

Effect of lotus seed paste as a fat replacer on the quality attributes of pork patties

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Citation: Huang S., Chen F., Tang M., Zhao S., Chen D. (2025): Effect of lotus seed paste as a fat replacer on the quality attributes of pork patties. Czech J. Food Sci., 43: 311–319.

Abstract: The potential of lotus seed paste (LSP) as a fat substitute in pork patties was investigated. Pork patties were prepared by substituting varying levels of fat (0, 20, 40, and 60%) with LSP. LSP addition increased moisture while reducing fat content. Compared to control, LSP-added pork patties had significantly higher thiobarbituric acid reactive substances, L^* values and microbial counts ($P < 0.05$), but lower thawing, centrifugal, and cooking losses, and diameter reduction. Furthermore, LSP incorporation enhanced hardness, springiness, chewiness and adhesiveness of the patties. Patties with 60% fat replacement by LSP had the highest b^* value and cohesiveness, and the lowest a^* value. Substituting 40% or more fat significantly improved the colour, taste, texture and overall acceptability of pork patties ($P < 0.05$).

Keywords: meat product; food ingredient; fat substitute; physicochemical properties; storage stability

Pork patties are popular due to their nutrition, taste, and convenience (Fu et al. 2018). They typically contain high levels of animal fat (Park et al. 2016), which significantly contribute to the texture, flavour and juiciness of pork patties (Hygreeva et al. 2014). However, excessive intake of animal fat has been associated with an increased risk of some chronic diseases (Bouvard et al. 2015; Sacks et al. 2017; Fu et al. 2018). This has increased the demand for healthier low-fat meat products. Yet, simply reducing fat worsens texture and flavour, prompting the use of non-meat fat replacers.

Lotus seed, the mature fruit of the perennial aquatic herb *Nelumbo nucifera*, is a nutritionally dense food source rich in starch (> 50% dry weight), protein, and bioactive compounds such as polyphenols and flavonoids (Dhull et al. 2022; Wang et al. 2022). China is the world's leading producer of lotus seeds, with an annual production reaching 20 000 metric tonnes in 2023 (Liu et al. 2024). Recognised for its low glycaemic index (Zhu et al. 2019), lotus seed exhibits various health-promoting properties, including anti-inflammatory, anti-tumour, and anti-amnesia effects (Shahzad et al. 2021), making it a functional food

ingredient (Zhang et al. 2019). Lotus seeds have been processed into a variety of food products, such as lotus seed millet noodles, mooncakes, lotus seed juice, and lotus seed wine. Shahzad et al. (2021) demonstrated that substituting wheat flour with lotus seed flour enhanced the antioxidant activity, colour stability, and consumer acceptability of cookies. Additionally, lotus seed peel powder, a by-product of processing, has been employed as a nitrite alternative in meat preservation (Deng et al. 2024b), and as a substitute for fat and a potential antioxidant in food products (Deng et al. 2023). Lotus seed starch significantly influences the properties and quality of lotus seeds and related food products. This starch exhibits favourable characteristics such as thermal stability, high swelling power, and freeze-thaw stability (Dhull et al. 2022), suggesting its potential as a fat replacer. However, limitations such as poor water solubility, rapid retrogradation, and weak gel strength hinder its broader application (Dhull et al. 2022). Processing lotus seeds in combination with other ingredients can, to a certain extent, enhance their properties. For example, Deng et al. (2024a) reported that incorporating cellulose nanocrystals into lotus

seed starch-based films improved their mechanical and barrier properties.

Lotus seed paste (LSP) is produced by processing dried lotus seeds (peeling, coring, soaking, steaming) followed by grinding and stir-frying with sugar and oil (Cheng 2013; Dong et al. 2020). This process facilitates the integration of sugar and oil into gelatinised starch, thereby inhibiting retrogradation. The resulting paste exhibits a soft, cohesive texture and smooth mouthfeel (Cheng 2013), along with excellent plasticity, making it an ideal ingredient for fillings in food products like mooncakes and dumplings (Dong et al. 2020). Consequently, processing lotus seeds into paste form could improve their taste and applicability. LSP mimics fat's texture and mouthfeel while providing similar creaminess, suggesting its fat-substitution potential. However, no prior research has explored its application in meat products, particularly pork patties. This study therefore investigated the effects of LSP as a fat replacer on the physicochemical, textural, and sensory properties of pork patties, including their storage stability (16 days at 4 ± 1 °C). This study pioneers the application of LSP in meat matrices, offering a plant-based, nutrient-rich alternative to conventional fat replacers, with potential implications for healthier meat product innovation.

