled and their edible portions were carefully separated. The peels were dried in a hot air oven at 50°C for 18 h. The dried samples were ground into a fine powder in a mill (crushed in a laboratory-size mill). The materials that passed through a sieve were retained for use (Perez-Chabela *et al.*, 2021).

Yogurt manufacture

Yogurt was prepared according to the methods described by Tamime and Robinson (Tamime and Robinson, 1999). Milk containing 3% fat was divided into seven equal portions; the control was applied to the first section (C). The remaining six sections were thoroughly blended with respective amounts of 1, 2, and 3% mango powder (T1 to T3) and potato peel powder (T4 to T6). The milk was heated, and the used peel powders were added to the milk slowly while it was hot, stirring well with a high-speed mixer until completely dissolved. All milk treatments were heated at 85°C for 30 min, cooled to 42°C in an ice bath, and then inoculated with lyophilized starter culture ABF-5 (0.02%, 50 U) that contained *Lactobacillus acidophilus*, *Streptococcus thermophilus*, and *Bifidobacterium bifidum* (initial counts of log 10^7 CFU/mL for each of the containing bacteria strains). The yogurt treatments were then put into 100 mL plastic bottles with caps, which were then incubated at 42°C until a consistent coagulation was achieved to generate hard curd. The curds were then maintained at 4°C and tested one day after production. Each analysis was performed twice, and the experiments were repeated in triplicate.

Methods of analysis

The total solids, fats, and proteins, crude fiber, ash content, and titratable acidity of the yogurt were analyzed based on the methods of the Association of Official Analytical Chemists (AOAC 2016). The changes in pH in the yogurt samples during storage were measured using a laboratory pH meter with a glass electrode (HANNA, Instrument, Portugal). In brief, 10 g of the yogurt sample was mixed with 100 mL of distilled water and left to stabilize at room temperature. The pH of the solution was subsequently measured using a pH meter.

Determination of total phenolic contents

According to Maksimović *et al.* (2005), with minor modifications, the total phenolic content (TPC) of the extract of samples was measured using the Folin–Ciocalteu assay using gallic acid as the standard. In a nutshell, 100 µL of various test sample concentrations were combined with 1 mL of diluted FC reagent (1:10). 1 mL of 7.5% (w/v) sodium carbonate solution was added to the mixture after 10 min, and it was then left to incubate for 90 min in the dark. At 725 nm, the absorbance was measured. Gallic acid equivalents (GAE/100 g y) were used to calculate the phenol concentration using the calibration curve.

Radical scavenging activity (Scavenging DPPH)

The method developed by Apostolidis *et al.* (2007) was used for the measurement of DPPH radical scavenging activity. The absorbance of DPPH purple-colored solution at 517 nm was measured using a spectrophotometer (Thermo Scientific, Wilmington, NC, USA). The scavenging activity was calculated by the following formula:

$$\text{DPPH scavenging effect (\%)} = \frac{A_0 - A_1}{A_0} \times 100$$

where A0 is the absorbance of the control reaction, and A1 is the absorbance in the extract. Samples were analyzed in triplicate.

Rheological measurements of yogurt

The viscosity and released whey from yogurt samples were measured according to the method by Aryana (2003). The quantity of whey collected from every sample in graduated cylinder after 2 h of drainage at 20°C was used as an index of syneresis. The viscosity of yogurt samples was determined using Rotational Viscometer Type Lab. Line Model 5437. Measurements were taken at 30°C after 15 s, with the results expressed in centipoise (cP).

Sensory evaluation of yogurt

The sensory properties of yogurt samples were assessed following the methods described by Ali *et al.* (2021) by a team of trained professional panelists from the Faculty of Agriculture, Zagazig University. The following scoring points were used for different properties: flavor (45), body and texture (30), acidity (10), appearance and color (15) and total (100). The samples were packaged and labeled with a unique three-digit code for identification. The coded samples were then presented to the panelists on a tray. To minimize flavor carryover and ensure unbiased evaluations, panelists were provided with plain water to cleanse their palates after tasting each sample before advancing to the subsequent one.

Experimental design for yogurt treatments

This study was conducted with the approval of the Institutional Animal Care and Research Unit, Zagazig University and the Institutional Review Board Number ZU-IACUC/2/F/109/2023. A total of 40 male Wistar rats weighing 200 ± 10 g were provided by the Agricultural Research Center (Giza, Egypt). Animals were housed in a well-ventilated room with free access to food and water, controlled illumination (12 h of light and 12 h of darkness), an ambient temperature of 22 2°C, and relative humidity of 40–60%. According to the instructions of Reeves *et al*. (1993) for AIN-93M, all animals were allowed free access to a regular meal. Rats were allocated into five groups (eight rats in each group). Without further treatment, the first group, which received a basal diet served as the normal control (G1 or NC). The other group of rats were placed on an HFD (Nistor *et al.*, 1987) for 8 weeks, containing 67 g of standard diet, 31.70 g of animal fat (cow fat), 1% pure cholesterol, and 0.30 g of bile acid (sodium cholate), and were divided into the following subgroups: Group 2 (G2 or PC) was a positive control and stayed on the HF-diet and distilled water (1 mL/day) without receiving any therapy. Groups 3–5 (G3–G5), received 10 g/day of control yogurt, yogurt fortified with 2% mango peel powder, or yogurt fortified with 2% potato peel powder, respectively, orally via intestinal tube. At the end of the experiment (8 weeks), rats were fasted overnight and euthanized under complete anesthesia using xylazine and ketamine, 5 and 90 mg/kg, respectively. After careful separation of the abdominal skin from the thoracic cavity, blood was drawn from the posterior vena cava and placed into serum separator tubes. The blood samples were centrifuged at 3000 rpm for 10 min to obtain the sera, which were then stored at –20°C until analysis.

Biochemical analyses

Alanine aminotransferase (ALT) and aspartate aminotransferase (AST) were measured using the protocol described by Bergmeyer and Harder (1986). The method by Baranowski and Westenfelder (1986) was used to measure the serum creatinine level. The method by Marsh *et al.* (1965) was used to measure serum urea. The amount of total protein was calculated following the method by Schumann and Klauke (2003). Enzymatic colorimetric technique was used to quantify total cholesterol (Dougnon *et al.*, 2014). Triglycerides (TG) were measured following the method by Devi and Sharma (2004). Low-density lipoprotein-cholesterol (LDL-C) was also calculated using the Friedewald formula (Friedewald *et al.*, 1972) as follows:

$$\text{LDL-C} = \text{Total cholesterol} - (\text{High-density lipoprotein-cholesterol (HDL-C)}) - (\text{TG}/5).$$

Relative organ weight

All animals were euthanized by exsanguination under chloroform anesthesia on Week 8 of the dosing period. The heart, liver, and kidneys were meticulously torn out and quantified in grams (absolute organ weight). The relative organ weight of each animal was estimated as follows:

$$\text{Relative Organ Weight} = \frac{\text{Absolute organ weight (g)}}{\text{Body weight of rat on sacrifice day (g)}} \times 100.$$

Histopathological examination

Rats were euthanized 8 weeks after feeding on different treatments. The animals' kidneys, hearts, and livers were isolated and examined macroscopically, then fixed in 10% neutral formalin and embedded in paraffin. Sections with a thickness of five microns were prepared and stained with hematoxylin and eosin, as mentioned by Suvarna *et al*. (2018) and examined microscopically.

