

Assessment on Physicochemical and Sensory Qualities of Plant-Based Burgers Containing Cauliflower Stalk Powder as Binding Agent

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ABSTRACT

Plant-based burgers are becoming popular due to their environmental and health benefits, yet achieving the right texture and sensory attributes remains a challenge. This study investigates the potential of cauliflower stalk powder (CSP) as a natural binder and partial substitute for textured vegetable protein (TVP) in plant-based burgers by analyzing their physical and sensory properties. The CSP powder was prepared using microwave drying technology at 420 W for 28 min. The plant-based burgers were mainly formulated with oyster mushroom and TVP with progressive substitution of TVP by CSP powders at levels of 0 – 10% w/w as binding agent. The analysis revealed that springiness of the cooked plant based burgers increased by almost 10% with increasing level of CSP while firmness of the burgers reduced by 2% at increasing level of CSP substitution. Meanwhile, significantly lower cooking loss between 8.3 – 9.5% were observed for burgers with 7.5 and 10% w/w CSP compared to formulation with only 2.5% w/w CSP which recorded 15% cooking loss. Sensory evaluation revealed that burgers with CSP were perceived to have better texture, appearance and overall acceptance than burgers without CSP. Intermediate CSP inclusion (2.5 – 7.5% w/w) showed the most balanced performance, enhancing texture, moisture retention and sensory acceptance accordingly. These findings showed the potential of CSP in improving the textural and sensory quality of plant based burger, highlighting the suitability of cauliflower by product as a sustainable and effective binding agent for plant-based burger.

Keywords: binding agent, cauliflower stalk powder, physical properties, plant-based burger, sensory properties

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INTRODUCTION

Food security has become an essential concern globally as the population is expected to increase by 2.3 billion by 2050, bringing the total to 9.1 billion people. This growth will require a 70% increase in food production (Oluwole *et al.*, 2023) which can lead to resource depletion and increase greenhouse gas emissions especially related to meat based production. It has been reported that animal farming accounts for 14.5% of greenhouse gas emissions (Cheng *et al.*, 2022) and expected to rise progressively due to the sustained growth in global population and meat demand. Nevertheless, there are growing concerns about the health risks associated with high meat consumption. Diets rich in red and processed meat have been linked to high risk of cardiovascular disease, colorectal cancer and type 2 diabetes (Bing *et al.*, 2024). These concerns have fueled interest in plant-based food

alternatives as more sustainable and healthier dietary options.

Plant-based burger is among the alternatives widely commercialised for those seeking sustainable and healthier diets. Despite its growing availability, replicating the physical and organoleptic properties of meat burgers remains a recurring barrier for consumer acceptance (Godschalk-Broers *et al.*, 2022; Jean-Baptiste *et al.*, 2025). Previous survey and experimental studies on meat analogues provided evidence that consumers acceptance is limited by less positive texture profiles and lack of umami flavour associated with meat burgers (Michel *et al.*, 2021; Caputo *et al.*, 2023). This has prompted considerable research on improving the quality of plant-based meat to increase consumer acceptance. Hydrocolloids and wheat gluten have been used to create a fibrous structure in plant-based meat alternatives made

from various protein sources such as soy or pea. These ingredients help mimic the texture and mouthfeel of traditional meat products by forming an interconnected network via intermolecular and intramolecular disulfide bonds (Dinani *et al.*, 2023).

In addition to common binding agents like hydrocolloids and wheat gluten, alternative binders such as fruits and vegetables waste are gaining attention due to their sustainability and functional properties. Studies have shown that there is huge potential in utilising by-products from vegetable sources for developing food products, not only to reduce food waste but also to create functional and sustainable ingredients. Previously, cauliflower by products powder (leaves, stems, stalks) has been explored as functional ingredients in bakery products and beef sausage due to their bioactive components (Abul-Fadl *et al.*, 2012; Tukassar *et al.*, 2023). Meanwhile, the high fiber content and the presence of naturally occurring pectin and cellulose in cauliflower stems contribute to its ability to hold moisture and form a stable matrix, which is crucial for binding and texturizing agents (Sharma & Prasad, 2018). Moreover, functionalization of cell wall materials (CWM) derived from fruit and vegetable processing as texturizing agent has been highlighted by Van Audenhove *et al.* (2023). Disposal of cauliflower waste (leaves, stems, stalks) contributes to about 60% of vegetable total weight is of significant concern due to its highest waste index among all other vegetables.