MATERIAL AND METHODS

Material. Dried lotus (*Nelumbo nucifera*) seeds, pork backfat, pork loin (*musculus longissimus dorsi*) and other ingredients (salt, spices, sugar, monosodium glutamate, soy sauce, cooking wine and oyster sauce) were procured from Better Life Commercial Chain Share Co., Ltd. (Xiangtan, China). Other chemicals and reagents were commercially available analytical grade.

Preparation of lotus seed paste. LSP was prepared following the method outlined by Cheng (2013). Initially, dried lotus seeds were soaked in deionised water for 12 h. The soaked seeds were then combined with 5 times their mass of water and cooked in a 500 W electric rice cooker (CFXB30-B, Lianjiang Electrical Appliance Factory, Lianjiang, China) for 50 min. It is reported that the internal temperature of the cooker can reach ~ 100 °C during boiling (Huang et al. 2013). Subsequently, the cooked seeds were ground in a blender (SD-JR02, Sande Electrical Appliance Manufacturing Co., Ltd., Foshan, China) at maximum speed for 1 min to obtain a puree. This puree was then transferred to a wok and continuously stirred for 10 min under heating. Upon addition of 20% peanut oil and 5% sugar, the puree was heated and stirred persistently until it no longer adhered to the

wok, resulting in the formation of LSP. The reasons for choosing peanut oil to prepare LSP are as follows. First, peanut oil imparts a pleasant nutty aroma to the paste. Second, during the stirring process, peanut oil can thoroughly bind with the starch in lotus seeds and the added sucrose, resulting in a smooth, delicate texture without excessive stickiness (Xue et al. 2007). Additionally, peanut oil's moderate viscosity helps maintain the paste's structural integrity, preventing excessive spreading (Cheng 2013). Therefore, LSP is mostly prepared with peanut oil. The final LSP composition was determined as follows: moisture ($47.76 \pm 0.34\%$), protein ($6.39 \pm 0.29\%$), fat ($15.82 \pm 0.22\%$), starch ($16.57 \pm 0.11\%$), and ash ($1.51 \pm 0.00\%$). Colour parameters (CIE L^* , a^* , b^*) were measured as 71.45 ± 0.31 , 4.78 ± 0.07 and 17.40 ± 0.29 , respectively.

Preparation of pork patties. Pork patties were prepared in accordance with the recipe detailed by Li (2021). Three pork patty formulations (T1, T2 and T3) with LSP replacing partial backfat and a control (no LSP) were prepared (Table 1). Lean pork meat and backfat were separately minced using a meat grinder (DJQQLS128-C, Haowen Machinery Co., Ltd., Zhenjiang, China) through a 6 mm plate. The meat and other ingredients except LSP were blended in a mixer

Table 1. Formulation of pork patties with lotus seed paste (LSP) as a fat replacer (g)

Ingredients	Treatments			
	Control	T1	T2	T3
Pork meat	70	70	70	70
Pork backfat	30	24	18	12
Lotus seed paste	0	6	12	18
Total	100	100	100	100
Salt	2.00	2.00	2.00	2.00
Compound phosphate	0.15	0.15	0.15	0.15
Ascorbic acid	0.03	0.03	0.03	0.03
Spices	0.20	0.20	0.20	0.20
Sugar	0.50	0.50	0.50	0.50
Monosodium glutamate	0.50	0.50	0.50	0.50
Seafood soy sauce	0.15	0.15	0.15	0.15
Dark soy sauce	0.15	0.15	0.15	0.15
Cooking wine	0.10	0.10	0.10	0.10
Oyster sauce	0.20	0.20	0.20	0.20
Sodium nitrite	0.01	0.01	0.01	0.01

Control – pork patties without replacement of back fat by LSP; T1, T2 and T3 – pork patties with 20, 40 and 60% back fat replacement by LSP, respectively

<https://doi.org/10.17221/1/2025-CJFS>

(SZM-15, Xuzhong Food Machinery Co., Ltd., Guangzhou, China) for 5 min and refrigerated at 4 °C for 24 h. Subsequently, LSP was added and mixed for 1 min. The resulting blend was shaped using a household hamburger mould into patties with an approximate diameter of 9.5 cm and a thickness of 1.7 cm. These patties were weighed to determine their initial weight. After freezing at –18 °C for 30 min, they were vacuum packed and stored at 4 ± 1 °C for 16 days.