Statistical analysis

All experimental findings and related analyses were carried out in triplicate and expressed as means of standard deviation. The group variation was determined using a one-way ANOVA with a significance criterion of $P \leq 0.05$. Software Statistical 12.5 was used to carry out the analysis (Stat Soft Inc., Tulsa, OK, USA). The post-hoc analysis employed in the statistical evaluation was Tukey's Honest Significant Difference (HSD) test, designed to identify significant differences between groups.

Results and Discussion

Hypercholesterolemia is considered one of the most common metabolic diseases worldwide. This study investigated the remedial action of yogurt enriched with MPP and PPP on hyperlipidemic rats. In this respect, yogurt manufactured with 2% MPP and PPP was tested as an antihyperlipidemic agent in rats.

Chemical composition and phytochemical properties of mango or potato peels powder

Table 1 shows the chemical composition and phytochemical properties of mango and potato peel powder. As shown in Table 1, mango peel powder (MPP) has relatively lower protein (5.82%) and ash content (3.22%) compared to potato peel powder (PPP) (10.9 and 7.7%, respectively), while a higher moisture, fat, and carbohydrate contents (10.90, 2.36, and 77.7%, respectively) were observed in

Table 1. Chemical composition and antioxidant properties of potato and mango peel powder.

Components	Potato peel powder	Mango peel powder
Chemical composition (g/100 g /DW)		
Moisture	6.78 ± 0.4^{b}	10.9 ± 0.9^{a}
Crude protein	10.9 ± 0.8^{a}	5.82 ± 0.6^{b}
Crude lipids	2.0 ± 0.1^{b}	2.36 ± 0.5^{a}
Total ash	7.7 ± 0.8^{a}	3.22 ± 0.3^{b}
Crude fiber	7.6 ± 0.9^{b}	17.04 ± 1.0^{a}
Total carbohydrates	72.6 ± 0.3^{b}	77.7 ± 2.9^{a}
Antioxidant properties		
Total phenolic (mg/100 g/ DW)	370.0 ± 5^{b}	420 ± 8^{a}
Radical scavenging activity (RSA) %	84.6 ± 3^{b}	90.5 ± 2^{a}

MPP than in PPP (6.75, 2.0, and 72.6%, respectively). The MPP is characterized by the unique presence of fibers (17.04%) than PPP (7.6%). Additionally, the MPP is characterized by much higher levels of total phenolic content (TPC) (mg GAE/100 g), and antioxidant activity (AO)% than PPP, that is, 420.8 mg/100 g and 90.50% for MPP compared to 370.0 mg/100 g and 84.60% for PPP, respectively. These results are in line with those reported by (El-Faham *et al.*, 2016) who found that mango peels showed 12.07% moisture, 5.34% of crude protein, 2.42% fat, 3.06% ash, 16.62 crude fiber, 72.56% carbohydrates, and 282.61–515.62 mg GAE 100/g (DW) of total phenolic content by difference. Furthermore, Helal *et al*. (2020) found that protein, fat, ash, fiber, carbohydrate, and total phenolic contents of PPP were 10.98, 2.80, 7.92, 7.92, 70.38%.

Chemical composition of yogurt supplemented with MPP or PPP

Table 2 shows the effects of the addition MPP or PPP on the chemical composition and the physicochemical and phytochemical properties of yogurt. In Table 2, supplementation of yogurt with MPP and PPP significantly ($P \leq 0.05$) increased the TS, ash, and fiber contents from 13.34, 0.78 and 0.00% in the control samples to 15.14, 0.90, and 0.47% in the samples fortified with 3% MPP and to 15.84, 0.98, and 0.20% in the samples fortified with 3% PPP. Moreover, PPP yogurt samples had higher total solids (TS) and ash contents than MPP yogurt samples, while MPP yogurt samples had higher fiber content than PPP yogurt samples at the same concentration when compared with control yogurt. In contrast, the addition of MPP and PPP at different proportions did not affect the protein and fat contents of yogurt. These results were in agreement with that of Perez-Chabela *et al*. (2021) who found that addition of mango peel flour and potato peel flour as bioactive ingredients in the formulation of functional yogurt increased the TS, protein, ash, and fiber contents of yogurt. Also, Atwaa *et al*. (2020) found that supplementation of yogurt with mango waste pulp powder increased the TS, protein, ash, and fiber contents of yogurt.

Physicochemical and phytochemical properties of yogurt supplemented with MPP or PPP

The impact of the MPP and PPP addition on the pH, acidity, viscosity, synersses values, TPC and RSA% of yogurt is shown in Table 3. Data indicated that the addition of MPP and PPP to yogurt showed a significant ($P \leq 0.05$) increase in pH, viscosity, TPC, and RSA% of resultant yogurt. This finding was associated with a significant ($P \leq 0.05$) increase in pH values and this effect was associated with the level of added MPP and PPP. In addition, PPP yogurt samples had higher total acidity and viscosity and lower pH, synersses, TPC, and RSA% than MPP yogurt samples at the same concentration. The increase in viscosity observed in yogurt enriched with mango and potato peels can be attributed to the high dietary fiber content in these additives. Dietary fiber can bind water

Table 2. Chemical composition of yogurt supplemented with MPP or PPP.

Treatments*	T.S (%)	Fat (%)	Protein (%)	Ash (%)	Fiber (%)	Moisture (%)
C	13.34 ± 0.62^{g}	3.08 ± 0.12^{a}	3.78 ± 0.12^{a}	0.78 ± 0.04^{e}	0.00 ± 0.01^{e}	86.66 ± 0.74^{a}
T1	13.95 ± 0.63^{f}	3.14 ± 0.14^{a}	3.82 ± 0.12^{a}	0.82 ± 0.03^{d}	0.15 ± 0.01^{c}	86.05 ± 0.66^{ab}
T2	14.72 ± 0.65^{d}	3.18 ± 0.16^{a}	3.88 ± 0.14^{a}	0.85 ± 0.02^{c}	0.30 ± 0.02^{b}	85.28 ± 0.58^{c}
T3	15.14 ± 0.54^{b}	3.22 ± 0.15^{a}	3.94 ± 0.15^{cd}	0.90 ± 0.04^{b}	0.47 ± 0.01^{a}	84.86 ± 0.62^{c}d
T4	14.20 ± 0.55^{e}	3.11 ± 0.11^{a}	3.86 ± 0.16^{a}	0.85 ± 0.03^{c}	0.07 ± 0.01^{d}	85.80 ± 0.48^{b}
T5	15.02 ± 0.44^{c}	3.15 ± 0.14^{a}	3.94 ± 0.13^{a}	0.92 ± 0.02^{b}	0.14 ± 0.01^{c}	84.98 ± 0.55^{cd}
T6	15.84 ± 0.52^{a}	3.18 ± 0.12^{a}	4.05 ± 0.14^{a}	0.98 ± 0.01^{a}	0.20 ± 0.02^{d}	84.16 ± 0.70^{d}

Values (means ± SD) with different superscript letters are statistically significantly different ($p \leq 0.05$). C1: Control yogurt, T1: Yogurt containing (1% Potato peel), T2: Yogurt containing (2% Potato), T3: Yogurt containing (3% Potato), T4: Yogurt containing (1% Mango), T5: Yogurt containing (2% Mango) , T6: Yogurt containing (3% Mango).

