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Influence of Mangosteen Peel Extract on Oxidative Stability, Nutritional Values, Physicochemical Features and Sensory Preference of Soy-Based Burgers

Running head: Preservation of Soy-Based Burger with Mangosteen Peel Extract

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SUMMARY

Research background. Despite being a substantial and expanding market segment, there remain challenges concerning the shelf-life of plant-based meat alternatives when synthetic preservatives are not utilized. Consequently, it is necessary to investigate the integration of natural extracts into these products to extend their shelf-life.

Experimental approach. The dried mangosteen peel extract powder was characterized for its total phenolic content and flavonoid content and antioxidant capacity. The fresh soy-based burgers were then formulated to six treatments including control (no antioxidant added), 10 mg butylated hydroxytoluene (BHT, a synthetic antioxidant), 10 mg, 7.5 mg, 5 mg and 2.5 mg dried extract and

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assessed for their proximate composition, physicochemical characteristics, protein and lipid oxidation, texture profile and sensory parameters over 10 days of storage.

Results and conclusions. The addition of the extract reduced the moisture content and cooking loss. In addition, the burgers with the extract (5–10 mg/100 g) had remarkably lower values of peroxides, thiobarbituric acid reactive substances and carbonyls, indicating their higher stability against lipid and protein oxidation. These effects of the extract were revealed to be better than those of BHT. In addition, extract-added burgers possessed improved texture in terms of springiness, chewiness and cohesiveness, resulting to higher texture scores. All treatments were accepted by consumers with the average score of approximate 7 over 9 points. Therefore, the extract from mangosteen peels could be used as an excellent natural antioxidant substitution for synthetic ones currently used in food preservation.

Novelty and scientific contribution. The study fulfils a need for the growing plant-based meat alternatives with an extended shelf-life of a healthier version by incorporation of natural antioxidant extract from mangosteen peels to replace synthetic butylated hydroxytoluene. In addition, the study also provides the evaluation of product quality throughout storage, presenting insights that could drive innovation in the use of natural preservatives within the food industry.

Keywords: shelf-life; TBARS; phenolic; peroxide; carbonyl; hedonic

INTRODUCTION

It is widely accepted that transitioning from meat-dominant diets to more plant-based alternatives is essential for reducing the adverse environmental impacts of the food system, while simultaneously improving human health outcomes and promoting animal welfare. Excessive consumption of meat-based products has been linked to various health issues such as obesity, type 2 diabetes, cardiovascular disease, and certain cancers (*1*). Moreover, it contributes to environmental issues like heightened greenhouse gas emissions and the degradation of terrestrial and aquatic biodiversity (*2*), which can result in climate change (*3*). In contrast, plant-based meat alternatives are demonstrated to reduce animal-based food sources, decrease overall environmental impact and limit public health considerations (*4*). With this consideration, recently, more than 4,400 items as plant-based meat alternatives have been introduced globally to increase the application of products made from plants in daily life consumption (*5*).

Several types of meat substitute products are available in the market such as sausage, burgers, tofu, bacon, steak, and meatball (*6*). In which, vegetarian burgers are of consumers' attention since they are ready-to-eat products with ease of preparation (*7*). Thanks to this convenience, burgers

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become a familiar fast food in daily life, which in turn the preservation and extension of the product's shelf-life also become the main goal that needs to be taken into consideration (*8*). The quality and shelf life of vegan burgers are mainly characterized by the oxidation of lipids due to the presence of edible oils in the formulation (*9*), and the products normally has a short shelf-life in cold storage without adding any antioxidants. Consequently, synthetic antioxidants like butylated hydroxyanisole (BHA) or butylated hydroxytoluene (BHT) are introduced, which are responsible for inhibition of fat oxidation in burger products (*9*). Nonetheless, these antioxidants pose numerous health concerns, potentially causing cancer and carcinogenesis which led to increasing demands of innovative research on organic extracts as alternatives (*10*), such as plant extracts rich in vitamins, carotenoids (carotene, lycopene, and astaxanthin), polyphenols and flavonoids.

Mangosteen (*Garcinia mangostana*) which is a tropical plant and widely cultivated in South East Asian countries (*11*). Mangosteen peels are considered as a good source of bioactive compounds such as phenolic acids, xanthones (nonpolar compounds), flavonoids, and condensed tannins or pro-anthocyanidins (polar compounds), which primarily exhibit the antioxidant and medical properties. However, to date the research mostly focuses on exploration of the components of mangosteen peel extracts in pharmaceutical applications (*12*) while there is still lack of investigation on the utilization of bioactive compounds of this extract in food. This study hence aimed to examine the efficiency of mangosteen peel extract in preventing lipid and protein oxidation of soy-based burgers and extending their shelf-life. The effects of this extract supplementation on the nutritional composition, physicochemical features, texture profile and sensory preference of the products were also investigated.