Colour measurements. The colour values (CIE L^* , a^* , and b^*) were determined using a colorimeter (Chroma Meter CR-400, Konica Minolta, Sencing, Inc., Japan) at three random locations on the surface of each sample, and the average values were recorded.

Determination of thiobarbituric acid reactive substances (TBARS). TBARS value was determined according to Lu and Zhang (2010) with minor modifications. Briefly, 5 g patty sample was vortexed with 25 mL 7.5% trichloroacetic acid solution for 30 s and left to stand for 30 min. After filtration (#102 filter paper), 5 mL filtrate along with 5 mL 20 mM thiobarbituric acid aqueous solution was incubated at 90 °C for 40 min, subsequently cooled in an ice bath for 1 h, and then centrifuged at 4 °C (285 × g) for 5 min. The supernatant was vigorously shaken with 5 mL chloroform and allowed to separate into layers. The absorbance of the upper layer solution at 532 nm and 600 nm was measured with a spectrophotometer (Cary 60, Agilent technologies, Malaysia), and denoted as A_{532} and A_{600} respectively. The TBARS value, expressed as mg malondialdehyde (MDA) per kilogram of sample, was calculated as follows:

$$\text{TBARS (mg MDA} \cdot \text{kg}^{-1} \text{ sample)} = (A_{532} - A_{600}) \times M \times 10^3 / (\varepsilon \times l \times c) \quad (1)$$

where: M – the molar mass of MDA, 72.07 g·mol^{–1}; ε – the molar extinction coefficient of MDA, 1.56 × 10⁵ L·mol^{–1}·cm^{–1}; l – the absorption layer thickness in cm; c – the sample concentration in kg·L^{–1}; A_{532} , A_{600} – the absorbance of the upper layer solution at 532 nm and 600 nm, respectively.

Proximate analysis. The proximate composition of samples was determined following Chinese national standards: moisture content (GB5009.3-2010), starch content (GB/T 5009.9-2016), fat content (GB5009.6-2016), protein content (GB5009.5-2016), and ash content (GB5009.4-2016).

Thawing loss and centrifugal loss. Samples were frozen at –20 °C and then thawed at room temperature.

Sample weights were recorded before (w_0) and after (w_1) thawing to calculate thawing loss.

$$\text{Thawing loss (\%)} = (w_0 - w_1) / w_0 \times 100 \quad (2)$$

Each sample was wrapped in filter paper and centrifuged for 20 min at 1760 × g. Weights before (w_2) and after (w_3) centrifugation were recorded to determine centrifugal loss.

$$\text{Centrifugal loss (\%)} = (w_2 - w_3) / w_2 \times 100 \quad (3)$$

Cooking properties. Cooking properties were assessed by measuring weight loss and diameter reduction after baking at 200 °C for 15 min (flipped at 7.5 min) followed by cooling to 25 °C. Raw (w_4) and baked (w_5) patty weights were recorded for cooking loss calculation. Raw (D_0) and baked (D_1) patty diameters were measured to calculate diameter reduction.

$$\text{Cooking loss (\%)} = (w_4 - w_5) / w_4 \times 100 \quad (4)$$

$$\text{Diameter reduction (\%)} = (D_0 - D_1) / D_0 \times 100 \quad (5)$$

Texture profile analysis. Texture profile of sample was analysed using a texture analyser (Universal TA, SHTB1125, Shanghai, China) following Zhao et al. (2022). The pork patties were baked in a 200 °C electric oven (YXD-Z2021, Chengdu Lechuang Automation Technology Co., Ltd., Chengdu, China) for 15 min (flipped at 7.5 min) and cooled to room temperature. Cooked patties were cut into 2 × 2 × 1 cm³ cuboids and compressed to 50% their original height using a P50 probe at a speed of 2.0 mm·s^{–1}. The speed before and after the test was set to 3.0 mm·s^{–1}, with a test interval of 5.0 s. Hardness, springiness, adhesiveness, chewiness, resilience, and cohesiveness were recorded (Argel et al. 2020; Guo 2021).

Microbiological analysis. The total plate count and coliforms count were carried out for raw pork patties during storage according to Chinese national standards GB4789.2-2016 and GB4789.3-2016, respectively. Results were expressed as log CFU (colony forming units)·g^{–1} sample.