Therefore, this study aimed to evaluate the potential of cauliflower stalk powder (CSP) in enhancing the quality of plant-based burgers with particular emphasis on its role as a partial substitute for textured vegetable protein (TVP). Plant-based burgers formulated using oyster mushroom as the base ingredient were prepared with varying levels of CSP (0 – 10% w/w), replacing a corresponding proportion of TVP. Quality of the burgers were evaluated based on their physicochemical and sensory attributes. This study highlighted the broader implications for the food industry in terms of waste reduction and the promotion of sustainable ingredients.

MATERIALS AND METHODS

Raw Materials

Chilled fresh oyster mushroom and fresh cauliflower were purchased from a local market in Muar, Johor. Isolated soy protein (ISP) (Radiant Whole Food, Radiant Code Sdn. Bhd., Malaysia), textured vegetable protein (TVP) (Saviour, GMT2 MALAYSIA SDN. BHD., Johor.), palm oil (BURUH, Lam Soon Edible Oils Sdn. Bhd., Malaysia), salt (Double Swallow, Seng Hin Brothers Enterprises Sdn. Bhd., Malaysia), garlic powder (McCormick, McCormick Foods Australia Pty. Ltd., Australia), onion powder (McCormick, McCormick Foods Australia Pty. Ltd., Australia), nutritional yeast (MH Food, Matahari Sdn. Bhd., Malaysia), black pepper (Sang Kangcil), sugar (Kijang, Spicon Products Sdn. Bhd., Malaysia) and curry powder (BABA, Baba Products (M) Sdn. Bhd, Malaysia) were bought from online platform.

Preparation of Cauliflower Stalk Powder

The CSP was prepared in accordance with the method described in Soner (2019), Singh *et al.* (2019) and Malik *et al.* (2025). The whole fresh cauliflower was washed thoroughly to remove any remaining dirt and impurities. Then, the stalk of the cauliflower was cut from the whole cauliflower and blanched in boiling water at 100 °C for three minutes. The blanched cauliflower stalk was drained for 30 min and cooled at room temperature before being soaked in a solution with 0.25% citric acid and 0.25% Potassium metabisulfite (KMS) for 30 min at room temperature. Then, the cauliflower stalk was drained and cut into small pieces using a food processor (Panasonic, MK-K51P, Japan) and strained using a muslin cloth. The processed cauliflower was then spread evenly on the turntable of a microwave oven (Midea MM720CGE-WH 20L, China). The cauliflower stalk was dried under 420 W power for 28 min with a three min interval to prevent the cauliflower stalk from being burnt and achieve moisture content less than 8%. The dehydrated cauliflower was then ground and sieved using a 100-mesh filter and the CSP powder with less than 0.60 mm in size was obtained.

Preparation of plant-based burger

The plant-based burgers were formulated based on the ingredients and ratios shown in Table 1 which was modified from Rajaretnam & Malik (2023). Fresh oyster mushrooms were gently blotted with absorbent paper to remove excess surface moisture before mixing with the other ingredients to control moisture variability. All ingredients were weighed accordingly on a weighing machine (OHAUS; Ohaus

Corporation, USA) before being mixed homogeneously in a food processor (Panasonic Model MK-K51P). The well-mixed burger mixture was then portioned into 25 g each and moulded using a round-shaped non-stick moulder. The burger patties were then kept in a zip lock bag respectively and froze under $-18\text{ }^{\circ}\text{C}$ in the chest freezer (PFZ-204G; Pensonic, Malaysia) overnight. For analysis, the plant-based burgers were pan-fried on medium heat for three min each side until golden brown.