MATERIALS AND METHODS

Materials and chemicals

Dried mangosteen (*Garcinia mangostana*) peel was purchased from Thanh Binh Herbal Tea Co., Ltd (Ho Chi Minh City, Vietnam). The ingredients used for soy burger formulation were purchased at a local supermarket, except for texture vegetable soy protein and food additives, which were ordered from VINASING Science Development Co., Ltd and Green Cosmetics Store (Ho Chi Minh City, Vietnam), respectively. Chemicals of the analytical grade were supplied by local distributors, where Folin–Ciocalteu reagent and 2,2-diphenyl-1-picrylhydrazyl (DPPH) were purchased from Sigma-Aldrich; dinitrophenyl hydrazine (DNPH), guanidine hydrochloride, and sodium phosphate were originated from Acros (Belgium); trichloroactic acid (TCA), 2-thiobarbituric acid (TBA), potassium sulfate, acetic acid, acetic acid glacial, ethanol, sodium hydroxide, and copper (II) sulfate were purchased from Fisher (USA); aluminum chloride, ascorbic acid, boric, 2,6–di–tert-butyl-4-

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methylphenol (BHT), chloroform, ethyl acetate, hydrochloric acid (HCl), Tashiro indicator, potassium iodine, sodium thiosulfate, starch solution, sulfuric acid, hexane, sodium carbonate, and sodium chloride were originated from China.

Phenolic extraction of mangosteen peels

The mangosteen peel extract was prepared following a modified method of Zhou *et al.* (*13*). Initially, 5 g of dried mangosteen peels were ground into a powder and sieved through a 250 μm sieve. The powders were extracted with 75 mL of ethanol-distilled water (70:30 *V*/*V*) at 60 °C for 15 min. The resulting mixture was centrifuged at 4 °C with 4,500 rpm for 15 min to obtain the filtrate. Subsequently, the filtrate was further concentrated using a rotary evaporator (Steroglass, Italy) at 70 °C with 100 rpm until no more solvent could be removed. The concentrated mangosteen peel extract was subsequently frozen for 24 h and then subjected to freeze-drying (Gamma 2-16 LSCplus, Martin Christ, Germany). The dried extract powder was kept in zipper bags with moisture absorbent pads (LPS, 5 g/bag) and stored in a freezer until further usage.

Soy burger preparation

Soy-based burgers were processed according to the method of Trujillo-Mayol *et al.* (*14*). In summary, the formulation consisted of 70 % textured vegetable soy protein (hydrated at a ratio of 1:2 w/w) combined with 30 % of an emulsion comprising 40 % sunflower oil, 30 % egg white, 19.5 % water, 10 % starch, and 0.5 % salt. The formulation consisted of six groups. The lyophilized powder of mangosteen peel extract was incorporated into the burger formulation at four different contents (2.5, 5, 7.5 and 10 mg/100 g burger). The fifth group included BHT (10 mg/100 g burger) as a positive control, and the last one did not include any antioxidant source (negative control). BHT was added to the burger formulation at 10 mg, compliant with the guidelines by The Vietnamese Ministry of Health for food additives management (*15*).

The burger patties, weighing (50±2) g each, were formed using a burger press kitchen food mold with dimensions of 1 cm thickness and 5 cm diameter. They were then wrapped in oxygen-permeable PVC film and kept refrigerated at 4 °C. For assessing cooking loss and sensory attributes, the burgers were pan-fried. To maintain uniform cooking conditions across samples, six burger patties were evenly distributed along the edges of a preheated pan. The patties were cooked for 6 minutes, flipped once at the 3-minute mark, and continued cooking until the internal temperature reached 75 °C.

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Determination of total phenolic content (TPC), total flavonoid content (TFC) and antioxidant activity of the dried mangosteen peel extract

To determine TPC and TFC, 1 g of peel extract powder was dissolved with 100 mL ethanol 70 % (*V*/*V*). TPC was determined by using the Folin-Ciocalteu method (*16*) and expressed as mg gallic acid equivalent (GAE)/g dried extract. In brief, 0.5 mL extract was mixed with 0.5 mL of 10 % (*m*/*V*) Folin-Ciocalteu solution, vortexed and left for 5 min. After that, 0.5 mL of 7.5 % (*m*/*V*) sodium carbonate solution was added to the mixture, followed by 2.25 mL distilled water. The mixture was kept for 30 min at room temperature in the dark before measuring the absorbance at 765 nm using a spectrophotometer (V-770 UV/Vis/NIR, Jasco, Tokyo, Japan).

On the other hand, TFC was estimated using the aluminum chloride colorimetric technique (*17*) and expressed as mg rutin equivalent (RE)/g dried extract. In brief, 1 mL extract was mixed with 0.3 mL of 5 % (*m*/*V*) $NaNO_2$. The mixture was allowed to stand for 5 min and then 0.3 mL of 10 % (*m*/*V*) $AlCl_3$ was added. After incubation for 5 min, 2 mL of 1 N NaOH and 1.4 mL of distilled water were added, and the absorbance was then measured at 510 nm.