Sensory evaluation. Sensory evaluation was performed by 15 trained panellists (6 male, 9 female) from the university's Department of Biological and Food Engineering. The pork patties were baked as described above. The cooked samples (cooled to 40 °C, cut into 2 × 2 × 1.7 cm³ pieces) were randomly coded and evaluated for colour, aroma, taste, texture, and overall accept-

ability using a 5-point hedonic scale (1 = not acceptable, 5 = excellent) (Gao et al. 2014; Bahmanyar et al. 2021).

Statistical analysis. SPSS version 19 (SPSS Inc., IBM Company, USA) software was used to analyse the data. Each formulation was repeated two times, and all samples were tested three times. The mean values, along with their standard errors, were reported for each formulation. Normality was assessed via histograms, Q–Q plots, and Shapiro–Wilk tests. Non-normally distributed sensory data were analysed using the non-parametric Kruskal–Wallis test followed by Dunn's post hoc test, while other data were evaluated by a parametric analysis of variance (ANOVA) with Duncan's multiple range test. Significance was defined at $P < 0.05$.

RESULTS AND DISCUSSION

Proximate composition. Table 2 shows the proximate composition of raw pork patties added with varying quantities of LSP. LSP addition did not affect protein or ash content ($P > 0.05$), but significantly reduced fat content ($P < 0.05$). The fat content decreased from 21.28% to 13.97% as the backfat replacement increased from 0 to 60%. Gao et al. (2014) reported similar results when the fat in pork patties was replaced with various levels of glutinous rice flour. Moisture content increased significantly ($P < 0.05$) at 40% and 60% fat replacement levels, but the differences between T2 and T3 were insignificant ($P > 0.05$). This increase can be ascribed to the high water-holding capacity of LSP.

Thawing loss, centrifugal loss and cooking properties. The parameters of thawing loss and centrifugal loss are crucial indicators of the water retention capacity in meat products. Determinations of thawing loss and centrifugal loss were conducted on the raw pork patties. As shown in Table 3, control pork patties had the highest losses, while LSP addition significantly reduced both parameters ($P < 0.05$), with improvement correlating with higher LSP levels. Compared to the

control sample, the T3 sample demonstrated reductions of 44.4% in thawing loss ($0.10 \pm 0.01\%$) and 31.3% in centrifugal loss ($1.23 \pm 0.02\%$). This confirms LSP enhances water-holding capacity of pork patties when partially replacing fat. T1 showed similar cooking loss to control ($P > 0.05$), but loss decreased significantly as fat replacement rose to 60% ($P < 0.05$). The T3 sample exhibited the lowest cooking loss ($15.34 \pm 1.82\%$), representing a 37.5% decrease compared to the control ($P < 0.05$). During cooking, fat melting and protein denaturation occur, leading to the loss of both constitutive water and melted fat (Vieira et al. 2009). After baking, control samples shrank by 16.11% in diameter. Shrinkage decreased significantly with higher fat replacement ($P < 0.05$), reaching just 8.89% at 60% fat replacement. This occurs because cooking denatures muscle protein, causing water and fat loss that reduces diameter (Carvalho et al. 2019).

Texture analysis. Table 4 shows the texture profile of cooked pork patties with varying LSP levels. LSP addition significantly increased hardness compared to the control ($P < 0.05$), likely due to reduced fat content (Kumar 2021). The smaller fat globules of peanut oil (compared to pork backfat) provided a greater surface area for protein coverage, thereby increasing resistance to compression (Youssef and Barbut 2009). Similar findings were reported by de Oliveira Fagundes et al. (2017) and Cirstea et al. (2023). While T1 exhibited lower hardness than T2 and T3, no significant difference was observed between T2 and T3 ($P > 0.05$). A similar trend was noted for springiness. LSP-added patties had significantly higher springiness ($P < 0.05$), indicating a greater degree of recovery in sample height (Ozturk-Kerimoglu et al. 2022). This improvement may stem from LSP's gel network formation and water retention capacity (Rather et al. 2016).