Table 3. Physicochemical and phytochemical properties of yogurt supplemented with MPP or PPP.

Treatments	Acidity (Lactic acid %)	pH values	Viscosity (cP)	Synersses (mL/100 mL)	TPC mg GAE/100 g	RSA%
C	0.90 ± 0.01^{a}	4.28 ± 0.01^{f}	5240 ± 20.12^{g}	29.40 ± 0.60^{a}	40.60 ± 1.28^{g}	20.60 ± 1.02^{g}
T1	0.86 ± 0.02^{c}	4.33 ± 0.01^{d}	5270 ± 33.14^{f}	27.90 ± 0.52^{b}	45.8 ± 1.14^{f}	26.4 ± 1.01^{f}
T2	0.82 ± 0.02^{d}	4.37 ± 0.02^{b}	5340 ± 35.10^{e}	26.00 ± 0.50^{d}	48.6 ± 1.20^{d}	30.2 ± 1.04^{d}
T3	0.78 ± 0.01^{e}	4.42 ± 0.02^{a}	5400 ± 50.11^{c}	24.30 ± 0.58^{f}	53.7 ± 1.30^{b}	33.5 ± 1.01^{c}
T4	0.88 ± 0.01^{b}	4.30 ± 0.05^{e}	5350 ± 28.18^{d}	26.70 ± 0.65^{c}	50.3 ± 2.22^{e}	28.4 ± 1.04^{e}
T5	0.85 ± 0.02^{c}	4.35 ± 0.05^{c}	5600 ± 20.25^{c}	25.00 ± 0.70^{e}	57.5 ± 2.20^{c}	35.2 ± 1.02^{b}
T6	0.83 ± 0.01^{d}	4.38 ± 0.06^{b}	5820 ± 28.14^{a}	23.00 ± 0.55^{g}	65.9 ± 1.66^{a}	40.8 ± 1.00^{a}

Values (means ± SD) with different superscript letters are statistically significantly different (P ≤ 0.05). TPC: total phenolic content, RSA: Radical scavenging activity.

within the product, enhancing its viscosity and reducing the rate of whey separation. Furthermore, the natural antioxidants present in mango and potato peels, which may also exhibit antimicrobial properties, contributed to an increase in pH values and a decrease in total acidity compared to the control yogurt. These changes enhance the product's overall acceptability to consumers. Similar results were reported by Atwaa *et al.* (2020) and Perez-Chabela *et al.* (2021), who reported that the addition of mango waste pulp powder, mango peel, and potato peel flour decreased the acidity and synersses and increased pH, viscosity, TPC, and RSA% of supplemented yogurt.

Sensory evaluation of yogurt supplemented with MPP or PPP

To our knowledge, the success of the included product is ultimately determined by its sensory quality. The sensory analysis considers a variety of strong and delicate techniques incorporated to gauge consumer and other product reactions. Results that are strong and repeatable are produced by testing under ideal conditions and by analyzing the data. The sensory tests are conducted on a specific product to show how consumers perceive volatile component analysis for flavor perception (Drake, 2007). Results presented in Table 4, show the average scores for sensory evaluation of probiotic yogurt treatments. Data indicated that the addition of MPP and PPP significantly (P ≤ 0.05) improved the sensory scores for flavor, body and texture, and total scores of resultant products. Moreover, the addition of date MPP and PPP at a level of 3% showed the highest sensory scores. These results are in agreement with those of Eman *et al.* (2015), Atwaa *et al.* (2020), and Perez-Chabela *et al.* (2021) who investigated the addition of lupin flour, mango waste pulp, and mango peel or potato peel flour improved the sensory attributes of fortified yogurt compared with control yogurt.

Final weight and body weight gain in all groups of rats

The Effects of yogurt supplemented with MPP and PPP on the final weight (FW) and body weight gain (BWG) of hyperlipidemic rats are shown in Table 5. These findings revealed that the initial weights of nontreated non-hyperlipidemic rats (negative control), hyperlipidemic

Table 4. Sensory evaluation of yogurt supplemented with MPP or PPP.

Treatments	Body and texture (30)	Appearance and color (15)	Acidity (10)	Flavor (45)	Total (100)
C	27.0 ± 0.5^{c}	14.0 ± 0.8a	7.0 ± 0.4^{c}	42.0 ± 0.7^{c}	90.0 ± 0.5^{d}
T1	27.0 ± 0.7^{c}	13.0 ± 0.6^{b}	8.0 ± 0.5^{b}	43.0 ± 0.6^{b}	91.0 ± 0.8^{c}
T2	28.0 ± 0.4^{b}	12.0 ± 0.5^{c}	9.0 ± 0.7^{a}	44.0 ± 0.5^{a}	93.0 ± 0.6^{a}
T3	29.0 ± 0.5^{a}	11.0 ± 0.4^{d}	9.0 ± 0.6^{a}	44.0 ± 0.4^{a}	93.0 ± 0.7^{a}
T4	27.0 ± 0.6^{c}	14.0 ± 0.8a	7.0 ± 0.4^{c}	42.0 ± 0.6^{c}	90.0 ± 0.5^{d}
T5	28.0 ± 0.7^{b}	13.0 ± 0.7^{b}	8.0 ± 0.6^{b}	43.0 ± 0.5^{b}	92.0 ± 0.4^{b}
T6	29.0 ± 0.4^{a}	13.0 ± 0.6^{b}	8.0 ± 0.5^{b}	43.0 ± 0.8^{b}	93.0 ± 0.6^{a}

Values (means ± SD) with different superscript letters are statistically significantly different (P ≤ 0.05).

Table 5. Final weight and body weight gain of hyperlipidemic rats treated with fortified yogurt.

Groups	Parameters			
	Initial Weight (g)	Final Weight (g)	BWG %	Feed intake (g/day)
G1	200.6 ± 3.6^{a}	288.0 ± 2.7^{e}	30.34 ± 1.2^{d}	20.12 ± 0.75^{a}
G2	201.2 ± 2.8^{a}	330.3 ± 3.5^{a}	39.08 ± 1.4^{a}	20.04 ± 0.84^{a}
G3	203.3 ± 2.5^{a}	309.8 ± 4.2^{b}	34.37 ± 1.3^{b}	19.90 ± 0.88^{ba}
G4	202.2 ± 4.3^{a}	298.4 ± 2.6^{d}	32.23 ± 1.2^{c}	19.82 ± 0.92^{ba}
G5	200.2 ± 4.6^{a}	300.4 ± 3.4^{c}	33.35 ± 1.5^{bc}	19.78 ± 0.94^{ba}

Mean values of eight rat's ± SD. A, b, c, etc., of the small letters in the same column are significantly different at (P ≤ 0.05). G1 (-Ve): negative control rat fed on basal diet. G2 (+Ve): positive control rat fed on fat diet, G3: obese rats fed on Control Yogurt, G4: obese rats fed on yogurt containing (2% Mango peel powder), G5: obese rats fed on yogurt containing (2% Potato peel powder).