The antioxidant activity was assessed through the DPPH radical scavenging capacity (*18*). The peel extract powder and BHT were dissolved in methanol 80 % (*V*/*V*) to prepare different concentrations. Each concentration (1 mL) was mixed with 3 mL 0.1 mM DPPH in methanol and vortexed for 40 min. The absorbance was then recorded at 517 nm. The inhibition concentration (IC_{50}) was calculated based on the linear regression of the curve plotting between % inhibition and antioxidant concentrations.

Proximate composition, cooking loss, mass loss and pH of soy burgers

Proximate composition (moisture, ash, protein, lipids, and carbohydrates content) of soy burgers were measured according to the standard methods (*19*). Cooking loss was measured as described in the method of Moghtadaei *et al.* (*20*) by weighing the soy burgers before and after frying. Mass losses of soy burgers during refrigerated storage were calculated on day 1, day 5 and day 10 as described in the method of Ganhão *et al.* (*21*). pH determination was followed to the method of Sallam and Samejima (*22*) using a digital pH meter. The sample of 10 g was homogenized with 40 mL distilled water for one minute. The homogenate was filtered before measuring pH.

Lipid and protein oxidation in soy burgers

Peroxide value (PV, mmol/kg of sample) and thiobarbituric acid reactive substances (TBARS, nmol MDA/g of sample) were measured as lipid oxidation parameters while protein carbonyl content was used as an indicator for protein oxidation. Regarding PV, this value was measured following to

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the standard method (*23*), where the fat was extracted with the solvent acetic acid:chloroform (2:1, *V*/*V*) and PV was determined by titration. For the determination of TBARS, the analysis was performed according to the methods of Sobral *et al.* (*24*) and the results were expressed as nmol MDA per gram of sample. Firstly, 5 g of sample was homogenized with 20 mL 7.5 % (*m*/*m*) TCA and 10 mL BHT (4.5 % *m*/*V* in ethanol) for 5 min. The supernatant (2 mL), which was obtained by centrifuging at 4,500 rpm for 10 min, was mixed with 2 mL of 40 mM TBA in acetic acid glacial. The mixture was heated in a water bath at 90 °C for 45 min. After cooling at room temperature for 10 min, the absorbance was measured at 532 nm.

Carbonyl content was measured based on the traditional spectrophotometric DNPH carbonyl assay described by Özer and Secen (*25*) and expressed as nmol of carbonyl per mg of protein. Briefly, 5 g of sample was homogenized with 50 mL of 20 mM sodium phosphate buffer (pH 6.5) containing 0.6 M NaCl. Two equal aliquots of 25 mL were then mixed with 5 mL of ice-cold 10 % (*m*/*V*) TCA to precipitate protein before centrifugation at 4500 rpm for 5 min at 4°C. After decanting supernatants, one pellet was treated with 1 mL of 2 N HCl and the other was processed with 1 mL of 0.2 % (*m*/*V*) DNPH in 2 N HCl. Both samples were incubated for 1 h at room temperature, and vortex after each 15 min. After reaction, the samples were precipitated with 5 mL of 10 % (*m*/*V*) TCA and subsequently centrifuged at 4500 rpm for 5 min at 4 °C. The collected pellets were washed three times with 2 mL of the solvent ethanol:ethyl acetate (1:1, *V*/*V*). The pellets were then dissolved with 5 mL of 20 mM sodium phosphate buffer containing 6 M guanidine HCl (pH 6.5). Centrifugation was subsequently conducted at 4500 rpm for 2 min at 4 °C to remove insoluble fragments. The absorbance of the final solution was measured at 280 and 370 nm.

Texture profile and sensory tests of soy burgers

The texture profile analysis of soy-based burgers was conducted using a CT3 Texture Analyzer from Brookfield Engineering Laboratories, Inc., USA. Samples measuring 2.5 cm×2.5 cm× cm from each formulation underwent two-cycle compression to 75 % of their original height at room temperature, moving at a constant velocity of 1 mm/s. Parameters assessed in the texture profile analysis included hardness, cohesiveness, springiness, and chewiness.

For sensory evaluation, the hedonic test method described by Kazemi *et al.* (*26*) was employed. Thirty panelists were recruited, including students and staffs (22 females and 8 males) at International University, Vietnam within the age of 18–50. The panelists evaluated the burgers in individual booths under white fluorescent light. They were asked to rate their preferences regarding the appearance, texture, odor, taste, color, and overall acceptability of the burgers using a 9-point hedonic scale, where a score of "9" indicated extreme liking, "5" indicated neutrality, and "1" indicated

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extreme disliking. Water was offered to rinse their mouths between each sample. The samples were coded and served randomly.

Statistical analysis

All measurements were conducted in triplicate. One-way analysis of variance using Minitab software (*27*) with Fisher post-hoc test or independent *t*-test was applied to compare means with the significant level of 95 %.