Replacing 40–60% fat with LSP significantly increased pork patty chewiness ($P < 0.05$), while 20% replacement showed no effect ($P > 0.05$). T3 exhibited the highest

Table 2. Proximate composition of raw pork patties added with different amounts of LSP

Treatment	Protein (%)	Fat (%)	Moisture (%)	Ash (%)
Control	13.86 ± 0.24^a	21.28 ± 1.50^a	55.67 ± 2.59^b	2.92 ± 0.13^a
T1	14.07 ± 0.30^a	19.08 ± 1.47^b	55.98 ± 0.82^b	2.99 ± 0.05^a
T2	14.15 ± 0.26^a	16.85 ± 0.37^c	60.09 ± 0.68^a	2.97 ± 0.08^a
T3	14.24 ± 0.25^a	13.97 ± 0.55^d	60.25 ± 0.65^a	2.93 ± 0.08^a

^{a–d}different letters denote significant differences within the same column ($P < 0.05$); control – pork patties without replacement of back fat by LSP; T1, T2 and T3 – pork patties with 20, 40 and 60% back fat replacement by LSP, respectively; LSP – lotus seed paste

<https://doi.org/10.17221/1/2025-CJFS>

Table 3. Thawing loss, centrifugal loss and cooking properties of pork patties added with different levels of LSP

Treatment	Diameter reduction (%)	Thawing loss (%)	Centrifugal loss (%)	Cooking loss (%)
Control	16.11 ± 0.64 ^a	0.18 ± 0.01 ^a	1.79 ± 0.06 ^a	24.55 ± 0.57 ^a
T1	14.44 ± 0.91 ^b	0.13 ± 0.01 ^b	1.52 ± 0.10 ^b	24.29 ± 0.32 ^a
T2	10.56 ± 0.64 ^c	0.12 ± 0.01 ^c	1.41 ± 0.01 ^c	18.69 ± 1.07 ^b
T3	8.89 ± 0.91 ^d	0.10 ± 0.01 ^d	1.23 ± 0.02 ^d	15.34 ± 1.82 ^c

^{a–d}different letters denote significant differences within the same column ($P < 0.05$); control – pork patties without replacement of back fat by LSP; T1, T2 and T3 – pork patties with 20%, 40% and 60% back fat replacement by LSP, respectively; LSP – lotus seed paste

Table 4. Texture profile of cooked pork patties added with different amounts of LSP

Treatment	Hardness (gf)	Springiness	Adhesiveness (gf)	Chewiness (gf)	Resilience	Cohesiveness
Control	3 975.00 ± 358.30 ^c	0.62 ± 0.05 ^c	1 990.03 ± 350.95 ^c	1 230.24 ± 246.12 ^c	0.25 ± 0.02 ^b	0.48 ± 0.04 ^b
T1	4 769.20 ± 798.99 ^b	0.71 ± 0.01 ^b	2 301.42 ± 493.46 ^c	1 638.38 ± 360.66 ^c	0.26 ± 0.01 ^b	0.49 ± 0.03 ^b
T2	6 020.00 ± 361.81 ^a	0.83 ± 0.06 ^a	3 089.19 ± 462.70 ^b	2 554.15 ± 304.12 ^b	0.40 ± 0.13 ^a	0.51 ± 0.06 ^{ab}
T3	6 694.00 ± 670.64 ^a	0.80 ± 0.01 ^a	3 730.00 ± 584.51 ^a	2 991.93 ± 447.16 ^a	0.29 ± 0.03 ^b	0.56 ± 0.03 ^a

^{a–c}different letters denote significant differences within the same column ($P < 0.05$); control – pork patties without replacement of back fat by LSP; T1, T2 and T3 – pork patties with 20, 40 and 60% back fat replacement by LSP, respectively; LSP – lotus seed paste

chewiness ($P < 0.05$), likely due to its greater hardness. As Selani et al. (2016) reported, higher hardness and cohesiveness typically require greater mastication effort.

Replacing 20% fat with LSP showed no significant effect on adhesiveness ($P > 0.05$), but increased significantly at higher replacement levels ($P < 0.05$). LSP incorporation softened the structure, increasing adhesiveness and producing denser patties with greater hardness and chewiness. T3 showed the highest cohesiveness, likely due to its dense structure (Ozturk-Kerimoglu et al. 2022) and lower fat-protein ratio, which may promote denser protein network formation (Youssef et al. 2011). Other samples showed similar cohesiveness. For resilience, only T2 differed significantly ($P < 0.05$), with others showing comparable values.