Table 1. The formulation of plant-based burgers

Ingredients	Amount (% w/w)				
	Control	Formulation 1 (F1)	Formulation 2 (F2)	Formulation 3 (F3)	Formulation 4 (F4)
Oyster Mushroom	40	40	40	40	40
CSP Powder	–	2.5	5	7.5	10
Textured Vegetable Protein (TVP)	40	47.5	45	42.5	40
Palm Oil	4	4	4	4	4
Salt	1	1	1	1	1
Garlic Powder	0.5	0.5	0.5	0.5	0.5
Onion Powder	0.5	0.5	0.5	0.5	0.5
Nutritional Yeast	0.5	0.5	0.5	0.5	0.5
Black Pepper	0.5	0.5	0.5	0.5	0.5

Note: Control = (0% CSP, 40% TVP); F1 = Formulation 1 (2.5% CSP powder); F2 = Formulation 2 (5% CSP powder); F3 = Formulation 3 (7.5% CSP powder); F4 = Formulation 4 (10% CSP powder)

Analysis on Physicochemical Properties of Plant-Based Burgers

Determination of Texture Properties

A single compression test on the cooked plant-based burger was performed based on Gonzales *et al.* (2020) to evaluate the patty's firmness and springiness using a texture analyser (TA.XT Plus; Stable Micro System, UK). A flat 75 mm probe was employed for the compression test. The probe was lowered at a pre-test speed of 1 mm/s and the patty was compressed at a test speed of 1 mm/s to a predetermined distance of 30% of its original height. After compression, the probe was retracted at a post-test speed of 1 mm/s. The trigger force was set to 0.5 – 1.0 g to ensure accurate detection of sample contact.

Determination of Moisture Content

The moisture content of each plant based burger was measured using a thermogravimetric moisture analyser (MX-50; A&D, Japan). Two gram of the burger patty was weighed and tested at $160\text{ }^{\circ}\text{C}$ for 30 min to ensure rapid and

complete moisture evaporation in complex matrices rich in protein and dietary fibre (Wang *et al.*, 2021).

Determination of pH Value

The pH of the raw and cooked meatless burger patty was analysed using a pH meter (700, Eutech Instruments, Singapore). Five gram of the cooked plant-based burger was added with 20 ml of deionised water and homogenised using a homogeniser (Sellem *et al.*, 2024).

Determination of Cooking Loss

Cooking loss was measured based on the difference in weight of the raw and cooked burger patty (Pang *et al.*, 2020). Eq. (1) was used to calculate the cooking loss percentage,

$$\text{Cooking loss (\%)} = \frac{(w_1 - w_2) \times 100}{w_1} \quad \text{Eq. (1)}$$

where w_1 represents the weight of plant-based burger patty before cooking, w_2 represents the weight of cooked plant-based burger patty.

Sensory Evaluation

A five point hedonic scale was used in assessing consumer preference on the plant-based burgers (Tabaldo-Tucar & Solar, 2019). A total of 50 semi-trained panellists participated, who are individuals with prior exposure to sensory evaluation through food science coursework and who had attended at least one calibration session. Before the evaluation, panellists were briefed about the sensory attributes they need to evaluate (texture, taste, appearance, aroma and overall acceptance) and how to use the five point hedonic scale. The panel was made up of mixed-gender group between the ages of 20 – 35 years. Burger samples were coded with random three-digit numbers and presented in a random order to minimise bias. Samples were served at room temperature in a controlled sensory room to ensure consistent evaluation conditions.

