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Role of broccoli flower powder as a novel plant-based ingredient in the development of the dumpling

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Dumplings are a popular food item globally, made from a meat filler of ground meat and vegetables wrapped in wheat flour dough. Replacing broccoli flower powder with ground pork in dumplings creates a promising opportunity to develop dumplings that offer additional nutritional benefits. Broccoli flower (*Brassica Oleracea var. italica*) offers a range of benefits, particularly in its dietary aspects, with a protein content of approximately 21% and the inclusion of soluble dietary fiber. The objectives of this study were to determine whether substituting ground pork with broccoli flower powder in the dumpling filling would enhance the texture and nutritional properties of the dumpling. Broccoli flower powder was substituted for 10%, 20%, and 30% of the ground pork in the dumpling filling. Attributes such as pH, color, cook loss, and texture analysis were used to analyze the dumplings. The cooking loss showed an increasing trend from 23% to over 30% when broccoli flower powder was used to substitute the dumpling filling at a rate of 20% or more. However, no significant differences were observed between the cooking loss of control and the dumpling ($p < 0.05$). The hardness of the dumplings decreased from 5,900 g in control to below 2,100 g in the samples with broccoli flower powder substituted for ground pork. The decrease in hardness was attributed to the reduction in protein content when broccoli flower powder was substituted for ground pork. Results showed improvement in functional and nutritional properties. The 10% substitutions showed the best functional properties without severely affecting the textural properties. Overall, replacing broccoli flower powder with ground pork in dumplings created promising dumplings that contain additional dietary benefits; however, limitations, especially in their textural properties, need to be improved for the product to have the potential to be accepted by consumers.

KEYWORDS

broccoli flower powder, dumpling, dumpling filling, food product development, pork

1 Introduction

Dumplings are a popular food item globally, made from a meat filler of ground meat and vegetables wrapped in wheat flour dough (Huang et al., 2019; Iwama, 2024). There are many varieties of dumplings globally, from Pierogi in Eastern Europe, Tortellini in Italy, Empanadas from Latin America, and Samosas from India, each of which uses a variety of ingredients and cooking methods to prepare the dumpling (Yarvin, 2017). In addition, dumplings are now a popular convenience food, as they are commonly purchased food

products in the retail marketplace (Huang et al., 2014; Kim et al., 2024). Dumplings are a staple food in many international cultures. Dumplings are steamed, fried, or baked and made from simple, readily available ingredients. There is a substantial increase in the demand for dumplings, with a compound annual growth rate of 16% observed between 2017 and 2021 (Kim et al., 2024).

Gyoza dumplings are a national dish of Japan due to their well-rounded nutritional profile and exceptional variety (Iwama, 2024). The gyozas originated in China and were first introduced to Japan. Japanese chefs and home cooks adapted the dumpling to suit local tastes and cooking methods, leading to the creation of what is now known as gyoza. A key distinction is the shift from traditional Chinese cooking methods, such as boiling (sui-gyoza) or steaming (mushi-gyoza), to the pan-fried method (yaki-gyoza). This technique, which involves first frying the dumplings to create a crispy bottom and then simmering them to cook the filling, is a signature element of Japanese gyoza. The thinner wrappers often used in Japan facilitate this distinctive crispy texture. With pan-fried cooking being the most popular method since the 20th century and preferred by consumers, gyoza dumplings have become popular in Western Cuisine in recent years (Iwama, 2024; Park et al., 2024).

Plant-based ingredients are increasing in demand, as consumers look for natural food sources, rich in nutritional value, and have a low environmental impact (Benimana et al., 2025). Plant-based sources have the benefits of zero cholesterol and low-fat content, along with low calories (Karabulut et al., 2024). However, challenges in creating plant-based meat analogs that completely mimic the texture of meat still exist, such as a softer texture and low binding capacity, both of which bring distinct attributes to plant-based products that may be unfavorable to the consumer (Karabulut et al., 2024). As a result, the development of meat emulsions with a mix of animal and plant protein is desired to improve nutritional quality, among other benefits (Bakhsh et al., 2021; Karabulut et al., 2024).

Broccoli flower (*Brassica Oleracea* var. *italica*) offers a variety of benefits, particularly in its nutritional aspect, with a protein content of approximately 21% and the inclusion of soluble dietary fiber (Benimana et al., 2025; Shang et al., 2023). Protein in broccoli is a functional source of plant protein. At the same time, its fiber content also offers health benefits, such as reducing the risk of metabolic syndromes, in addition to its high antioxidant capacity, which can help mitigate the risk of various health ailments (Benimana et al., 2025; Shang et al., 2023). High antioxidant capacity may also be critical in maintaining the quality of the dumpling fillings over time, as it may help in retarding the oxidation of the ingredients (Huang et al., 2014; Huang et al., 2019). However, the applications for broccoli flower powder are scarce in the literature, and challenges to its attributes are expected, given the difficulties in attributes observed when non-meat proteins are used as substitutes for meat products (Malila et al., 2024). To assist the low binding capacity observed in plant proteins, guar gum was used as a binder to improve the binding capacity of the dumplings, where ground pork is substituted with broccoli flower powder (Han et al., 2023).