rats (positive control), hyperlipidemic rats' yogurt, hyperlipidemic rats given yogurt supplemented with 2% MPP, and hyperlipidemic rats given yogurt supplemented with 2% PPP were 288.0 ± 2.7, 330.0 ± 3.5, 309.0 ± 4.2, 298.0 ± 2.6, and 300.0 ± 3.4 g, respectively. The treatments had a significant (P ≤ 0.05) impact on the FW and BWG of the rats. The lower BWG values (32.23%) were produced in hyperlipidemic rats receiving 10 g/day of yogurt supplemented with 2% MPP, followed by 33.35% in rats receiving only 10 g/day of yogurt supplemented with 2% PPP. In contrast, the animals administered yogurt supplemented with 2% MPP had lower FW (298.4 g) and BWG (by 32.23%) than the positive control group. The increased MPP and PPP content from bioactive substances such as phenolic acids, flavonoids, vitamins, and minerals may have contributed to the decline in blood fat levels in rats along with a decrease in relative weight. These bioactive components may be responsible for the improvement in the final weight and BWG of hyperlipidemic rats fed yogurt augmented with 2% MPP and PPP (Aznar-Ramos *et al.*, 2022; Singh *et al.*, 2020). Accordingly, MPP and PPP improved the nutritional status and decreased the BWG of hyperlipidemic rats (Althwab *et al.*, 2019; Umbreen *et al.*, 2020). Compared to other hyperlipidemic rats, hyperlipidemic rats given yogurt and 2% MPP supplementation experienced the best results in terms of FW and BWG.

Yogurt is one of the most physiologically active foods that humans ingest. It contains a lot of protein, vitamins, and minerals. Furthermore, the nutritional content is very excellent in comparison to the cost. Potential nutritional benefits are also related to the eating of bacteria that are normally present during consumption. Yogurt thus acts as a primary source of live bacteria in the human diet as well as a vehicle for the administration of extra probiotic bacteria. Yogurt could be a simple and inexpensive way to boost the nutritional content of your diet by consuming living bacteria and their metabolites. Yogurt can also be used as a carrier for certain probiotic bacteria and/or prebiotic ingredients, which can provide additional benefits. These variables suggest that yogurt may play a larger part in food-based dietary guidelines (Gómez-Gallego *et al.*, 2018). The first theorized mechanism was the "gel-forming" action and the possible viscosity of non-digestible carbohydrates (fiber). Indeed, pectin or guar gum may contribute to the so-called bulking effect (i.e., water retention), which was previously thought to be the primary mechanism underlying the observed results (Van Hul and Cani, 2019).

Carbohydrate fermentation in the lower gastrointestinal tract is linked to fluctuations in bacterial populations and the production of various end products, notably short-chain fatty acids (SCFAs) (e.g., acetate, butyrate, and propionate). Although SCFAs have been studied in a variety of contexts and linked to gut health (Chambers *et al.*, 2018), it is worth noting that these compounds can also enter the circulation and spread to various periphery organs (e.g., the liver, adipose tissue, and the brain (Canfora *et al.*, 2015). As a result, they have been linked to the regulation of energy, glucose, and lipid homeostasis, as well as the regulation of immunity and cancer (Cani and Jordan, 2018). As a result, these microbial metabolites have numerous physiological impacts. Prebiotic fermentation modulates gut peptides produced by L-cells, such as glucagon-like peptide-1 (GLP-1) and peptide YY (PYY), both of which are implicated in the regulation of hunger, body weight, and glucose metabolism (Drucker, 2018). As a result, we discovered that endogenous GLP-1 synthesis was boosted (greater mRNA expression, peptide production, and secretion, as well as an increase in the number of generating cells). As a result, the healthier phenotype was associated with higher GLP-1 and PYY levels in portal vein blood (Cani *et al.*, 2006). This discovery was later replicated using resistant starches or arabinoxylans (Zhou *et al.*, 2008). The ability of SCFAs to interact with specific G protein-coupled receptors such as GPR-43 (also known as FFAR2 for free fatty acid receptor 2) and GPR-41 (also known as FFAR3) is

generally attributed to the molecular event explaining how fermentation increases gut peptides (Nøhr *et al.*, 2013). Polyphenols have electron-donating phenolic groups in their structures, allowing them to counteract cellular damage caused by reactive oxygen species in the intestine. Despite this, new research suggests that their antioxidant capability is not the primary reason for their impacts on body fat storage (Rothenberg *et al.*, 2018). A variety of polyphenols have been demonstrated to lower nutritional intake in the gastrointestinal system by interacting with and inhibiting digestive enzymes, consequently impairing carbohydrate, fat, and protein digestion and absorption, resulting in decreased energy efficiency (Barrett *et al.*, 2018). Other putative mechanisms of action include inflammation reduction, glucose homeostasis modulation, adipogenesis, and lipid synthesis suppression, increased energy expenditure via thermogenesis, fat oxidation stimulation, and fecal lipid excretion (Pan *et al.*, 2016).

Liver, kidney, and heart weights in all groups of rats

The presented data in Table 6 showed the relative organ weights of the liver, kidney, and heart of the various groups. The positive control group showed a significant increase in relative liver, kidney, and heart weight (3.72, 0.61, and 0.291 g/100 g body weight, respectively) compared with the treated groups feeding on 10 g/day MPP yogurt (3.69, 0.62, and 0.291 g/100 g body weight), and treated groups feeding on 10 g/day MPP yogurt (3.66, 0.62, and 0.292 g/100 g body weight). Whereas, the liver relative weight of treated groups feeding on 10 g/day MPP yogurt (3.69 g/100 g body weight), and 10 g/day MPP yogurt (3.69 g/100 g body weight) showed a significant decrease in liver weight in comparison to the normal control group (G1). On the other hand, the treated group feeding on 10 g/day MPP yogurt and 10 g/day MPP yogurt showed a nonsignificant in relative kidney weight in comparison to the relative kidney of the normal control group. As for the heart ratio, all treated groups (G4, G5) feeding on 10 g/ day MPP yogurt and 10 g/day MPP yogurt showed a significant decrease when compared to the positive control group (G2). These effects may be due to a higher phenolic content of MPP (Aznar-Ramos *et al.*, 2022) and PPP (Singh *et al.*, 2020) Where there are no significant differences in feed intake, there are no significant differences in energy intake for all groups. These results are in agreement with several previous studies (Elkahoui *et al.*, 2018; Umbreen *et al.*, 2020) found no significant differences in relative weight change for the liver and kidney, while there were slight differences in the relative weight of the heart, testes, and spleen in different experimental groups of rats fed on mango peel or potato peel compared with positive control rats.

Table 6. Effect of yogurt supplemented with MPP and PPP on the relative organ weights of rats (g/100 g body weight).

Groups	Liver	Kidney	Heart
G1	3.73 ± 0.01^{b}	0.62 ± 0.002^{b}	0.298 ± 0.002^{b}
G2	3.72 ± 0.02^{b}	0.61 ± 0.003^{c}	0.296 ± 0.001^{b}
G3	3.93 ± 0.02^{a}	0.64 ± 0.002^{a}	0.303 ± 0.001^{a}
G4	3.69 ± 0.01^{c}	0.62 ± 0.004^{b}	0.291 ± 0.002^{c}
G5	3.66 ± 0.02^{d}	0.62 ± 0.002^{b}	0.292 ± 0.001^{c}

Mean values of eight rat's ± SD. A, b, c, etc., of the small letters in the same column are significantly different at (P ≤ 0.05).