Statistical Analysis

The SPSS software was used in analysing the experimental data. A Levene's test was performed to assess the homogeneity of variance. One-way analysis of variance (ANOVA) was applied to determine significant differences among samples. When the assumption of homogeneity was satisfied ($p > 0.05$), Tukey's honestly significant difference (HSD) test was used for post hoc multiple comparisons. The statistical

significance was set at $p < 0.05$. All experiments were conducted in triplicate and results are expressed as mean \pm standard deviation.

RESULTS AND DISCUSSION

Physicochemical Properties of Plant-Based Burger

Table 2 summaries the physicochemical properties of raw and cooked plant-based burgers incorporated with cauliflower CSP powder as a partial replacement for TVP.

Firmness and Springiness

Firmness and springiness which are closely related with biting sensation and perceived juiciness of burgers (Petrat & Dam, 2023) exhibited significant differences ($p < 0.05$) between raw and cooked burger patties. Both parameters increased by approximately 5 – 7% after cooking. This increment is attributed to the heat induced denaturation of protein from oyster mushroom and TVP leading to aggregation and formation of a cohesive three-dimensional network (Liu *et al.*, 2022). Inclusion of CSP further strengthens this structure by interacting with denatured proteins and gelatinised starch. This protein-starch interaction enhances moisture retention and contributes to a firmer, yet elastic texture associated with improved juiciness.

Table 2. Physical properties of raw and cooked plant-based burger

Physical Properties		Control	F1	F2	F3	F4
Firmness (kg)	Raw	4.31 \pm 0.06ab	4.20 \pm 0.25a	4.11 \pm 0.11a	4.71 \pm 0.04b	6.79 \pm 0.16c
	Cooked	8.48 \pm 0.18a	11.78 \pm 0.25b	11.66 \pm 0.25b	9.29 \pm 0.75a	9.44 \pm 0.35a
Springiness (%)	Raw	27.80 \pm 0.39a	28.31 \pm 0.26a	36.04 \pm 0.09c	39.82 \pm 0.03d	40.41 \pm 0.31e
	Cooked	27.57 \pm 0.15a	35.90 \pm 0.25c	41.47 \pm 0.49d	44.12 \pm 0.13e	45.50 \pm 0.50f
Moisture Content	Raw	64.22 \pm 0.34c	64.47 \pm 0.56c	63.15 \pm 0.62bc	61.74 \pm 0.61b	62.02 \pm 0.37b
	Cooked	51.04 \pm 0.47d	48.66 \pm 0.41b	49.87 \pm 0.48bcd	50.73 \pm 0.45cd	46.47 \pm 0.80a
pH	Raw	6.22 \pm 0.01e	6.10 \pm 0.01d	6.04 \pm 0.01c	5.89 \pm 0.01b	5.84 \pm 0.01a
	Cooked	6.15 \pm 0.00e	6.03 \pm 0.01d	5.94 \pm 0.01c	5.81 \pm 0.01b	5.75 \pm 0.01a
Cooking Loss		10.77 \pm 0.43b	15.16 \pm 0.51c	10.08 \pm 0.37b	8.3 \pm 0.79a	9.54 \pm 0.66ab

Note: Control (0% CSP, 40% TVP); F1 = Formulation 1 (2.5% CSP); F2 = Formulation 2 (5% CSP); F3 = Formulation 3 (7.5% CSP); F4 = Formulation 4 (10% CSP). Values are expressed as mean \pm SD of triplicate determinations. Means with different lowercase superscript letters within the same column and row are significantly different at $p < 0.05$

Comparing between the raw plant-based burgers, increasing CSP substitution led to a progressive increase in firmness and springiness. This finding suggests CSP's contribution to structural integrity as a fibrous component

supporting the solid matrix (Aamer & Hussain, 2016; Sayem *et al.*, 2024). Similar improvement in structural integrity has been reported by Kaur *et al.* (2022) in hen meat cutlets enriched with CSP.

