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Antioxidant Properties and Sensory Preference of Broccoli Affected by Culinary Practices

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Abstract

Broccoli provides a good source of many nutrients and bioactive compounds. However, bitterness of broccoli deterred sensory desirability and furthermore impacted its consumption. Cooking and seasoning addition can be used to reduce the bitterness and to increase the preference of vegetables. The objective of this study aims to investigate the effect of blanching and flavor enhancement with various sauces on the bioactive and organoleptic properties. Broccoli was prepared: raw (C), blanched (B), blanched and flavored with Japanese style sauce (F1), with cheese (F2), and with Chinese style sauce (F3). The bioactive compounds (polysaccharide and phenolic compounds), antioxidant properties (DPPH and ABTS scavenging activities), and sensory preference characteristic were evaluated. The results showed blanching and combined with seasonings significantly altered the color parameters (a*, C* and h°) of broccoli. While blanching and sauces additions improved antioxidant contents and capacity as well as all sensory acceptances tested. Compared to the control, blanching and sauces additions increased the contents of phenolic compounds and polysaccharides from 8.3 to 8.4-10.0 and from 78 to 93-106 mg/g dw, respectively. While blanching and sauces increased the scavenging capacity of DPPH and ABTS from 1.29 to 1.43-1.83 and from 3.28 to 4.52-5.27mg Trolox/100g, respectively. Principal component analysis (PCA) analysis further showed blanching and sauces additions were positively correlated with the acceptance of flavor, taste and overall but negatively correlated to color acceptance. In conclusion, blanching or flavorings retained color acceptance (sensory score >5) and enhanced antioxidant capacity and sensory preference.

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Introduction

Broccoli (*Brassica oleracea* var. italica), belonging to a cruciferous vegetable, contains macro- and micro-nutrients (protein, vitamins and minerals) as well as excellent sources of bioactive phytochemicals such as dietary fiber, phenolic compounds, flavonoids, polysaccharides and glucosinolates.[1] Those bioactive compounds were reported to associate with several health-promoting benefits including anticancer, antioxidant, anti-inflammatory, neuroprotective and metabolic disorder regulatory effects.[2]

In addition to provide daily required nutrients, many disease risks could also be reduced by sufficient intake of fruits and vegetables.[3] However, intrinsic and extrinsic factors including vegetable properties (odor, taste, texture, appearance) and/or cultural preference and other factors (cost, availability, and preparation methods and time) were identified as important determinants of ultimate vegetable consumption.[4] Bitter taste is the main unpleasant taste responsible for consumer's rejection of certain vegetables.[5] Heat treatments including blanching, boiling, roasting and steaming influenced sensory characteristics of vegetables.[6] Glucosinolates, the bitter components of broccoli, might leach into heating medium or breakdown during heating process.[7] Blanching (3 min) significantly removed 55% bitter content and thus improved preference of cauliflower.[8] However, over-cooking released sulfurous compounds from cauliflower and produced an unpleasant odor and bittertaste;[5] which resulted in more vegetable waste.[9] Long time (1.5-2 h) between cooking and consumption caused loss of attractive color and flavor and increased vegetable wastes.[10]

Flavor enhancement has been proposed to overcome undesirable taste of vegetable and increase vegetable consumption. Spice MyPlate revealed flavor enhancement by spices and herbs addition overcome undesirable taste of vegetables.[11] and increased 18.2% vegetable intake.[12] Bakke[13] found that sugar and salt reduced bitterness and enhanced preference of vegetables. Incorporation of light butter and salt increased the consumption of steamed vegetables by 6.6 and 0.5%, respectively.[14] Higher preference of spice and/or herb seasoned vegetables against the unseasoned counterparts was also reported.[15] Non-vegetables ingredients, such as bean products and mushroom in mixed-vegetable dishes, also promoted vegetable flavor and increased vegetable consumption.[10]

While the previously published studies are mainly focused on the preference and consumption of vegetables, the effects of cooking methods and seasoning additions on the vegetable functionalities are rarely found. Thus, the objective of this study is to evaluate the effect of blanching alone and in combination with various sauces additions on the functionality and sensory desirability of broccoli simultaneously.