Effects of MPP and PPP-supplemented yogurt on blood lipid profiles of hyperlipidemic rats

According to Table 7, hyperlipidemic rats that consumed yogurt with MPP and PPP supplements had lower (85.60 and 90.30 mg/dL) (P ≤ 0.05) total cholesterol levels than the positive control group (102.60 mg/dL), respectively). Additionally, the Triglyceride and LDL levels were greater in the positive control group (G2) (P ≤ 0.05) than in the other groups, with values of 135.80 and 47.04 mg/dL, respectively. Triglyceride and LDL levels in hyperlipidemic rats given yogurt supplemented with MPP and PPP were reduced, at 93.60, 31.28, and 99.40, 37.74 mg/dL, respectively. The positive control group (G2) had lower HDL-C values (28.40 mg/dL) (P ≤ 0.05) compared to the positive control group (G2) to the normal and treated hyperlipidemic groups. In this respect, rats who consumed yogurt enriched with MPP and PPP had significantly higher HDL levels (P ≤ 0.05; 37.20 and 34.50 mg/dL, respectively). The antihyperlipidemic effects of mango peel powder (MPP) and potato peel powder (PPP) may be attributed to their diverse array of bioactive compounds. MPP contains polyphenols and flavonoids, including mangiferin (a xanthonoid), gallic acid, gallotannins, quercetin, and catechin. In contrast, PPP is rich in compounds such as caffeic acid, gallic acid, pyrogallol, benzoic acid, chlorogenic acid, and dietary fiber. These bioactive components can interact with lipids and their degrading enzymes, promoting the emulsification and hydrolysis of fats. This interaction facilitates the formation of micelles, which enhances the absorption of lipids, potentially contributing to the antihyperlipidemic effects observed with these powders (Althwab *et al.*, 2019; Umbreen *et al.*, 2020). Minerals, vitamins, polyphenols, and flavonoids are a few of these ingredients. Snatching free radicals, maintaining HDL-binding paraoxonase activity by chelating oxidized metal ions, and inhibiting LDL oxidation can all contribute to the antihyperlipidemic effect (Kashyap *et al.*, 2019). Also, (Preciado-Saldaña *et al.*, 2022) and (Salem *et al.*, 2023)

Table 7. Effect of yogurt supplemented with MPP and PPP on the serum lipid profile in hyperlipidemic rats.

Groups	Triglycerides (mg/dL)	Total cholesterol (mg/dL)	HDL (mg/dL)	LDL (mg/dL)
G1	86.20 ± 2.30^{d}	81.50 ± 2.40^{d}	38.70 ± 1.20^{a}	25.56 ± 1.14^{e}
G2	135.80 ± 3.60^{a}	102.60 ± 3.50^{a}	28.40 ± 1.80 ^{d}	47.04 ± 2.12^{a}
G3	101.18 ± 3.82^{b}	90.30 ± 3.66^{b}	32.80 ± 1.601^{b}	38.46 ± 2.12^{b}
G4	93.60 ± 3.10^{b}	85.60 ± 2.40^{b}	37.20 ± 1.55^{c}	31.28 ± 1.60^{d}
G5	99.40 ± 2.70^{c}	90.30 ± 2.55^{c}	34.50 ± 1.80^{c}	37.74 ± 2.04^{c}

Mean values of eight rat's ± SD. A, b, c, etc., of the small letters in the same column are significantly different at ($P \leq 0.05$).

discovered that the mango peel powder or potato peel powder had a hypocholesterolemia impact.

Effect of yogurt supplemented with MPP and PPP on liver and kidney function parameters in hyperlipidemic rats

The effects of yogurt supplemented with MPP and PPP on the liver parameters of liver in hyperlipidemic rats are shown in Table 8. Rats treated with a high-fat diet showed a substantial increase ($P \leq 0.05$) in plasma AST and ALT levels and a significant decrease ($P \leq 0.05$) in total protein when compared to the control group. However, when compared to the positive control group, the administration of yogurt supplemented with MPP and PPP led to a significantly lower plasma level of the liver markers AST and ALT and a significantly higher plasma level of total protein. A possible explanation might be the high phenolic acid and flavonoid contents of MPP and PPP, which is shown in Table 1, might have antioxidant activities by snatching free radicals that are responsible for the hepatoprotective actions of MPP and PPP (Aznar-Ramos *et al.*, 2022; Singh *et al.*, 2020). These findings are consistent with previous studies (El-Gindy *et al.*, 2022; Ulla *et al.*, 2017) revealed the hepatoprotective benefits of mango peel powder or potato peel powder. Comparatively to other hyperlipidemic rats, hyperlipidemic rats with MPP and PPP improved liver function test findings. The positive control group (G2) plasma creatinine and urea values rose considerably ($P \leq 0.05$). Furthermore, these observed values considerably decreased in the hyperlipidemic rats who received yogurt and yogurt with MPP and PPP supplements (Table 8). The high concentration of bioactive substances in MPP and PPP, such as vitamins, minerals, flavonoids, and polyphenols, might act as superoxide scavengers and prevent the generation of reactive oxygen species and uric acid (Aznar-Ramos *et al.*, 2022; Singh *et al.*, 2020). In addition, several previous works (Althwab *et al.*, 2019; Umbreen *et al.*, 2020) found that mango peel or potato peel had nephroprotective effects, and these findings corroborated their findings. Comparatively to other hyperlipidemic rats, hyperlipidemic rats fed MPP and PPP-supplemented yogurt had the greatest results for serum renal function.

Histopathological examination

In the present study, liver sections of the control negative group (G1) showed preserved hepatic cords, central veins portal triad's structures, vascular tributaries, biliary system, sinusoids, Von Kupffer's cells, and supporting stroma (Figures 1A and 1B). Renal parenchyma and stroma of control negative rats were normal with keeping features of the vascular structures, nephron units, collecting tubules, and papillary and pelvic structures (Figures 1C and 1D).

Table 8. Effect of yogurt supplemented with MPP and PPP on liver and kidney function parameters in hyperlipidemic rats.

Groups	Aspartate aminotransferase (AST U/L)	Alanine aminotransferase (ALT U/L)	Total protein (mg/dL)	Creatinin (mg/dL)	Urea (mg/dL)
G1	61.13 ± 2.12^{e}	56.72 ± 1.68^{e}	7.92 ± 0.42^{a}	0.75 ± 0.12^{e}	20.76 ± 1.20^{e}
G2	96.32 ± 2.58^{a}	85.11 ± 1.84^{a}	6.34 ± 0.26^{d}	1.04 ± 0.31^{a}	28.84 ± 2.02^{a}
G3	77.84 ± 2.45^{b}	69.18 ± 1.15^{b}	6.78 ± 0.65^{c}	0.93 ± 0.22*b*	29.32 ± 1.76^{b}
G4	63.21 ± 1.25^{d}	59.11 ± 1.12^{d}	7.22 ± 0.44^{b}	0.80 ± 0.14^{d}	26.36 ± 1.18^{c}
G5	70.93 ± 1.40^{c}	63.00 ± 1.14^{c}	7.20 ± 0.40^{b}	0.86 ± 0.12^{c}	23.80 ± 1.24^{d}

Mean values of eight rat's ± SD. A, b, c, etc., of the small letters in the same column are significantly different at ($P \leq 0.05$).