Previous research has mainly focused on improving the quality of dumplings using plant-based ingredients, such as rice and soy flour which led to improvements such as increased elasticity and soy flour which led to improvements such as increased elasticity with rice flour and improved ability to bind water with soy flour (Moin et al., 2019; Zeng et al., 2023). Some studies have demonstrated that

TABLE 1 Formulation of dumpling filling with broccoli flower powder (BFP)^a. All values are in grams.

Ingredient	Control	10% BFP	20% BFP	30% BFP
Ground pork	150	135	120	105
Broccoli powder	0	15	30	45
Cabbage	33	33	33	33
Soy sauce	10	10	10	10
Onion	10	10	10	10
Garlic	5	5	5	5
Ginger	0.8	0.8	0.8	0.8
Salt	1	1	1	1
Pepper	0.3	0.3	0.3	0.3
Water	0	15	30	45
Guar	0	2.3	2.4	2.6
Total	210.1	227.4	242.5	257.7

Control, Dumpling made with 0% broccoli flower powder.

^aBFP, Includes 0, 10, 20, and 30% by weight of broccoli flower powder.

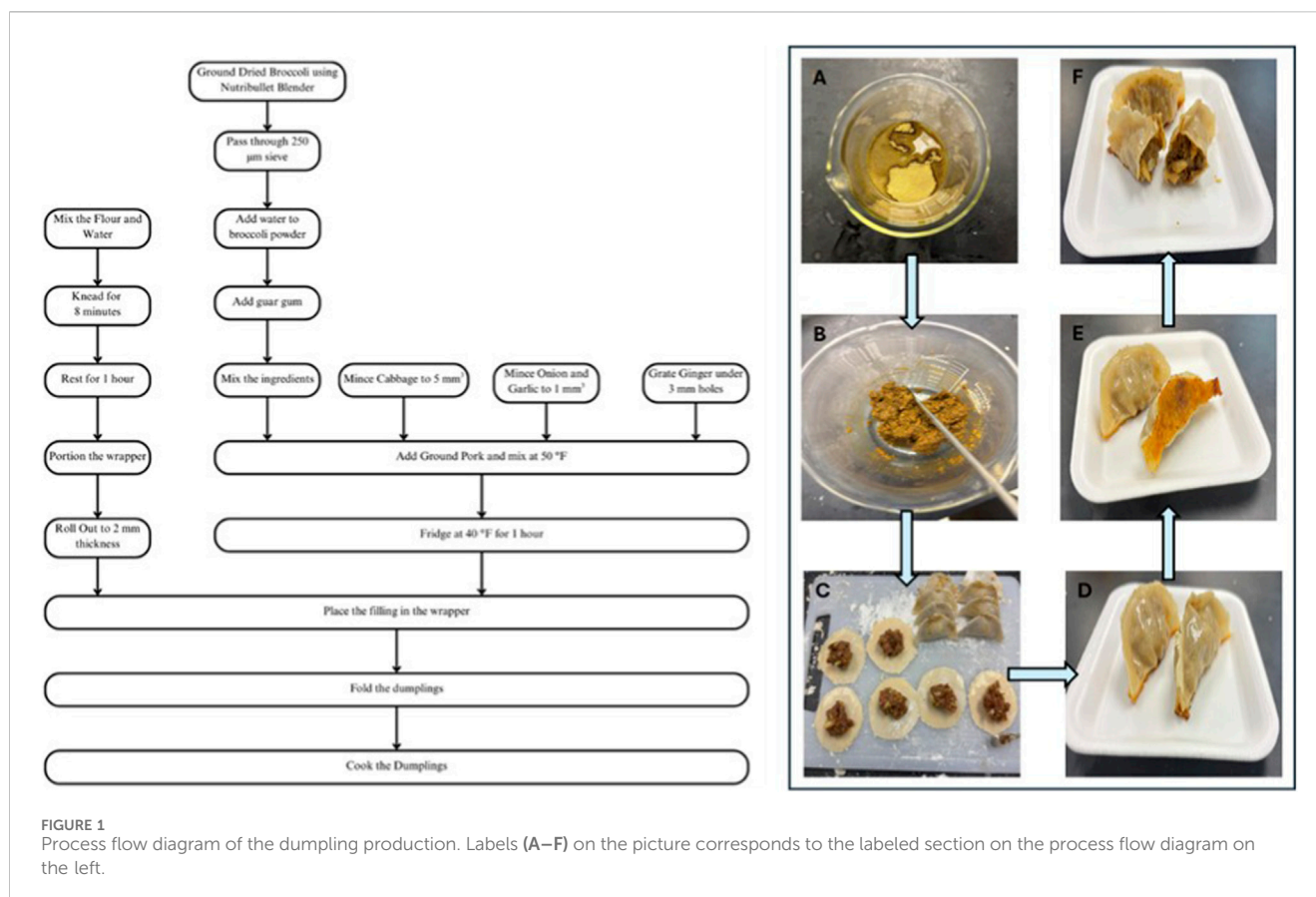
cooking dumplings using various methods, including steaming, baking, boiling, and deep-frying, improves the overall quality and consumer acceptability (Park et al., 2024). There has been a lack of research on the incorporation of novel plant-based ingredients as substitutes for meat.