Sensory evaluation. Figure 1 shows the sensory traits of cooked pork patties with varying levels of LSP. Replacing 20% fat with LSP did not significantly alter sensory properties of pork patties ($P > 0.05$). T2 and T3 scored similarly in colour and texture ($P > 0.05$), both surpassing T1. LSP addition didn't notably affect the aroma ($P > 0.05$), likely due to the faint smell of LSP being masked by meat's aroma. Increasing fat substitution (20–60%) did not significantly impact overall acceptability ($P > 0.05$). T2's taste score matched T3 but exceeded T1. Results indicate that incorporating LSP enhances consumer preference without compromising sensory quality. No significant difference ($P > 0.05$) in sensory

traits existed between T2 and T3, suggesting that more fat substitutes do not ensure better sensory scores.

Thiobarbituric acid reactive substances (TBARS) value. Figure 2 shows the TBARS values of raw pork patties with varying levels of LSP during 16-day refrigerated storage. LSP-added pork patties showed significantly higher TBARS than control ($P < 0.05$), indicating reduced oxidative stability. Similar results were reported by Poyato et al. (2015) who substituted pork backfat in burger patties with a polyunsaturated gelled emulsion. The peanut oil incorporated in LSP contains a high content of unsaturated fatty acid. This may make the reformulated pork patties more susceptible to oxidation during storage (Cirstea et al. 2023). The higher the amount of LSP added, the higher the TBARS value of the pork patties. At the end of storage, the TBARS values of T1, T2 and T3 samples (0.65 ± 0.02 , 0.75 ± 0.04 , and $0.87 \pm 0.02\%$) were 15.22, 39.13 and 63.04% higher than that of the control ($0.58 \pm 0.03\%$). These results indicated that samples with higher degree of fat substitution had lower oxidative stability, which could be due to the higher lipid oxidation of LSP. Trindade et al. (2009) reported that a TBARS value of 2 mg MDA·kg⁻¹ meat patties was the threshold at which a loss in sensory quality and consumer perception of oxidation becomes evident. Despite increasing with LSP content and storage time, TBARS values remained below this limit, indicating acceptable lipid oxidation levels in all patties.

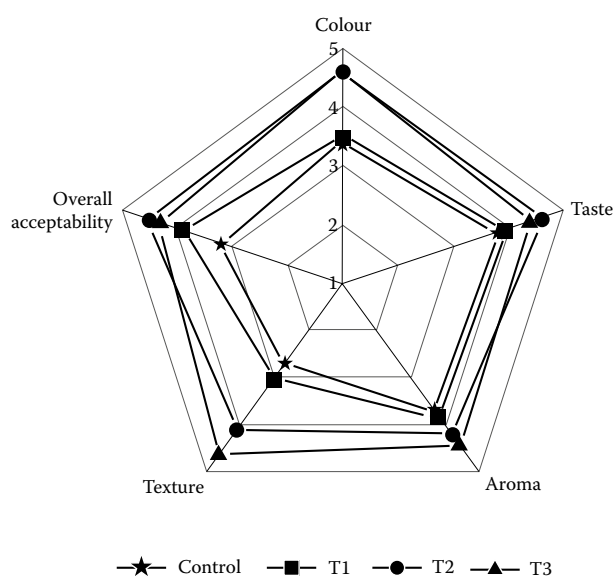


Figure 1. Sensory properties of cooked pork patties with different levels of lotus seed paste

Instrumental colour. Table 5 displays the colour change of raw pork patties with varying levels of LSP and storage time. Incorporation of LSP generally increased the L^* and b^* values, while decreasing the a^* values of pork patties. Notably, T3 exhibited the highest lightness and lowest redness, likely due to LSP's white colour. Kurt and Genççelep (2018) suggested that lightness may vary with the

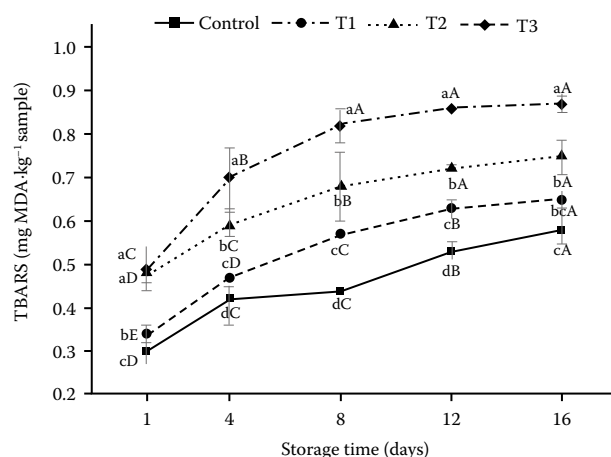


Figure 2. TBARS values of raw pork patties with different levels of lotus seed paste over a 16-day storage period at 4 °C