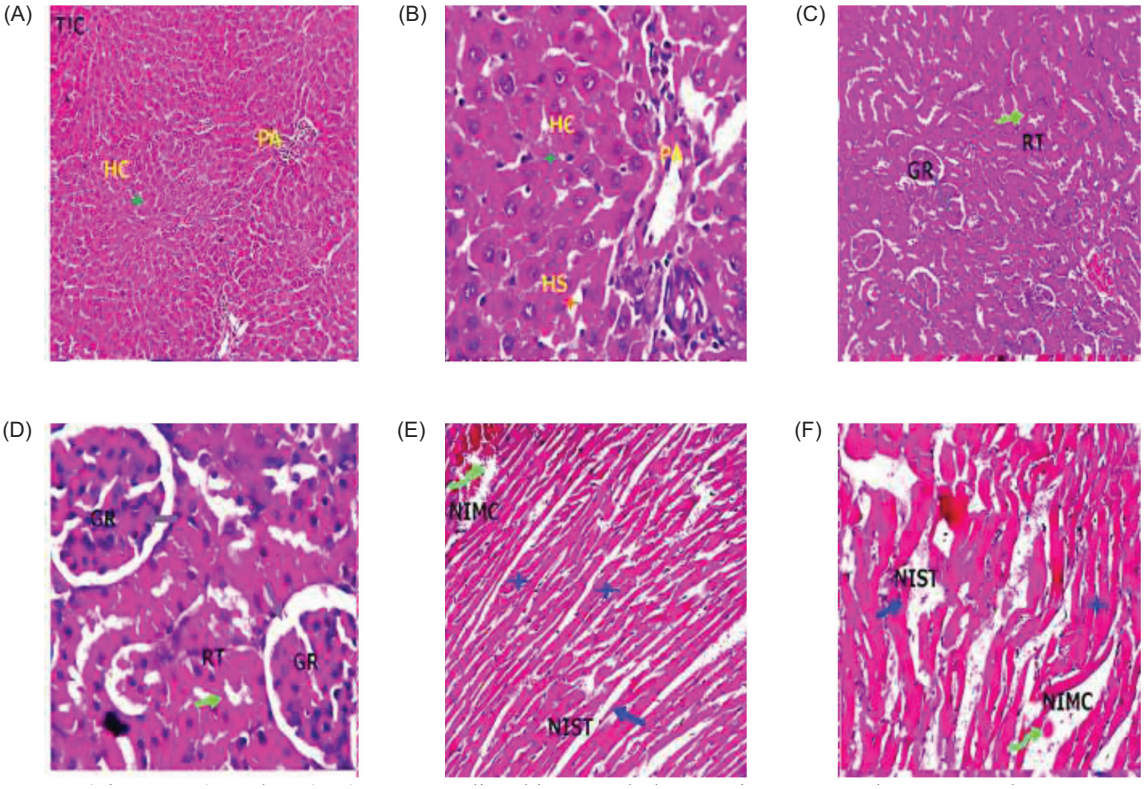

Figure 1. Photomicrographs from liver (A, B), Kidney (C, D), and heart (E, F) tissue sections of G1 (the control negative group) stained with H&E showing preserved hepatic cords (HC, green star), central veins, portal triad's structures (PA, yellow arrow), vascular tributaries, biliary system, sinusoids and Von Kupffer's cells (HS, orange star). Renal parenchyma appears normal showing features of the vascular structures and nephron units (glomerulus, proximal and distal convoluted tubules, and loops of Henle), (GR, gray arrow, RT, light green arrow). Cardiac tissue shows normal coronary and intermuscular blood vessels (NIMC, curved green arrow), interstitial syncytium (NIST, dark blue arrows), and cardiomyocytes (dark blue star).

Cardiac histomorphology pointed out normal coronary and intermuscular blood vessels, interstitial syncytium, and cardiomyocytes. No apparent tissue changes were recorded in any of the examined organs (Figures 1E and 1F).

About Group 2 (G2), the examined sections showed hepatocellular degenerative and microsteatitic changes, portal vascular congestion, sinusoidal dilatation, biliary proliferation, and round cell infiltration (Figures 2A and 2B). Renal tissue showed focal interstitial nephritis (round cells aggregation), and tubular degeneration with occasional vacuolation and or microsteatosis beside marked glomerular shrinkage and hyalinization (Figures 2C and 2D). Cardiac changes were pronounced and represented by coronary and intermuscular congestion, cardiomyocytic atrophy, and degeneration besides interstitial edema and hemorrhages (Figures 2E and 2F).

Regarding Group 3 (G3), liver sections showed normal hepatic parenchyma a part of some sections which revealed moderate portal vascular dilatation, biliary proliferation, chronic lymphocytic cholangitis, and Von-Kupffer cells reactivity (Figures 3A and 3B). The kidneys in some cases showed moderate renal tubular degeneration and a few glomeruli were partially lobulated (Figures 3C and 3D). Heart sections in most cases were normal, keeping features of coronary and intermuscular blood vessels, interstitial tissue, and cardiomyocytes (Figures 3E and 3F).

Concerning Group 4 (G4), the examined sections showed marked tissue changes represented by hepatocellular degenerative and microsteatitic changes, portal vascular congestion, sinusoidal dilatation, biliary proliferation, and round cell infiltration. Extramedullary hematopoiesis was seen in some cases (Figures 4A and 4B). Renal tissue showed focal interstitial nephritis (round cells aggregation), tubular degeneration with occasional vacuolation, and or microsteatosis besides moderate glomerular shrinkage. The renal arterioles and venules were moderately dilated with associated perivascular edema (Figures 4C and 4D). Cardiac changes were represented by coronary and intermuscular congestion, focal cardiomyocytic degeneration, and moderate interstitial edema (Figures 4E and 4F).