The objectives of this study were to determine whether substituting ground pork with broccoli flower powder in the dumpling filling would enhance the texture and nutritional properties of the dumpling. The incorporation of broccoli flower powder in dumpling filling to substitute ground pork is a novel approach to improve the nutritional properties of the dumplings (Benimana et al., 2025; Shang et al., 2023). Broccoli flower powder was substituted for 10%, 20%, and 30% of the ground pork in the dumpling filling. Attributes such as pH and the color of the dumpling of the filling before and after cooking, along with cooking loss, and texture analysis of the dumplings after cooking were used to analyze the dumplings. The successful incorporation of broccoli flower powder in dumpling fillings to replace ground pork would open up two routes of product innovation. First, it demonstrates the ability of broccoli flower powder to be successfully incorporated into a formulation, enhancing its nutritional properties while maintaining or improving its functional properties. Secondly, it enables the substitution of novel plant proteins into meat emulsions, creating innovative products that combine the benefits of both plant and animal proteins.

2 Materials and methods

2.1 Raw materials and chemicals

Guar Gum (MB Herbals, Ahmedabad, India) and Dried Broccoli Flowers (Birch & Meadow, Linden, UT, USA) were procured from an online source. All other ingredients were purchased locally from a supermarket in Athens, GA, USA. Ground Pork (20% Fat) was



stored at 0°F (−18 °C), while cabbage, onions, garlic, ginger, and soy sauce were stored in refrigerated (4 °C) conditions. All ingredients were purchased in advance of the study, and was stored for 12 h at minimum before usage.

2.2 Preparation and formation of dumplings

Before the dumpling filling was made, the vegetables were processed. Cabbage was minced to approximate 5 mm squares, while onion and garlic were minced to approximately 1 mm³ cubes. Ginger was grated under a zester grater with 3 mm holes. The dried broccoli flower was ground using a blender (Nutribullet, Capital Brands, Los Angeles, CA, USA) and processed through a 250 µm sieve. All ingredients except the broccoli flower powder were stored at 4 °C before use. The dumpling filling formulation is presented in Table 1. Broccoli flower powder was used to substitute the pork until a substitution rate of 30%, as it was the maximum concentration until the breakdown of the filling was observed. Water was added in an equivalent amount to the broccoli flower powder to hydrate and swell the powder (Silva et al., 2012). In contrast, guar gum was added to a 1% concentration in the total formulation of the filling. The broccoli flower powder was mixed with water and guar gum to achieve initial swelling and mimic the texture of the ground pork. All ingredients were weighed to the specified amounts in Table 1, then mixed by hand while maintaining the temperature at 10 °C for 4 min. The mixture was then cooled at a refrigerated temperature of 4 °C for 1 h.

Dumpling wrappers were formed by mixing 126 g of flour with 50 g of water at room temperature. Once the flour was hydrated with water, the dough was kneaded by hand for 8 min, then rested at room temperature for 1 h. Dumplings were then portioned out in approximately 15 g ± 4.0 g and rolled out to a thickness of 2 mm. 20.1 ± 3.5 g of filling was then added to the dumpling, and then the dumplings were folded and immediately cooked (Figure 1).

2.3 Cooking of dumplings

Dumplings were cooked using a pan-fry method. A frying pan was heated to 190 °C, and then 5 mL of soybean oil was spread evenly in the pan. Twelve dumplings were placed in it. After cooking for 2 min, a mixture of 90 mL of water and 6 g of flour was added to the pan, and aluminum foil was used to cover it. After 5 min, the aluminum foil was removed, and the samples were heated until the mixture of flour and water had evaporated entirely and the internal temperature reached 70 °C. Dumplings were transferred to aluminum foil once fully cooked and analyzed after cooling to room temperature.

2.4 pH

The pH of the dumpling filling was measured using a pH meter (Orion Versa Star Pro, Thermo Scientific, Waltham, MA, USA). The

pH probe (8172BNWP) was calibrated using a three-point calibration (pH 4.0, 7.0, and 10.0). Three points from the raw fillings and the pH of the cooked fillings from three dumplings were used to measure the pH.

2.5 Color measurements

The color of the dumplings was measured using an EZ Miniscan Colorimeter (4500 L, HunterLab, Reston, VA, USA) using the D65 illuminator and an observer angle of 10°. After calibration on a black and white tile, three measurements were made on the raw sample and the cooked sample using the CIE L* (lightness), a* (redness), b* (yellowness) color space.

2.6 Cooking loss

The cooking loss of the dumpling filling was determined using the method of Huang et al. (2014) with modifications. The dumpling filling was weighed before cooking (W_0), and after cooking, the wrapper was removed for the dumpling filling to be weighed again (W_1). The following formula analyzed the cooking loss:

$$\text{Cooking Loss (\%)} = \frac{W_0 - W_1}{W_0} \times 100$$

2.7 Texture profile analysis

The texture of the proteins was analyzed using a TA-XT Plus Texture Analyzer (Godalming, UK). A 30 kg load cell was used for the analysis. The texture profile analysis was conducted using the method of (Settapramote et al., 2024) with modifications. The TA-30 probe (75 mm) was used for analysis of the textural properties. The following conditions were used: pre-test speed, test speed, and post-test speeds of 2 mm/s, Target Strain of 50%, Trigger Force of 5 g. Three measurements were taken from each treatment. Hardness, Springiness, Chewiness, Cohesiveness, and Resilience of the dumplings were reported.