RESULTS AND DISCUSSION

Bioactive properties of mangosteen peel extract

Table 1 presents the data for bioactive compounds of the dried extract. It contained 311.3 mg GAE/g dried extract for total phenolic content and 176.1 mg RE/g dried extract of total flavonoid content. These values were comparable with those reported for the phenolic extract from cloves (TPC of 456 mg GAE/g and TFC of 100 mg catechin equivalent/g) used in preservation of beef burgers (*28*), or those for the pomegranate peel extract (TPC of 392 mg GAE/g and TFC of 104 mg quercetin equivalent/g) for minced beef preservation (*29*), and higher than those of green leaf extracts (TPC of 4.53-27.19 mg GAE/g) for preservation of meat products (*30*). The high TPC and TFC values of the dried extract resulted to its high antioxidant capacity, where its IC_{50} was 31.7 mg/mL. In comparison, the IC_{50} of BHT, a commonly used synthetic antioxidant, was 41.7 mg/mL. Therefore, it could be concluded that the antioxidant capacity of the dried mangosteen peel extract was 1.3-fold higher than BHT. Since the recommended amount of BHT to be added into burgers was 10 mg/100 g, the contents of the dried extract to be investigated varied from 2.5 to 10 mg/100 g.

Proximate composition and cooking loss of soy-based burgers

Table 2 summarizes the proximate composition (dry basis) of the soy-based burgers. The addition of different levels of the extract and BHT varied the moisture of the burgers, but no significant differences (p>0.05) were observed as compared with that of the negative control sample, except a slight decrease (p<0.05) recorded for the burger with 10 mg dried extract. A small decline in moisture was also reported for other food incorporated with plant extracts (*31,32*). As the result of moisture variation, the fat contents were significantly different among certain samples. However, the variation was small, which was less than 0.7 %. In general, the proximate composition of all samples included approximate 37–38 % protein, 12 % fat, 5 % ash and 44–45 % carbohydrate. This result was similar to the research of Savadkoohi *et al.* (*33*) for a type of plant-based meat produced from soy protein

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isolate and egg albumin as ingredients, where the protein, fat, ash, and carbohydrate content were of about 35, 14, 5 and 44 % respectively.

Cooking loss referred to the loss of liquid (moisture and fat) and other juices of soy burger patties before and after frying. This parameter was related to different factors such as cooking time, type, and amount of ingredients in the formulation. Table 2 indicates that the addition of the extract caused lower ($p<0.05$) cooking losses, especially the samples with 10 mg dried extract which showed the lowest percentage of cooking loss (5.7 %), while the control and BHT had the greatest values, *i.e.* 6.7 %. The changes in the cooking loss were mostly contributed by the denaturation of proteins, led to lower water and fat holding capacities and hence the enhanced loss of water and fat (*34*). Moreover, it was noticed that the percentage of cooking loss decreased with an increase in the amount of the extract. The reduction in cooking loss may be due to the enhanced emulsion stability and the binding capacity of extract components, such as polyphenols, to preserve water and fat within the matrix. Improved water and fat holding capacity and reduced cooking loss were also reported previously for the food added with phenolic-rich plant extracts (*28,35*).

Mass loss and pH value of stored soy burgers

Mass loss is considered as the reduction in mass of products during refrigerated storage and the collected data are presented in Table 3. Due to moisture evaporation, the mass loss of all samples increased when the storage time prolonged. The dried extract addition at 10 mg/100 g could reduce the mass loss as compared with the control ($p<0.05$). This was consistent with the discussion from Table 2, where the dried extract could retain water.

pH of soy burgers was also an important factor that contributed to the quality of the final products, and the data are presented in Table 3. The initial pH of the control burger sample was 6.95. This value was considered higher than those of common meat-based products (*e.g.* beef), which are around 5.5. This is the intrinsic property of several plant-based meat products due to the slight alkalinity of their components. In this study, the main ingredients of soy-based burgers were textured vegetable soy protein (pH 7.42–7.43) (*36*) and egg white (pH 7.6–7.9) (*37*), leading to their high pH value. The neutral or higher pH values were also reported previously for other meat analogues (*38,39*). Meanwhile, the burger samples added with the dried extract showed significantly ($p<0.05$) higher pH values (7.11–7.17) whereas the lowest value was observed in the case of BHT addition (6.70). In formulation, the dried extract was well mixed with the egg-white-containing emulsion before combined with the hydrated soy protein. There may exist the interaction between components in the extract (*e.g.* phenolic compounds) with those of egg white (*40*), that might destabilize its natural buffering system and cause a pH shift to a slightly higher value (*41*). Over storage, pH slightly

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increased in all samples. This increase may be due to the volatile bases from possible decomposition of nitrogenous compounds (*42*). However, the pH changes in this study were small, less than 0.2 over 10 days of storage. The pH increase over storage in protein-rich food was also observed in previous studies (*43*).