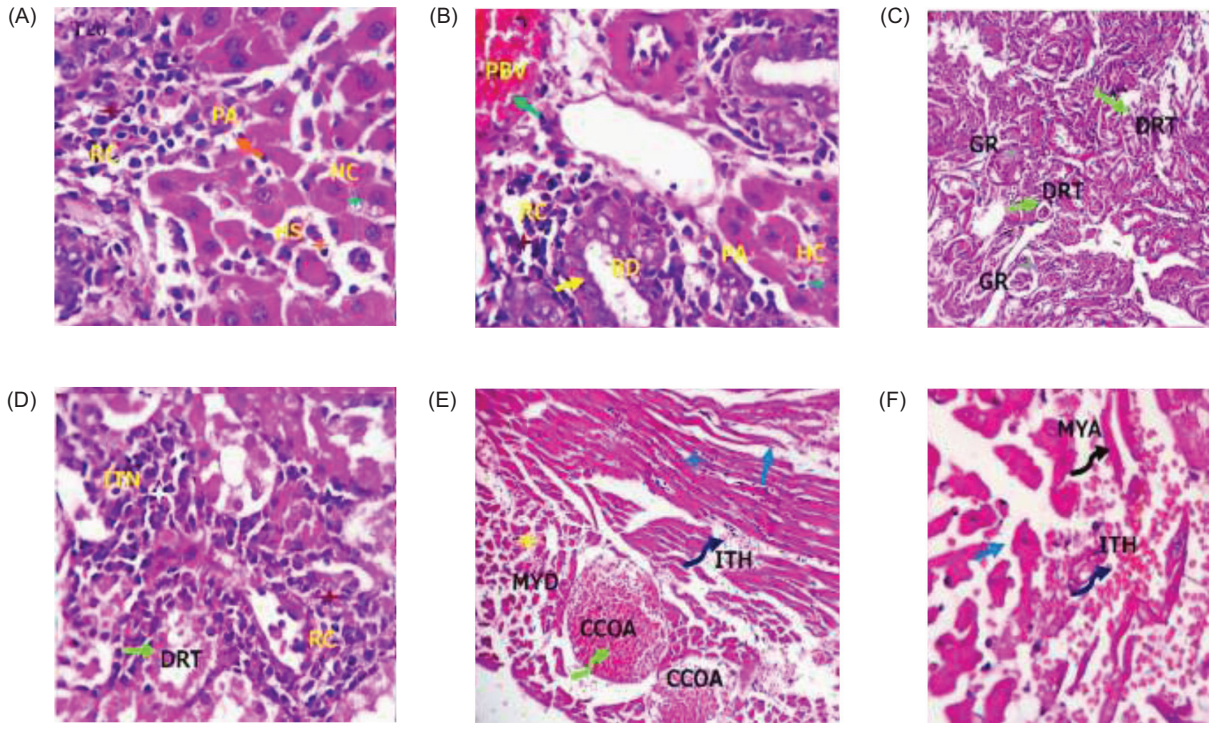

Figure 2. Photomicrographs from liver (A, B), Kidney (C, D), and heart (E, F) tissue sections of G2 (positive control rat fed on fat diet) stained with H&E showing hepatocellular degenerative and microsteatitic changes (HS, green star), portal vascular congestion (PBV, dark green arrow) sinusoidal dilatation (HS, orange star), biliary proliferation(BD, yellow arrow) and round cells infiltration (RC, brown star). Renal tissue shows focal interstitial nephritis (round cells aggregation) (ITN, RC, brown star), tubular degeneration with occasional vacuolation and or microsteatosis (DRT, light green arrows) beside marked glomerular shrinkage and hyalinization (GR, gray stars). Cardiac changes are represented by coronary and intermuscular congestion (CCOA, curved green arrows), cardiomyocytic atrophy and degeneration (MYD, MYA, yellow star and curved black arrow) beside interstitial edema (blue arrow), and hemorrhages (ITH, curved dark blue arrows).

Regarding Group 5 (G5), the sections of this group showed hepatocellular degenerative and microsteatitic changes beside characteristic focally disrupted, disorganized atrophied hepatocytes. Marked Portal vascular congestion, sinusoidal dilatation, biliary proliferation, and round cell infiltration were also seen (Figures 5A and 5B). Renal tissue showed focal interstitial nephritis (round cells aggregation) and tubular degeneration with occasional vacuolation and or microsteatosis beside glomerular lobulation (Figures 5C and 5D). Cardiac changes were characteristic and represented by coronary and intermuscular congestion, necrotic cardiomyocytes (cardiomalacia), cardiomyocytic atrophy, and degeneration beside focal interstitial edema (Figures 5E and 5F).

Given the above findings, this study reports that fruit and vegetable waste could be a good source of dietary fiber and phenolic substances in yogurt preparation since milk and its products are completely free of fiber and contain very little phenolic substances. Furthermore, the use of mango and potato byproducts as functional components helped reduce circulating fat in rats. However, the present research has some limitations such as the effect of fortifying yogurt with mango peel powder and potato peels on the vitality and activity of yogurt starter microbes and its effect and its association with other properties of the product were not studied. Moreover, the measurement of adipocytes in obese rats was not performed, suggesting further research to explore these mentioned limitations.

Conclusions

Collectively, fortified yogurt with mango or potato peel can be used as a beneficial food supplement for preventing overweight and obesity by reducing weight gain and serum cholesterol levels. The incorporation of mango or potato peel powder significantly enhanced the chemical, antioxidant, rheological, and sensory properties of yogurt. These enhancements provided additional nutritional and health benefits to the final product, especially when fortified with up to 2% of these additives. Notably, the consumption of yogurt containing 2% mango or potato peel powder led to substantial reductions in levels of LDL, TC, TG, AST, ALT, creatinine, and urea. Conversely, these

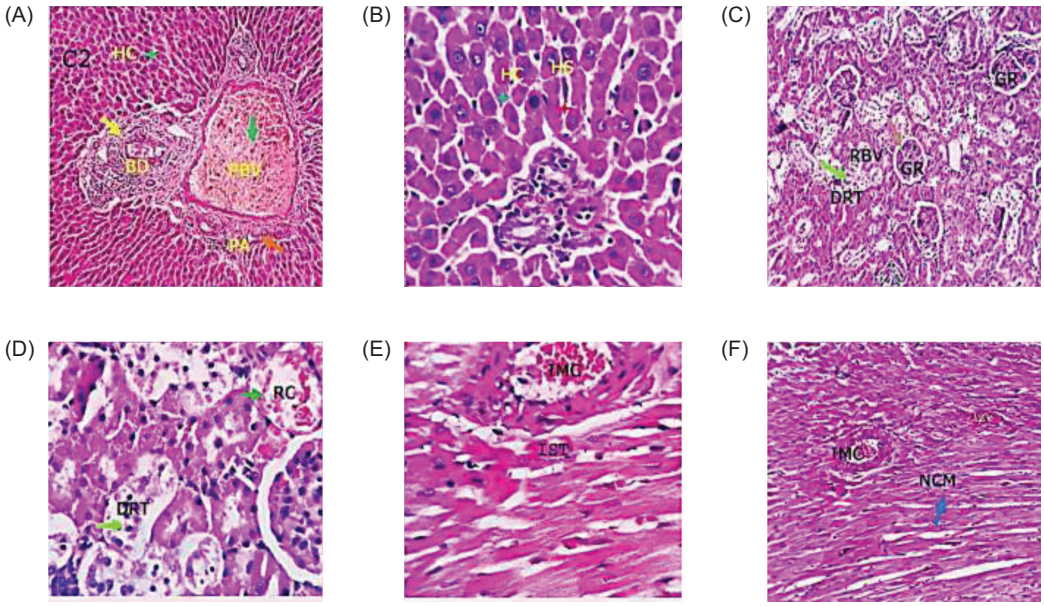

Figure 3. Photomicrographs from liver (A, B), Kidney (C, D) and heart (E, F) tissue sections of G3 (obese rats fed on Control Yogurt) stained with H&E showing moderate portal vascular dilatation (PBV, green arrow) biliary proliferation, chronic lymphocytic cholangitis (BD, yellow arrow) and Von- Kupffer cells reactivity (HS, red star). Kidneys show moderate renal tubular degeneration (DRT, light green arrow) and a few glomeruli are partially lobulated (GR, gray arrow). The heart is normal with keeping features of coronary and intermuscular blood vessels, interstitial tissue and cardiomyocytes (IMC, IST, and NCM).