2.8 Kramer shear cell analysis

The Kramer Shear Cell analysis was conducted using the method of (Park et al., 2024) with modifications. A five-blade Kramer Shear Cell was used in the experiment; samples were analyzed at a test speed of 2 mm/s and a target strain of 90%. Three measurements were taken from each treatment, and Young's Modulus, along with total Shear Cell Work, was reported. The Young's Modulus was reported by the change in stress between the strain points of 30% and 42%, with the area being an oval of 3.8 cm by 6.4 cm. The Breaking point was also reported, which was defined as the maximum force observed by the texture analyzer during the analysis and the strain that was applied when that point was reached.

2.9 Statistical analysis

Each treatment was conducted three times in triplicate. One-way analysis of variance (ANOVA) was performed on the data to detect significant differences between treatments, with a significance level of $\alpha = 0.05$, using R (version 4.4.2). All samples were tested for normality by determining whether the skewness and kurtosis were within an absolute value of 1. The homogeneity of variance was tested using Levene's method with a significance level of 0.05, and the Welch Test was conducted if the homogeneity of variance assumption was violated. Post-hoc Tukey tests were conducted to determine significant differences between groups if the ANOVA revealed significant differences. Additionally, a Pearson correlation analysis was performed on all textural attributes to assess the relationship between each textural attribute of the dumplings.

3 Results and discussion

3.1 pH and color

The pH and color of dumplings are shown in Table 2. The pH of the dumpling filling decreased significantly when broccoli flower powder was substituted for ground pork in dumpling fillings; this trend was observed in both raw and cooked fillings. The change is significant, as it is not observed in textured vegetable protein, such as textured soy protein, which did not experience a decrease in pH when used as a substitute for beef patties (Bakhsh et al., 2021). Interestingly, dumpling fillings with broccoli protein showed signs of decreased pH after cooking, compared to other meat fillings and patties, in which the pH of the filling generally increases as the product is cooked (Bakhsh et al., 2021). The decrease in pH can be attributed to the presence of flavonoids and phenolic compounds in broccoli, both of which are acidic (Al Juhaimi et al., 2024). The pH of broccoli ranges from 6.13 to 6.7, depending on the cooking method. It should be noted that dried broccoli flower powder was used, which eliminated the moisture in the broccoli, making the powder much more acidic (Tangkham, 2019). The acidifying nature of broccoli is critical as lowering the pH of food products can enhance their shelf life; however, nutrient loss is also possible, as vitamins can degrade with low pH (Ameje et al., 2025; Dissanayake, 2017; Mills, 2004). Furthermore, the acidic nature of dumplings with broccoli flower powder likely indicates the presence of flavonoids and phenolic compounds, both of which are related to antioxidant capacity, which can also help in enhancing the shelf-life of the protein due to its ability to retard oxidation (Huang et al., 2014; 2019). Overall, the pH of the dumpling filling decreased as broccoli flower powder substituted ground pork, both in its raw form and its cooked form.

The color of the raw fillings differed significantly when broccoli protein was added, as evidenced by the noticeable changes in lightness and redness of the filling, with both attributes decreasing in value. The decrease in lightness and redness can be attributed to the dark green nature of the broccoli flower powder; similar differences were observed when textured soy protein was used to substitute beef patties (Hong et al., 2022). The lightness of the fillings decreased when the dumplings were cooked; this can be

TABLE 2 pH and color attributes of dumplings with broccoli flower powder (BFP)*.

Attribute		Control	10% BFP	20% BFP	30% BFP	P-value
Uncooked pH		5.88 ± 0.26 ^a	5.78 ± 0.19 ^a	5.64 ± 0.30 ^{ab}	5.41 ± 0.19 ^b	0.001
Cooked pH		6.54 ± 0.38 ^a	5.98 ± 0.30 ^b	5.51 ± 0.22 ^c	5.39 ± 0.14 ^c	<0.001
Uncooked	L*	60.1 ± 4.5 ^a	47.4 ± 3.6 ^b	44.6 ± 2.4 ^{bc}	41.1 ± 3.9 ^c	<0.001
	a*	10.1 ± 3.0 ^a	7.2 ± 2.1 ^b	6.2 ± 1.6 ^b	5.6 ± 1.1 ^b	0.005
	b*	20.9 ± 1.7 ^a	18.6 ± 3.6 ^{ab}	17.1 ± 3.7 ^b	15.3 ± 1.0 ^b	0.001
ΔE		0.0	13.2	16.4	20.3	
Cooked	L*	38.6 ± 10.6	30.1 ± 14.7	32.4 ± 11.3	34.0 ± 6.6	0.363
	a*	6.5 ± 2.4	7.8 ± 4.3	6.9 ± 2.1	8.3 ± 1.7	0.499
	b*	16.3 ± 2.8	19.5 ± 8.6	20.8 ± 7.5	19.5 ± 3.8	0.471
ΔE		0.0	9.2	7.7	5.9	

^{a,b,c} Different superscript letters in uncooked pH, cooked pH, Uncooked L*, Uncooked a*, and Uncooked b* indicate significant differences at $p < 0.05$.

Control, Dumpling made with 0% broccoli flower powder.

*BFP, Includes 0, 10, 20, and 30% by weight of broccoli flower powder.

L*, Lightness (black = 0, white = 100).

a*, Greenness/Redness (green = -100, red = 100).