However, upon cooking, slightly lower firmness at high CSP concentration (7.5 – 10%) was observed. This finding may result from enhanced water retention during cooking which could soften the cooked matrix (Woo *et al.*, 2024). Additionally, the reduced TVP content at higher CSP may limit the protein network formation. The observed changes in firmness and springiness indicate a denser, less elastic structure at high CSP levels which may compromise biting quality. This suggests that moderate CSP levels optimise textural quality while maintaining consumer-preferred bite and juiciness. In product formulation, this highlights the importance of balancing fibre inclusion with protein content to achieve desirable texture in plant-based burgers which is crucial for consumer acceptability.

Moisture Content

Cooking significantly reduced moisture content ($p < 0.05$) due to evaporation and heat induced protein denaturation, which can draw water out of the burger matrix (Haghighi *et al.*, 2021). In raw burgers, moisture content decreased by approximately 2% with increasing CSP and decreasing TVP levels. This observation is consistent with TVP's role in water binding reported by Baune *et al.* (2022) and Hong *et al.* (2022) as its reduction limits the patty's capacity to retain water.

Interestingly, cooked patties recorded increasing trend of moisture content up to 7.5% CSP concentration (F1 until F3) demonstrating the formation of hydrophilic matrix by CSP that traps water during cooking. This hydrophilic network helps in reinforcing the burger matrix contributing to the observed firmness and springiness in cooked samples. Furthermore, as water mobility is restricted it can compensate for the weaker protein network development at lower TVP levels. This observation highlights the role of CSP alongside TVP in maintaining structural integrity and textural resilience in cooked patties (Mishra *et al.*, 2023).

pH.

The raw and cooked plant-based burger patties showed significant differences ($p < 0.05$) in pH values across formulations. Increasing CSP level led to a slight decrease in pH reflecting the mild acidity of CSP. This result is

consistent with previous findings by Begum *et al.* (2021) and Abul-Fadl (2012), who reported decreasing pH in sausages and meat cutlets with increased cauliflower powder. Besides, interactions between ingredients within the food matrix may increase hydrogen ion levels, contributing to the observed pH reduction (Babu *et al.*, 2024). Maintaining an appropriate pH range is essential for shelf-life stability, microbial safety and flavor perception, indicating that CSP inclusion must be considered in formulation design to balance functionality with product safety.

Cooking Loss

Cooking loss varied significantly ($p < 0.05$) among formulations of the plant-based burger. A decreasing trend of cooking loss was observed with increasing CSP level from 2.5 to 7.5%, reflecting the water binding capacity of CSP (Kaur *et al.*, 2022; Qin *et al.*, 2022). Similar observations have been reported in studies by Aamer & Hussain (2016) and Woo *et al.* (2024), where higher cauliflower powder levels reduced cooking loss in fish burger and low-fat chicken sausage respectively.

However, burgers with 5% and 10% CSP showed no significant difference ($p > 0.05$) in cooking loss compared to the control sample (0% CSP). This non-linear trend indicates that CSP's binding efficiency is not directly proportional to its concentration. At lower substitution levels (5%), the quantity of fiber may be insufficient to form a cohesive matrix, whereas at higher substitution levels (10%), fiber could disrupt the protein network due to reduced TVP content. Since TVP contributes significantly to the protein structure, emulsion stability and textural integrity of plant-based meat analogs, decreasing its proportion could offset the potential benefits provided by CSP (Kim *et al.*, 2024; Theavy *et al.*, 2025). This observation suggests that the concentration of CSP has an influential role on the overall binding capacity in the plant-based burger matrix.

Nevertheless, the increase in water-holding capacity and reduced cooking loss observed at intermediate CSP levels can be primarily attributed to the water-binding capacity of dietary fibre (Rafiudin *et al.*, 2019; Mishra *et al.*, 2023; Malik *et al.*, 2025). Excessive fibre

incorporation may have disrupted matrix continuity, limiting further improvements in moisture retention.