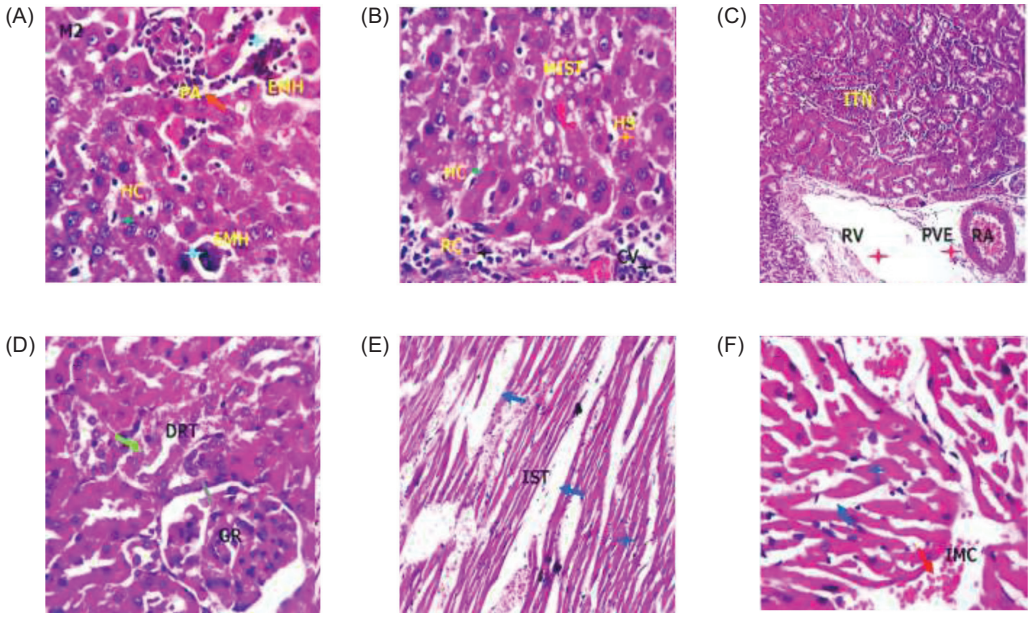

Figure 4. Photomicrographs from liver (A, B), Kidney (C, D) and heart (E, F) tissue sections of G4 (obese rats fed on yogurt containing (2% Mango peel powder) stained with H&E showing hepatocellular degenerative and microsteatitic changes (curved orange arrow), portal vascular congestion (dark green arrow), sinusoidal dilatation (HS, orange star), and round cells infiltration (RC, black star) Extramedullary hematopoiesis is also seen (EMH, light blue arrow). Renal tissue shows focal interstitial nephritis (round cells aggregation) (ITN, RC, black star), tubular degeneration with occasional vacuolation and or microsteatosis (DRT, light green arrows) beside moderate glomerular shrinkage (GR, gray stars) The renal arterioles and venules are moderately dilated with associated perivascular edema (RA, RV, PVE, red stars). Cardiac changes are represented by coronary and intermuscular congestion (IMC, red arrow), focal cardiomyocytic degeneration (blue stars), and moderate interstitial edema (IST, dark blue arrows) are also seen.

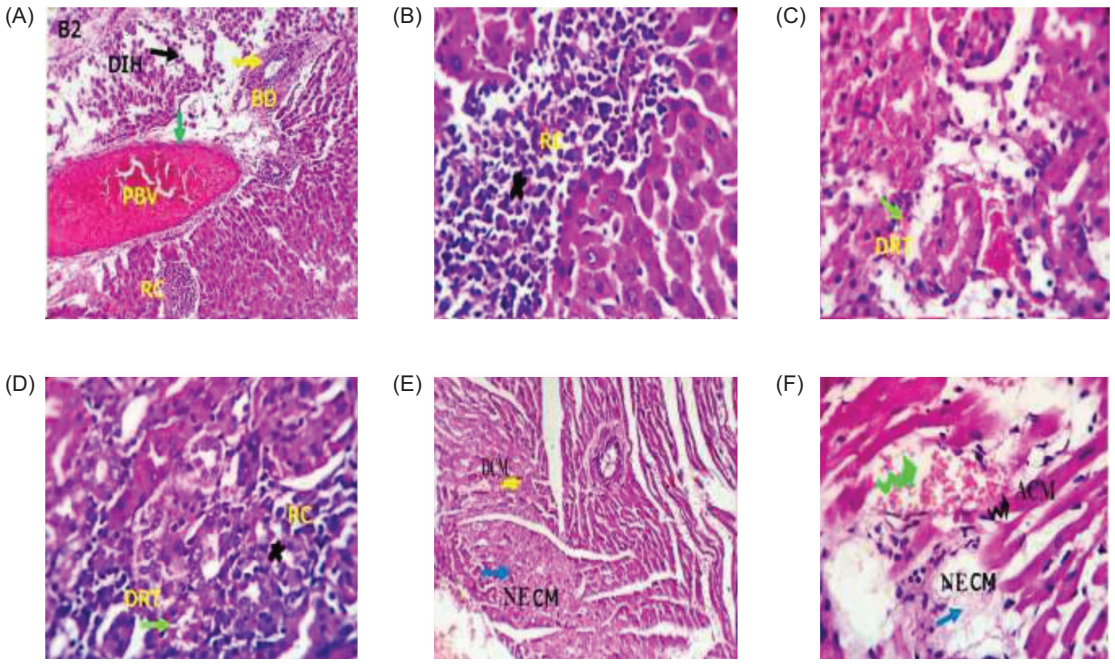

Figure 5. Photomicrographs from liver (A, B), Kidney (C, D) and heart (E, F) tissue sections of G5 (obese rats fed on yogurt containing (2% Potato peel powder) stained with H&E showing hepatocellular degenerative and microsteatitic changes beside characteristic focally disrupted, disorganized atrophied hepatocytes (DIH, black arrow), portal vascular congestion (PBV, dark green arrow), biliary proliferation (BD, yellow arrow) and round cells infiltration (RC, black star). Renal tissue shows focal interstitial nephritis (round cells aggregation) (RC, black star) and tubular degeneration with occasional vacuolation and or microsteatosis (DRT, light green arrows). Cardiac changes are represented by coronary and intermuscular congestion (curved light green arrows), cardiomyocytic atrophy and degeneration (DCM. ACM, yellow star and curved black arrow) beside necrotic cardiomyocytes (cardiomalacia) (NECM, dark blue, blue arrows.)

rats exhibited increased levels of HDL and total protein. Further research is warranted to explore the effects of adding mango or potato peel powder to various dairy products, along with an investigation of the underlying mechanisms contributing to these health benefits.

Institutional Review Board Statement

The study obtained the approval of the Institutional Review Board (Ethics Committee) of the Zagazig, University, Egypt (approval number: ZU-IACUC/2/F/109/2023.

Data Availability Statement

The data that supports the findings of this study are contained within the manuscript. Further information is available upon request from the corresponding author.

Author Contributions

O.H.D., A.E-R.M.S., and H.S.S. were involved in the study's design, methodology, analysis, and writing of the paper. D.A.A, N.D., M.A.H, M.F.E., A.A.H., and EKE contributed to the methodology, drafting, and preparation of the manuscript for publication revision and funding acquisition. All authors revised the manuscript and approved the final version to be published.

Conflicts of Interest

The authors declare no conflict of interest.

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Informed Consent Statement

Not applicable.

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