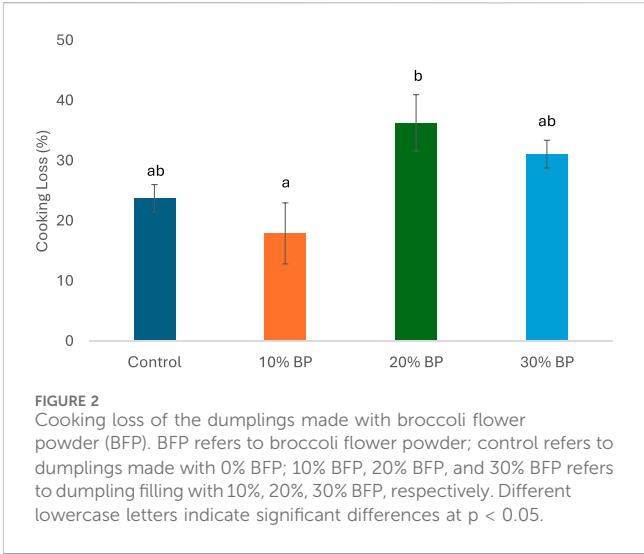
b*, Blueness/Yellowness (blue = -100, yellow = 100).

ΔE, Color Difference between Control and 10%, 20%, 30% BFP.

attributed to the formation of dark-colored complexes formed by the Maillard reaction when being pan-fried; the phenomenon was also seen in beef patties substituted with textured soy protein (Hong et al., 2022; Settaramote et al., 2024). However, the color did not differ significantly between the broccoli-substituted dumpling filling and the control in the cooked samples; this is significant, as consumers can differentiate minor differences in food products to conclude differences in food quality and characteristics (Schifferstein et al., 2019). Overall, a difference in the color of dumpling fillings was observed in the raw form when broccoli flower powder was substituted for ground pork; however, the difference was not observed in the cooked fillings.

3.2 Cooking loss

The cooking loss is presented in Figure 2. The cooking loss increased considerably when broccoli flower powder was used to substitute the dumpling filling at a rate of 20% or more, as it increased from 23% in the control to 36% under 20% substitution and 31% under 30% substitution. However, no significant differences were observed between the cooking loss of the control and the dumpling, which had broccoli protein substituted for ground pork ($p < 0.05$). The cooking loss of the control dumplings was similar to the values obtained by Huang et al. (2019), Huang et al. (2014) observed an increase in cooking loss when fat was added to dumplings. However, the results contrast with those of Hong et al. (2022), in which textured vegetable proteins showed decreased cooking loss compared to the values observed in the dumplings. Additionally, the cooking loss decreased for various plant proteins when they were substituted in chicken batter (Lin and Barbut, 2024). When meat products are cooked, the meat fibers shrink along with the denaturation of proteins. These changes in meat protein led to a decrease in moisture retention, resulting in a



reduction of the mass of the filling (Vu et al., 2022). As plant protein is denatured during processing, the reduction in moisture retention that occurs during cooking is prevented; as a result, the cooking loss decreases. However, the increase in cooking loss can be attributed to the lack of protein in the broccoli flower powder; unlike textured protein from other studies, only a fifth of the powder contains protein (Benimana et al., 2025). Protein is critical in holding the water from the protein and preventing its release; with less protein available, less water can be held in the filling, leading to an increase in cooking loss (Benimana et al., 2025; Vu et al., 2022). The cooking loss may not have decreased at 10% substitution due to the guar gum, which acted as the binding agent to minimize cooking loss; however, after 20% substitution, the loss of the protein via broccoli flower powder substitution was large enough to counter the binding effect of guar gum (Sharma et al., 2018). The contradiction in

TABLE 3 Textural Attributes of dumplings with broccoli flower powder (BFP)*.

Textural attribute	Control	10% BFP	20% BFP	30% BFP	P-value
Hardness (g)	5,900 ± 1860 ^a	2030 ± 690 ^b	1840 ± 820 ^b	1790 ± 910 ^d	<0.001
Springiness (%)	80.1 ± 4.9	77.1 ± 6.7	75.7 ± 8.7	76.9 ± 12.2	0.743
Cohesiveness (%)	55.4 ± 10.2	57.5 ± 6.2	57.6 ± 4.3	54.0 ± 7.2	0.686
Chewiness (g)	2,500 ± 410 ^a	900 ± 330 ^b	810 ± 440 ^b	730 ± 370 ^b	<0.001
Resilience (%)	26.2 ± 3.3 ^a	23.2 ± 5.4 ^{ab}	22.0 ± 3.5 ^{ab}	18.6 ± 3.1 ^b	0.022
Young's Modulus (Pa)	8,600 ± 2200 ^a	5,500 ± 2200 ^{ab}	1900 ± 1200 ^{bc}	1700 ± 1000 ^c	<0.001
Kramer shear cell work (kg*s)	104.7 ± 7.7 ^a	88.1 ± 26.2 ^b	80.9 ± 10.3 ^c	63.6 ± 18.9 ^c	<0.001

^{a,b,c,d} Different superscript letters in Hardness, Chewiness, Resilience, Young's Modulus, and Kramer shear cell work indicate significant differences at $p < 0.05$.

Control = Dumpling made with 0% broccoli flower powder.