Lipid and protein oxidation in stored soy burgers

Table 4 presents the changes in peroxide values (PV), an indicator for primary lipid oxidation, in soy-based burger samples with or without antioxidants over storage. The PV had an increasing trend when the storage time increased from day 1 to day 10. The negative control soy burger samples exhibited significantly ($p<0.05$) higher PVs at any period of storage as compared to the samples added with BHT or the dried extract. In addition, the PV values of the treated samples on day 10 (2.68–3.07 mmol/kg) were still lower than that of untreated samples on day 1 (3.34 mmol/kg). The rise in peroxide value (PV) observed during storage was due to the formation of hydroperoxides during the initial stage of lipid oxidation. It was noticed that the sample with 10 mg dried extract exhibited significant lower PV values ($p<0.05$) than the positive control sample added with BHT while the lower extract amounts (2.5–7.5 mg) resulted to equivalent effects to BHT. Therefore, the extract with an adequate dose could be considered to have an effective capacity to slow down fat oxidation. This may be due to the high amount of phenolic compounds such as flavonoids, xanthones, anthocyanins, *etc.*, present in the extract.

The peroxides produced from the first stage of lipid oxidation could be further degraded into secondary products, which were measured by TBARS values. Table 4 also presents the changes in TBARS of soy-based burger over storage. TBARS values were observed to increase ($p<0.05$) over the storage time for all samples, indicating that secondary oxidation products were accumulated more and more. The change pattern in TBARS was quite consistent with that of PV. Negative control samples exhibited significantly ($p<0.05$) higher TBARS values at any storage period as compared to the burger samples treated with BHT and the dried extract. After 10 days of storage, the samples with the extract at the level from 5 mg/100 g exhibited lower TBARS values than the BHT one. In consideration of both primary and secondary lipid oxidation stages (PV and TBARS), the extract with the amount of 5 mg could provide better prevention of lipid oxidation than BHT of 10 mg.

In addition to lipid oxidation, protein oxidation in burger samples over storage was also measured through the content of carbonyls (*44*). Table 4 also illustrates their content changes over storage. After one storage day, the carbonyl contents among samples were not remarkably different with the variation of less than 0.09 nmol/mg protein. During the storage, the samples without addition and with BHT exhibited quicker increases in carbonyl content than all samples added with the extract.

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At day 10, the values of the negative and positive control samples were 0.81 and 0.72 nmol/mg protein, respectively, significantly higher ($p<0.05$) than those of the samples treated with the extract (0.53–0.58 nmol/mg protein). The elevation in carbonyl content observed in all samples during storage might be attributed to both physical and chemical interactions between proteins and various reactive species such as free radicals (*e.g.* ROS) and non-radical entities (*e.g.* H_2O_2 and ROOH) generated during lipid oxidation (*45*). In addition, the better efficiency of the extract in retarding protein oxidation could be resulted from the abundant presence of phenolic compounds, which were able to either bind with proteins, form complexes with them, or inhibit lipid oxidation (*46*). These phenolic compounds may include α-mangostin, β-mangostin, γ-mangostin, chlorogenic acid, vanillic acid, protocatechuic acid, ferulic acid, etc., which were previously identified for mangosteen peel extracts (*47*).

Texture profile of soy burgers

Among texture profile attributes, hardness evaluates the force required to induce deformation, chewiness assesses the force necessary to masticate solid food to a swallowable consistency, cohesiveness gauges the internal resilience of the food's structure, and springiness quantifies the elasticity (*32*). Table 5 lists the texture profiles of soy-based burgers in comparison between day 1 and day 10. At day 1, all samples had no significant different hardness ($p>0.05$), which was in the range of 9.2–11.5 N. However, the addition of BHT or the extract seemed to increase the springiness, chewiness and cohesiveness of soy burgers, except the 10 mg addition. These increases could be attributed to the interaction between BHT or phenolic compounds in the extract and protein molecules, rendering a stronger fibrous network (*48*). However, an excess amount of polyphenols could render the network become excessively rigid, leading to the decreases in these attributes, as reported by Ma and Ryu (*32*). Comparing day 1 and day 10 among formulations, the hardness of the negative control sample increased while those of other samples with addition slightly decreased or remained unchanged. The increase in hardness of the negative control over storage may be associated with the oxidative damage of proteins, which formed protein carbonyls and crosslinking among proteins (*49*). Meanwhile, the springiness, chewiness and cohesiveness of all samples kept unchanged or increased over storage, except the 10 mg addition. This again confirmed that the excessive addition of the extract may remarkably alter the structural network of burger and its rearrangement behavior over storage.

Sensory evaluation

Sensory preference of consumers towards soy-based burgers was evaluated through their scores for sensory attributes including appearance, color, odor, texture, taste and overall

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acceptability. The results in Table 6 exhibits that no statistical differences were observed for five out of six sensory attributes, except texture, where the average score for each attribute varied between 6 and 7. This indicates that the addition of BHT or the extract would not significantly change the sensory quality of the burgers. Regarding texture, the addition of the dried extract seemed to increase the consumer's score of its resultant burgers as compared with the negative and positive BHT control samples, especially with the burger with 10 mg dried extract, where its score was significantly better ($p<0.05$). The higher preference would be because of the water-holding capacity of both textured soy proteins and phenolics in the extract, which improved springiness, chewiness and cohesiveness as discussed from Table 5. In conclusion, all the burgers with or without preservative addition had the overall acceptability of approximately 7 over maximum 9 points, implying their high chance to be accepted by consumers.