^{a-d} different letters denote a significant difference between treatments, while ^{A-D} signify a significant difference between storage time (days) ($P < 0.05$); TBARS – thiobarbituric acid reactive substances; MDA – malondialdehyde

colour properties of added material. Similarly, Ali et al. (2011) observed that fat-reduced patties had a higher brightness than high-fat raw patties when hydrated potato flakes were used as a fat substitute for pork patties. Incorporation of LSP reduced the redness of pork patties, likely due to the dilution effect caused by LSP's white colour.

Table 5. Effect of adding LSP as a fat substitute on colour parameters of raw pork patties

Colour parameters	Treatment	Storage time (days)				
		1	4	8	12	16
L^*	Control	61.24 ± 0.80 ^{cA}	61.17 ± 0.60 ^{cA}	59.11 ± 1.71 ^{cB}	61.00 ± 1.91 ^{bAB}	60.76 ± 0.39 ^{bAB}
	T1	63.96 ± 0.76 ^{bAB}	63.87 ± 0.71 ^{bAB}	63.42 ± 0.67 ^{bAB}	62.13 ± 1.76 ^{bB}	64.28 ± 1.48 ^{aA}
	T2	64.48 ± 0.96 ^{bAB}	63.21 ± 0.47 ^{bcB}	65.25 ± 0.69 ^{aA}	63.16 ± 0.73 ^{bB}	65.24 ± 1.42 ^{aA}
	T3	66.28 ± 1.03 ^{aA}	66.00 ± 2.46 ^{aA}	65.33 ± 0.83 ^{aA}	65.54 ± 0.63 ^{aA}	65.47 ± 0.68 ^{aA}
a^*	Control	4.46 ± 0.36 ^{aC}	5.65 ± 0.05 ^{aB}	5.83 ± 0.33 ^{aB}	6.51 ± 0.27 ^{aA}	6.74 ± 0.78 ^{aA}
	T1	3.93 ± 0.38 ^{bC}	5.48 ± 0.06 ^{bB}	5.93 ± 0.23 ^{aAB}	6.15 ± 0.58 ^{abA}	6.27 ± 0.19 ^{aA}
	T2	3.76 ± 0.21 ^{bD}	5.38 ± 0.06 ^{cC}	5.62 ± 0.26 ^{aBC}	5.80 ± 0.15 ^{bcB}	6.48 ± 0.47 ^{aA}
	T3	3.58 ± 0.27 ^{bB}	5.17 ± 0.05 ^{dA}	5.57 ± 0.24 ^{aA}	5.28 ± 0.58 ^{cA}	5.18 ± 0.63 ^{bA}
b^*	Control	11.63 ± 1.08 ^{bB}	12.98 ± 1.10 ^{aAB}	12.64 ± 0.92 ^{bAB}	13.33 ± 1.21 ^{bA}	12.47 ± 0.50 ^{bAB}
	T1	13.75 ± 0.89 ^{aA}	13.81 ± 1.09 ^{aA}	13.67 ± 0.19 ^{bA}	14.34 ± 0.97 ^{abA}	13.38 ± 0.80 ^{abA}
	T2	14.85 ± 0.31 ^{aAB}	14.26 ± 0.94 ^{aAB}	15.30 ± 0.95 ^{aA}	14.71 ± 1.15 ^{abAB}	13.66 ± 0.47 ^{abAB}
	T3	15.06 ± 0.92 ^{aA}	14.63 ± 1.38 ^{aA}	15.53 ± 0.77 ^{aA}	15.72 ± 0.27 ^{aA}	14.71 ± 1.37 ^{aA}

^{a-d}, ^{A-D} different letters denote significant differences within the same column and line, respectively ($P < 0.05$); control – pork patties without replacement of back fat by LSP; T1, T2 and T3 – pork patties with 20%, 40% and 60% back fat replacement by LSP, respectively; LSP – lotus seed paste

<https://doi.org/10.17221/1/2025-CJFS>

Table 6. Microbial counts (log CFU·g⁻¹) of raw pork patties with different levels of LSP