*BFP, Includes 0, 10, 20, and 30% by weight of broccoli flower powder.

Hardness, How hard the dumpling, in g-force.

Springiness, How much the dumpling springs back after the first force is applied, in percent.

Cohesiveness, How well the dumpling maintains the structure after the first compression, in percent.

Chewiness, How much force is required to chew the dumpling before swallowing, in g-force.

Resilience, Ability for the dumpling to recover its original shape after compression, in percent.

Young's Modulus, Stiffness of the dumpling when strain is applied, and it is expressed in pascals as unit.

Kramer Shear Cell Work, How much energy is required to chew a dumpling once, in kilogram-seconds as unit.

cooking loss from prior studies may be due to the differing properties between broccoli flower powder and other sources of vegetable powder; broccoli flower powder showed a lower water holding capacity compared to soy and pea flour (Benimana et al., 2025; Ma et al., 2022). Overall, the dumplings exhibited a trend of increasing cook loss as broccoli flower powder was incorporated into the ground pork; however, the differences were not statistically significant.

3.3 Texture profile analysis

The results of the texture profile analysis are presented in Table 3. The hardness of the dumplings significantly decreased between the control, which had a hardness of 5,900 g, and the samples with broccoli flower powder substituted for ground pork, which ranged from 1,790 to 2,030 g. Similar results were observed by Vu et al. (2022) when beef patties and plant-based patties were compared for hardness, and (Bakhsh et al., 2021), when beef patties were gradually mixed with textured soy protein. The decrease in hardness can be attributed to the reduction in protein content when broccoli flower powder was substituted for ground pork, as protein-protein interactions were more difficult to attain, resulting in a softer texture (Huang et al., 2014). Another reason is the denaturation and aggregation of myofibrillar protein when meat is cooked (Vu et al., 2022). The same phenomenon does not occur with dumplings that substitute broccoli flower powder for ground pork, due to the lower amount of myofibrillar protein and the lower protein content in the broccoli flower powder. Similar results were observed in terms of chewiness for beef patties and plant-based patties, where the chewiness decreased significantly when broccoli flower powder was used to replace ground pork; however, the opposite was observed when beef patties were gradually blended with textured soy protein (Bakhsh et al., 2021). Chewiness is calculated based on hardness, springiness, and chewiness; only

hardness had a significant difference between treatments. As chewiness is related to the energy required to break down a food product, it can be seen that a decrease in hardness yields less energy for the product to be chewed (Sañudo-Barajas et al., 2019). The decline in chewiness and hardness may significantly alter the consumer's liking of the product. In a study that observed the difference in sausages with varying pork content, the decrease in hardness and chewiness led to a decline in consumer liking of the texture (Baer and Dilger, 2014).

Interestingly, the chewiness of the sample was not significantly different between samples ($p > 0.05$), and no significant trend was observed between samples. This is in stark contrast to the studies of (Vu et al., 2022; Bakhsh et al., 2021) Both of which showed a decrease in cohesiveness between beef patties and plant-based patties, as well as blends of beef and plant-based patties. It also differs from Lin and Barbut (2024), who reported an increase in cohesiveness in chicken batters with the substitution of plant proteins. Plant proteins do not have a good binding capacity; as a result, cohesiveness is expected to decrease. However, the guar gum in the dumplings acted as the binding agent, maintaining the cohesiveness of the product (Karabulut et al., 2024; Sharma et al., 2018). Cohesiveness is a critical parameter in determining the deformation of a product after the first bite; a loss in cohesiveness would indicate an inability for the dumpling to hold its shape after the first bite and would likely decompose (Sañudo-Barajas et al., 2019). By maintaining the cohesiveness of the dumpling while adding broccoli flower powder, the dumplings are less likely to decompose differently when chewed on compared to conventional dumplings; thus, it is less likely that cohesiveness impacts consumer acceptability. Overall, replacing ground pork with broccoli flower powder results in a decrease in hardness and chewiness, which is attributed to the lower overall protein content and lower myofibrillar protein content; however, cohesiveness is maintained, thereby reducing the change in dumpling texture after the dumpling is deformed during the first bite.