CONCLUSIONS

The findings of this study consistently confirm that the dried mangosteen peel extract, which was high in phenolic compounds, was a feasible and efficient natural antioxidant. The incorporation of different extract levels of 2.5–10 mg/100 g was evaluated as a safe replacement of artificial antioxidants in soy-based burger formulations to efficiently prevent protein and lipid deterioration during ten days of chilled storage. Particularly, the highest level of the extract in soy burgers (*i.e.* 10 mg/100 g) was found to reduce the formation of oxidation products more efficiently than the use of BHT. The control soy-based burger had a high pH close to neutral (6.95) while the addition of the extract caused slight pH increases to 7.11–7.17. In terms of sensory preference, the presence of the extract could improve the score for texture while still kept the overall acceptability for the burgers. Consequently, the positive results of this natural antioxidant, in comparison with those of BHT, reveal its potential application in food industry.

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CONFLICT OF INTEREST

There are no conflicts of interest related to the publication of this article.

AUTHORS' CONTRIBUTION

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In this study, T.Q.B. Nguyen, N.H.K. Nguyen and N.B. Ma performed all the experiments and formal analyses, and wrote the original draft where the first author has the highest contribution. L.T.K. Vu and N.L. Le were in charge of the conceptualization, methodology development, supervision, reviewing and editing of the manuscript. N.L. Le also was in charge of funding and project management.

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Table 1. Antioxidant property of the mangosteen peel extract

Antioxidant property	Quantity
TFC as *w*(RE)/(mg/g)	176.1±80.5
TPC as *w*(GAE)/(mg/g)	311.3±10.5
Antioxidant activity (IC_{50})/(mg/mL)	31.7±2.0
Antioxidant activity of BHT (IC_{50})/(mg/mL)	41.7±2.2

TFC=total flavonoid content, RE=rutin equivalent, TPC=total phenolic content, GAE=gallic acid equivalent, BHT= butylated hydroxytoluene

Table 2. Proximate composition and cooking loss of soy burgers

Parameter	C-	C+	10 mg	7.5 mg	5 mg	2.5 mg
Protein/% db	$(38.2±0.5)^{a}$	$(37.3±0.6)^{a}$	$(37.5±0.1)^{a}$	$(37.4±0.2)^{a}$	$(38.2±0.1)^{a}$	$(38.1±0.5)^{a}$
Fat/% db	$(12.1±0.2)^{a}$	$(12.1±0.1)^{a}$	$(11.7±0.2)^{ab}$	$(11.5±0.3)^{b}$	$(11.7±0.2)^{ab}$	$(11.4±0.2)^{b}$
Ash/% db	$(5.2±0.11)^{a}$	$(5.0±0.2)^{a}$	$(5.1±0.1)^{a}$	$(5.0±0.1)^{a}$	$(5.2±0.1)^{a}$	$(5.1±0.1)^{a}$
Carbohydrate/% db	$(44.5±0.7)^{a}$	$(45.6±0.7)^{a}$	$(45.8±0.3)^{a}$	$(46.0±0.5)^{a}$	$(45.0±0.1)^{a}$	$(45.5±0.4)^{a}$
Moisture/% wb	$(62.7±0.2)^{ab}$	$(62.0±0.5)^{bc}$	$(61.9±0.4)^{c}$	$(62.0±0.1)^{bc}$	$(62.8±0.1)^{a}$	$(62.7±0.1)^{ab}$
Cooking loss/%	$(6.7±0.11)^{a}$	$(6.7±0.1)^{a}$	$(5.7±0.1)^{d}$	$(6.2±0.1)^{c}$	$(6.4±0.1)^{b}$	$(6.4±0.1)^{b}$

C-=no antioxidant; C+=10 mg butylated hydroxytoluene, 2.5 mg=2.5 mg dried extract, 5 mg=5 mg dried extract, 7.5 mg=7.5 mg dried extract, 10 mg=10 mg dried extract, db=dry basis, wb=wet basis.
Values in the same row with different letters present significant differences ($p<0.05$)