Microbial counts	Treatment	Storage time (days)				
		1	4	8	12	16
Total plate count	Control	3.09 ± 0.07 ^{bE}	3.36 ± 0.06 ^{bD}	4.98 ± 0.04 ^{bC}	5.82 ± 0.01 ^{bB}	6.83 ± 0.01 ^{bA}
	T1	3.31 ± 0.04 ^{aE}	3.74 ± 0.02 ^{aD}	5.16 ± 0.03 ^{aC}	6.13 ± 0.00 ^{aB}	6.84 ± 0.01 ^{bA}
	T2	3.42 ± 0.06 ^{aE}	3.75 ± 0.00 ^{aD}	5.19 ± 0.02 ^{aC}	6.14 ± 0.01 ^{aB}	6.86 ± 0.01 ^{aA}
	T3	3.45 ± 0.05 ^{aE}	3.77 ± 0.01 ^{aD}	5.22 ± 0.02 ^{aC}	6.14 ± 0.01 ^{aB}	6.87 ± 0.01 ^{aA}
Coliform count	Control	0.78 ± 0.11 ^{aD}	1.11 ± 0.06 ^{bC}	1.65 ± 0.06 ^{bB}	1.95 ± 0.00 ^{cA}	2.02 ± 0.03 ^{bA}
	T1	0.87 ± 0.12 ^{aD}	1.23 ± 0.00 ^{aC}	1.82 ± 0.05 ^{aB}	2.08 ± 0.05 ^{bA}	2.04 ± 0.00 ^{abA}
	T2	0.95 ± 0.07 ^{aD}	1.29 ± 0.01 ^{aC}	1.88 ± 0.04 ^{aB}	2.10 ± 0.02 ^{abA}	2.06 ± 0.03 ^{abA}
	T3	0.98 ± 0.04 ^{aD}	1.32 ± 0.03 ^{aC}	1.93 ± 0.04 ^{aB}	2.17 ± 0.02 ^{aA}	2.10 ± 0.02 ^{aA}

a–c, A–E different letters denote significant differences within the same column and line, respectively ($P < 0.05$); control – pork patties without replacement of back fat by LSP; T1, T2 and T3 – pork patties with 20%, 40% and 60% back fat replacement by LSP, respectively; CFU – colony forming units; LSP – lotus seed paste

LSP-added samples showed no significant change in b^* values during the whole storage ($P > 0.05$). T3's b^* value was significantly higher than that of control ($P < 0.05$). The difference in b^* values during storage of pork patties with different LSP levels were not significant ($P > 0.05$). These results showed that myoglobin largely remained stable. Cha et al. (2014) reported similar results in a study involving pork burger added with mushroom (*Tremella fuciformis*).

Microbial analysis. Table 6 shows microbial counts in raw pork patties over 16-day storage. Initial total plate counts for all samples were below 3.5 log CFU·g⁻¹. Then the counts presented continuous increase during the storage period. This result is in line with the studies by Bahmanyar et al. (2021). LSP-added pork patties had higher counts than control ($P < 0.05$), but no differences existed among LSP groups ($P > 0.05$). These results indicate that LSP incorporation in pork patties may elevate microbial contamination risk.

Coliform counts in all samples increased gradually during 12 days of storage, then stabilised. No significant differences were observed between control and LSP-added samples on day 1 ($P > 0.05$), but LSP-added patties later showed elevated counts. These findings align with the study by Salcedo-Sandoval et al. (2015).

According to Chinese standards (NY/T 632-2002), the maximum permissible limits for coliforms and total plate count in chilled pork are 2 and 6 log CFU·g⁻¹, respectively. Control samples exceeded these thresholds by day 16, whereas LSP-added samples surpassed them by day 12. These findings imply that addition of LSP as a fat substitute in pork patties may potentially reduce the shelf life of the product.

CONCLUSION

The present study evaluated the potential of LSP as a fat replacer in pork patties. The application of LSP as a replacer for fat in pork patties proved to be a viable approach from technological, nutritional, and sensory perspectives. The pork patties added with LSP exhibited enhanced water-holding capacity and reduced fat content, resulting in improved texture and sensory attributes. However, the incorporation of LSP into pork patties compromised colour, oxidative and microbial stability, thereby diminishing their shelf life. Consequently, further studies are needed on the storage stability of pork patties with added LSP.

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Received: January 2, 2025

Accepted: July 3, 2025

Published online: October 22, 2025