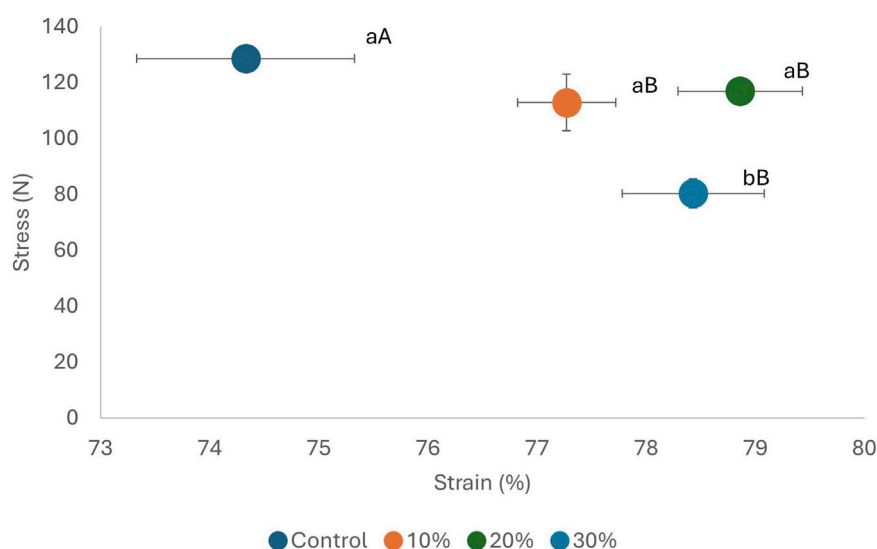


FIGURE 3

Fracture stress and fracture strain of the dumplings made with broccoli flower powder (BFP). BFP refers to broccoli flower powder; control refers to dumplings made with 0% BFP; 10% BFP, 20% BFP, and 30% BFP refers to dumpling filling with 10%, 20%, 30% BFP, respectively. Different lowercase letters indicate significant differences of fracture stress at $p < 0.05$, while different uppercase letters indicate significant differences of fracture strain at $p < 0.05$.

3.4 Kramer shear cell analysis

The Kramer Shear Cell is a test that compresses and shears the sample, mimicking the early stages of mastication, particularly in the back molars (Álvarez et al., 2020; Voisey, 1970). The results of the Kramer Shear Cell analysis are presented in Table 3. A variety of measurements can be obtained from a Kramer Shear Cell; this includes the Young's Modulus, total shear work, and the breaking point. Young's Modulus is related to the firmness of the product; as more broccoli flower powder is substituted for ground pork, the Young's Modulus decreases, and thus the firmness decreases (Sinha and Bhargav, 2020). The loss in firmness is similar to the loss of hardness observed in the texture profile analysis. Similarly, the shear work of the dumplings decreased as broccoli flower powder replaced ground pork in the dumpling filling, indicating a decrease in energy required to break down the dumplings (Figure 3). Studies that have conducted shear analysis on similar products are rare; however, one study that examined beef patties with plant proteins found an increase in shear force, in contrast to the results of this study (Ball et al., 2021). This can likely be explained by the use of broccoli flower powder instead of broccoli protein, as the broccoli flower powder contained lower amounts of protein compared to animal protein, and as a result, the protein-protein interaction decreased, leading to a more tender texture (Benimana et al., 2025). All values obtained from the Kramer Shear Cell analysis were significantly higher than those reported by Park et al. (2024); however, this discrepancy could be attributed to the difference in setup, as the compared study used a Mini Ottawa Cell, which is smaller in size compared to the apparatus used in this study. In addition, the prior study separated the filling and wrapper for the instrumental analysis, whereas this study conducted the analysis with the wrapper and filling combined.

The breaking point of the dumplings was calculated to determine the nature of their breaking, as shown in Figure 3. The breaking stress refers to the hardness of the dumpling, while the breaking strain refers to the ductility of the dumpling (Jayakumar et al., 2025). From the breaking point analysis, dumplings with 30% broccoli flower powder replacement had a significantly lower breaking stress, while the control dumpling without any broccoli flower powder replacement had a considerably lower breaking strain. As a result, the dumplings with a 30% replacement of broccoli flower powder have a significantly softer texture, while adding broccoli flower powder to the dumplings yields a much more malleable texture. The more malleable texture of dumplings with broccoli flower powder can be attributed to the increased fiber content, which is more flexible compared to proteins, which are much more rigid (Midwood and Schwarzbauer, 2002). Meanwhile, the lack of protein interactions is evident at a 30% broccoli replacement level, resulting in a significantly softer texture, as observed in the breaking point analysis. The decrease in breaking point force may be significant, as it has been associated with a reduction in sensory rating in meat sausages (Baer and Dilger, 2014). Overall, the Kramer Shear Cell analysis revealed that Total Shear Work and Young's Modulus decreased with the substitution of broccoli flower powder for ground pork in dumplings; in the breaking point analysis, broccoli flower powder led to more malleable dumplings with its fiber content, while excessive broccoli flower powder inclusion led to a softer breaking point of the dumplings.

3.5 Relationship between texture profile analysis and kramer shear cell analysis

Figure 4 shows the Pearson Correlation analysis between each textural attribute obtained through texture profile analysis and