Table 3. Physicochemical parameters (mass loss and pH) of stored soy burgers

Parameter	Day	C^-	C^+	10 mg	7.5 mg	5 mg	2.5 mg
Mass loss/%	1	$(0.13±0.02)^{aC}$	$(0.14±0.00)^{aC}$	$(0.19±0.04)^{aC}$	$(0.19±0.07)^{aC}$	$(0.21±0.09)^{aC}$	$(0.18±0.03)^{aC}$
	5	$(0.35±0.03)^{bB}$	$(0.51±0.02)^{aB}$	$(0.50±0.06)^{aB}$	$(0.44±0.01)^{aB}$	$(0.47±0.02)^{aB}$	$(0.48±0.03)^{aB}$
	10	$(1.43±0.04)^{aA}$	$(1.40±0.00)^{abA}$	$(1.32±0.05)^{cA}$	$(1.36±0.01)^{abcA}$	$(1.40±0.02)^{abA}$	$(1.33±0.03)^{bcA}$
pH	1	$(6.95±0.07)^{bB}$	$(6.70±0.02)^{cB}$	$(7.17±0.03)^{aB}$	$(7.16±0.01)^{aB}$	$(7.13±0.01)^{aB}$	$(7.11±0.01)^{aB}$
	5	$(7.08±0.04)^{bAB}$	$(6.76±0.02)^{cB}$	$(7.20±0.01)^{aAB}$	$(7.19±0.01)^{aAB}$	$(7.18±0.02)^{aAB}$	$(7.08±0.02)^{bB}$
	10	$(7.14±0.02)^{bA}$	$(6.90±0.03)^{cA}$	$(7.25±0.02)^{aA}$	$(7.22±0.02)^{aA}$	$(7.23±0.01)^{aA}$	$(7.20±0.01)^{abA}$

C-=no antioxidant; C+=10 mg butylated hydroxytoluene, 2.5 mg=2.5 mg dried extract, 5 mg=5 mg dried extract, 7.5 mg=7.5 mg dried extract, 10 mg=10 mg dried extract. $^{a–c}$ Mean values in the same row with different small letters present significant differences ($p<0.05$). $^{A–C}$ Mean values in the same column with different capital letters present significant differences ($p<0.05$)

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Table 4. Peroxide value (PV), thiobarbituric acid reactive substances (TBARS) and carbonyl content of soy-based burgers over storage

Parameter	Day	C-	C+	10 mg	7.5 mg	5 mg	2.5 mg
PV	1	$(3.34\pm0.17)^{aB}$	$(2.13\pm0.21)^{bB}$	$(1.79\pm0.28)^{bB}$	$(2.11\pm0.32)^{bB}$	$(2.40\pm0.32)^{bA}$	$(2.58\pm0.52)^{abA}$
/(mmol/kg)	5	$(3.78\pm0.31)^{aAB}$	$(2.82\pm0.07)^{bA}$	$(2.14\pm0.07)^{dAB}$	$(2.44\pm0.04)^{cdAB}$	$(2.71\pm0.11)^{bcA}$	$(2.86\pm0.18)^{bA}$
	10	$(4.28\pm0.20)^{aA}$	$(3.04\pm0.10)^{bA}$	$(2.68\pm0.07)^{cA}$	$(2.85\pm0.18)^{bcA}$	$(2.99\pm0.14)^{bcA}$	$(3.07\pm0.07)^{bA}$
TBARS	1	$(0.42\pm0.02)^{aC}$	$(0.32\pm0.00)^{cdC}$	$(0.29\pm0.02)^{dC}$	$(0.33\pm0.01)^{bcC}$	$(0.35\pm0.00)^{bcC}$	$(0.35\pm0.00)^{bC}$
/(nmol	5	$(0.75\pm0.04)^{aB}$	$(0.58\pm0.01)^{bB}$	$(0.44\pm0.01)^{eB}$	$(0.46\pm0.01)^{deB}$	$(0.51\pm0.03)^{cdB}$	$(0.54\pm0.01)^{bcB}$
MDA/g)	10	$(1.64\pm0.01)^{aA}$	$(1.27\pm0.01)^{bA}$	$(1.17\pm0.02)^{dA}$	$(1.18\pm0.00)^{dA}$	$(1.23\pm0.00)^{cA}$	$(1.26\pm0.01)^{bcA}$
Carbonyl	1	$(0.38\pm0.04)^{aC}$	$(0.37\pm0.01)^{abC}$	$(0.30\pm0.02)^{cC}$	$(0.31\pm0.03)^{bcB}$	$(0.34\pm0.02)^{abcC}$	$(0.37\pm0.01)^{aC}$
/(nmol/mg)	5	$(0.72\pm0.01)^{aB}$	$(0.52\pm0.02)^{bB}$	$(0.44\pm0.01)^{dB}$	$(0.48\pm0.01)^{cA}$	$(0.49\pm0.00)^{bcB}$	$(0.50\pm0.01)^{bcB}$
	10	$(0.81\pm0.01)^{aA}$	$(0.72\pm0.02)^{bA}$	$(0.53\pm0.00)^{cdA}$	$(0.54\pm0.02)^{dA}$	$(0.57\pm0.01)^{cA}$	$(0.58\pm0.02)^{cA}$

C-=no antioxidant; C+=10 mg butylated hydroxytoluene, 2.5 mg=2.5 mg dried extract, 5 mg=5 mg dried extract, 7.5 mg=7.5 mg dried extract, 10 mg=10 mg dried extract. $^{a–c}$ Mean values in the same row with different small letters present significant differences ($p<0.05$). $^{A–C}$ Mean values in the same column with different capital letters present significant differences ($p<0.05$)