Sensory Properties of Plant-Based Burger

Table 3 shows that plant-based burgers with CSP generally received higher sensory attribute scores than control sample, consistent with findings by Aamer & Hussain (2016). F4 achieved the highest mean texture score (3.80), aligns with the greater firmness and springiness observed in texture analysis (Table 2). This shows that the fibre in CSP helps to enhance mouthfeel and structural integrity (Aamer & Hussain, 2016; Sayem *et al.*, 2024).

In terms of taste, F1 with only 2.5% CSP scored highest (3.94) and plant-based burger without CSP scored the lowest (3.16). This indicates that moderate CSP inclusion may positively influence flavour perception. Although flavour compounds were not directly measured in this study, the high flavour score at low CSP level can be associated with the mild flavour characteristics of cauliflower derived products highlighted in previous studies (Hegazy & Ammar, 2019; Kaur *et al.*, 2022;).

Furthermore, Tukassar *et al.* (2023) reported positive effects of cauliflower by products incorporation in muffin only up to 10% when compared with 20 and 30% incorporation. Appearance and aroma scores generally showed no significant differences ($p > 0.05$), with all formulations rated similarly except for F2 scored higher aroma (4.04), consistent with findings by Aamer & Hussain (2016). This enhanced aroma perception may be attributed to a favourable interaction among formulation components, although further analysis of volatile compounds would be required to confirm this effect. Overall, F1 and F2 were most preferred in sensory evaluations, with F3 scoring lowest due to strong CSP flavours. Despite its physical advantages (texture, moisture contents and cooking loss), stronger CSP flavour in F3 may have reduced acceptability among semi-trained panellists. Future studies incorporating flavour profiling or consumer testing with seasoning optimisation could clarify these sensory effects (Fiorentini *et al.*, 2020). The overall sensory attributes of plant-based burger with CSP seem dependent on the amount of substitutions, which affects the textural properties and alters consumer acceptance.

Table 3. Mean sensory score of five formulations of plant-based burger which is based on hedonic scale anchors of 1 = dislike very much, 5 = like very much

Formulation	Attributes				
	Texture	Taste	Appearance	Aroma	Overall Acceptance
Control	3.10a	3.16a	3.64a	3.88ab	3.38ab
F1	3.74b	3.94b	3.82a	3.88ab	3.92c
F2	3.74b	3.68ab	4.00a	4.04b	3.90bc
F3	3.50ab	3.26a	4.04a	3.46a	3.24a
F4	3.80b	3.68ab	4.06a	4.00ab	3.82bc

Note: Control (0% CSP, 40% TVP); F1 = Formulation 1 (2.5% CSP); F2 = Formulation 2 (5% CSP); F3 = Formulation 3 (7.5% CSP); F4 = Formulation 4 (10% CSP). Values are expressed as mean of $n = 50$ panellists. Means with different lowercase superscript letters within the same column are significantly different at $p < 0.05$

CONCLUSIONS

The valorisation of vegetable waste such as cauliflower stalk as binding agent in the formulation of plant-based burger presents a promising avenue for enhancing the physicochemical and sensory profile of consumer goods. This study demonstrated that cauliflower stalk powder (CSP) enhances firmness, springiness and cooking loss of plant-based burgers. Sensory evaluation revealed that moderate CSP levels (2.5 – 7.5% w/w) provided the most balanced performance, combining

favourable texture, moisture retention and sensory appeal. However, lower or higher levels of CSP influenced flavor intensity and texture perceived. These findings highlight CSP's potential as a functional, sustainable ingredient for product development, capable of improving manufacturing consistency and sensory appeal. Future research could evaluate nutritional quality and glycemic impact, while industrial collaboration could support the development of CSP-based products. By integrating vegetable by-products into value-added applications, this approach contributes to sustainable, resource-

efficient plant-based food production and diversification of consumer offerings.

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Compliance with ethics guidelines Tian Siaw En, Nur Aqilah Baharuddin, Norazlin Abdullah and Nur Hafizah Malik declare that they have no conflict of interest or financial conflicts to disclose.

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