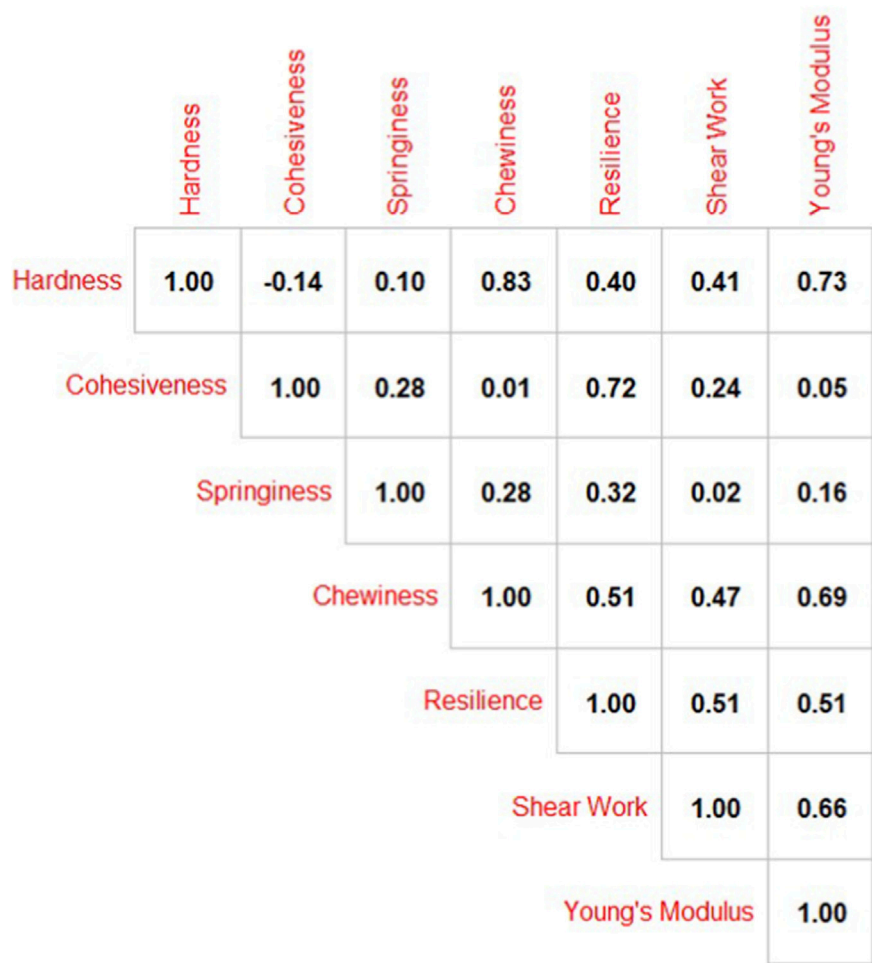


FIGURE 4
Pearson correlation analysis between each variable of texture profile analysis and Kramer shear cell analysis. -1.00 refers to perfect negative correlation, 0.00 refers to no correlation, and 1.00 refers to perfect positive correlation.

Kramer shear cell analysis. The two pairs that were similar in theory between the two tests were the Young's Modulus and hardness, along with the Kramer Shear Cell work and chewiness. Young's Modulus and hardness should be related as both refer to the hardness or firmness of the sample. In contrast, Kramer Shear Cell work and chewiness are related, as both concern the energy or work required to completely decompose the sample (Sañudo-Barajas et al., 2019). From the Pearson Correlation analysis, the degree of correlation between Young's Modulus and the hardness was 0.73, while the degree of correlation between Kramer Shear Cell work and chewiness was 0.47. Both pairs of variables exhibit a substantial positive correlation between the two tests, although Young's Modulus and hardness show a more significant degree of correlation (Figure 4). In addition, both pairs of analyses showed similarities in their trend when broccoli flower powder was added, in that all variables showed a decrease in their attributes when broccoli flower powder was used to replace ground pork. Thus, it can be concluded that similar trends exist between Young's Modulus and hardness, as well as between Kramer Shear Cell work and chewiness, and each set of variables exhibits a substantial positive correlation. Overall, the correlation between the two variables can be used to

relate the Kramer Shear Cell and Texture Profile Analysis, providing insight into the textural attributes of the dumplings.

4 Conclusion

In summary, this study examined the changes in functional and textural attributes resulting from the substitution of broccoli flower powder for ground pork in pan-fried Gyoza dumpling fillings. Some functional properties showed consistency or improvement with the control dumpling filling without any substitution of broccoli flower powder, such pH, cooked color, and cohesiveness; however, select attributes showed the limitation of the broccoli flower powder, such as the hardness, chewiness, Young's Modulus, and Kramer Shear Cell Work. In addition to observing the differences with the inclusion of broccoli flower powder, a correlation was developed between the Texture Profile Analysis and the Kramer Shear Analysis. Overall, the formulation with 10% broccoli flower powder replacement improves the quality of the dumplings the best, without severely altering its textural properties.

Future work should focus on establishing additional relationships between the attributes, particularly between the textural qualities and the sensory attributes. Understanding the relationship between the two attributes leads to a deeper understanding of the relationship between the texture and sensory characteristics of dumplings. This relationship has not been commonly analyzed. In addition, a critical limitation of the study is that sensory evaluation was not conducted; further studies on the sensory attributes of the dumplings and consumer acceptance is required.

Future work will focus on addressing the limitations of the dumpling fillings with broccoli flower powder, with specific the texture and cook-loss. Using additional guar gum as a binder may be a promising solution; however, the usage of other binders or ingredients may be critical in developing dumplings with improved properties. Additionally, physical modifications of broccoli flower powder, such as ultrasonication and high-pressure processing, may alter the powder's structure, making it more suitable for use in dumplings as a replacement for ground pork. Overall, replacing broccoli flower powder for ground pork in dumplings created promising dumplings that contain additional nutritional benefits; however, limitations, especially in their textural properties, need to be improved for the product to have the potential to be accepted by consumers.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

KK: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Writing – original draft. DT: Conceptualization, Formal Analysis, Investigation, Methodology, Writing – original draft. BS: Formal Analysis, Investigation, Methodology, Writing – original draft. KH: Formal Analysis, Investigation, Methodology, Writing – original draft. FB: Conceptualization, Formal Analysis, Investigation, Methodology,

Resources, Writing – original draft. AM: Conceptualization, Funding acquisition, Supervision, Validation, Writing – review and editing.

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