Table 5. Texture profile of soy-based burgers

Parameter	Day	C^-	C^+	10 mg	7.5 mg	5 mg	2.5 mg
Hardness /N	1	$(11.5\pm1.0)^{aB}$	$(10.6\pm1.5)^{aA}$	$(9.2\pm3.0)^{aA}$	$(10.5\pm1.2)^{aA}$	$(10.8\pm0.7)^{aA}$	$(10.4\pm1.4)^{aA}$
	10	$(14.3\pm0.4)^{aA}$	$(9.1\pm2.2)^{bA}$	$(9.0\pm0.6)^{bA}$	$(9.1\pm0.0)^{bB}$	$(7.7\pm1.0)^{cB}$	$(8.3\pm1.1)^{bcB}$
Springiness /mm	1	$(2.4\pm0.2)^{cB}$	$(2.7\pm0.1)^{abB}$	$(2.6\pm0.1)^{abcB}$	$(2.7\pm0.0)^{abA}$	$(2.8\pm0.1)^{aB}$	$(2.6\pm0.1)^{bcB}$
	10	$(2.8\pm0.1)^{bA}$	$(2.9\pm0.0)^{abA}$	$(3.0\pm0.0)^{aA}$	$(2.8\pm0.0)^{bA}$	$(2.9\pm0.1)^{abA}$	$(2.8\pm0.1)^{bA}$
Chewiness /(N·mm)	1	$(18.7\pm4.1)^{aB}$	$(22.7\pm4.4)^{abA}$	$(17.2\pm5.8)^{bA}$	$(22.6\pm2.0)^{abA}$	$(24.0\pm1.0)^{aA}$	$(19.7\pm2.5)^{abA}$
	10	$(33.8\pm3.1)^{aA}$	$(23.8\pm4.7)^{abA}$	$(10.6\pm0.2)^{cB}$	$(29.4\pm7.8)^{abA}$	$(20.2\pm1.8)^{bcA}$	$(20.8\pm3.3)^{bcA}$
Cohesiveness /%	1	$(0.68\pm0.10)^{bB}$	$(0.79\pm0.05)^{aB}$	$(0.72\pm0.04)^{abA}$	$(0.79\pm0.02)^{abB}$	$(0.80\pm0.03)^{aB}$	$(0.75\pm0.02)^{abB}$
	10	$(0.84\pm0.03)^{bA}$	$(0.90\pm0.03)^{abA}$	$(0.40\pm0.03)^{cB}$	$(0.85\pm0.00)^{abA}$	$(0.90\pm0.01)^{aA}$	$(0.89\pm0.01)^{aA}$

C-=no antioxidant; C+=10 mg butylated hydroxytoluene, 2.5 mg=2.5 mg dried extract, 5 mg=5 mg dried extract, 7.5 mg=7.5 mg dried extract, 10 mg=10 mg dried extract. $^{a–c}$ Mean values in the same row with different small letters present significant differences ($p<0.05$). $^{A–C}$ Mean values in the same column with different capital letters present significant differences ($p<0.05$)

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Table 6. Sensory evaluation in terms of appearance, color, odor, taste, texture, and overall acceptability of soy-based burgers in the 9-point scale

Attribute	C-	C+	10 mg	7.5 mg	5 mg	2.5 mg
Appearance	$(6.7\pm1.3)^{a}$	$(6.5\pm1.6)^{a}$	$(6.3\pm1.8)^{a}$	$(6.30\pm1.7)^{a}$	$(6.1\pm1.5)^{a}$	$(6.2\pm1.7)^{a}$
Color	$(6.7\pm1.1)^{a}$	$(6.6\pm1.0)^{a}$	$(6.0\pm1.5)^{a}$	$(6.3\pm1.6)^{a}$	$(6.0\pm1.6)^{a}$	$(6.6\pm1.5)^{a}$
Odor	$(6.8\pm1.5)^{a}$	$(6.4\pm1.8)^{a}$	$(6.5\pm1.5)^{a}$	$(6.6\pm2.0)^{a}$	$(6.6\pm2.0)^{a}$	$(6.6\pm1.7)^{a}$
Texture	$(6.3\pm1.6)^{c}$	$(6.5\pm1.5)^{bc}$	$(7.5\pm1.0)^{a}$	$(7.4\pm1.0)^{ab}$	$(6.7\pm1.7)^{ab}$	$(6.7\pm1.5)^{ab}$
Taste	$(6.9\pm1.5)^{a}$	$(6.7\pm1.7)^{a}$	$(6.6\pm1.8)^{a}$	$(6.9\pm1.6)^{a}$	$(6.9\pm1.6)^{a}$	$(6.8\pm1.5)^{a}$
Overall acceptability	$(7.2\pm1.1)^{a}$	$(6.9\pm1.4)^{a}$	$(7.1\pm1.1)^{a}$	$(7.2\pm1.5)^{a}$	$(6.7\pm1.6)^{a}$	$(7.0\pm1.4)^{a}$

C-=no antioxidant; C+=10 mg butylated hydroxytoluene, 2.5 mg=2.5 mg dried extract, 5 mg=5 mg dried extract, 7.5 mg=7.5 mg dried extract, 10 mg=10 mg dried extract. Values in the same row with different letters present significant differences ($p<0.05$)