Materials and Methods

Sample preparation

Broccoli (*Brassica oleracea* var. italica) was purchased from a local market (Yunlin, Taiwan). After cleaning, the florets and stems were separated and cut into pieces with the length of 4-5 cm.

Samples (florets or stems, 600 g each) were prepared: raw (control; C); blanched for 3 min in 2 L boiling water (B); blanched and then seasoned (1%) with Japanese style sauce (F1); with low moisture part skim shredded mozzarella cheese (Kirkland Signature, Costco Wholesale Corp., Seattle, WA, USA) then re-heated in a convection oven at 100 oC for 3 min (F2); and with Chinese style sauce (fried shallot and soy sauce) (F3). Japanese style sauce (Japanese dressing, UNI-President Chain Store Co., Taiwan) is composed of soy sauce, sugar, vinegar and olive oil and thus representing the taste mixture of salty, sweet, sour, and oily. Mozzarella cheese (Kirkland Signature, Costco Wholesale Corp., Seattle, WA, USA) provided milky flavor. While Chinese style sauce is composed of 10%fried shallot (I-Mei Foods Co., Ltd. Taoyuan, Taiwan) and 90% soy sauce (NaCl 7.2%; Yamaki Mentsuyu Soy Sauce, Costco Wholesale Corp., Seattle, WA, USA) for inducing fragrant and salty taste, respectively. Samples were placed in white ceramic bowls and served within I h after preparation at ambient temperature.

Determination of Color Parameters

The color parameters of floret and stem were finely cut and determined with a color difference meter (NE4000, Nippon Denshoku Industries, Tokyo, Japan) and expressed as Hunter L* (lightness-darkness), a* (greenness-redness), and b* (blueness-yellowness) values. Chroma value ($C^* = (a^{*2}+b^{*2})^{1/2}$) and hue angle were calculated from a* and b* values (h^o = arctan (b*/a*)+180°).[16]

Determination of Total Phenolic Contents

For the determination of antioxidant component contents and capacity, florets and stems were prepared in the following extraction process. Florets and stems were homogenized (Oster, Sunbeam Products, Inc., USA) for 2 min. The homogenized samples (1 g) were vortexed with 80% methanol for 5 min and then centrifuged at 10,000 rpm for 10 min. The content of total phenolic compounds was analyzed spectrophotometrically according to the methods of Brand-Williams[17] and Kim.[18] The mixture of 0.1 mL supernatant or gallic acid (as standard), 0.5 mL Folin-Ciocalteu's reagent and 0.4 mL sodium carbonate (7.5%) was thoroughly mixed, reacted at room temperature for 40 min and then measured the absorbance at 760 nm. Total phenolic content was expressed as mg gallic acid equivalent per g (dry weight) of sample (mg GAE/g).

Determination of Total Polysaccharides

The content of total polysaccharides was quantified spectrophotometrically using the phenol-sulphuric acid method.[19] The mixture of 0.2 mL supernatant or glucose (as reference standard), 0.2 mL of 5% aqueous solution of phenol and 1 mL of concentrated sulphuric acid was mixed thoroughly. The mixture was heated in a water bath at 100 °C for 10 min and then cool to room temperature; and the absorbance at 490 nm was measured. The total polysaccharide content was expressed as milligrams of glucose per g (dry weight) of sample (mg glucose/g).

Determination of Antioxidant Capacity

Antioxidant capacity including the scavenging abilities of DPPH and ABTS+ radicals were determined. DPPH scavenging was assayed using the methods of Demircan[20] with modifications. The mixture of 0.25 mL aliquot of the sample or Trolox (as standard) and 1.25 mL DPPH (0.1 mM) solution was incubated in the dark at room temperature for 60 min and then absorbance of reaction mixture was measured at 517 nm. The DPPH scavenging ability was expressed as mg Trolox/100 g dw.

ABTS+ scavenging effect was determined based on the method of Saepudin[21] with modifications. The mixture of 50 µL of the sample or Trolox (as standard) and 1.9 mL of ABTS·+ solution was incubated in the dark at room temperature for 6 min. Absorbance was measured at 734 nm. The ABTS+ scavenging ability was expressed as mg Trolox/100 g dw.

Sensory Evaluation

Sensory evaluation was conducted according to the Quantitative Sensory Testing described by Tao[22] with slightly modified. Sensory attributes including preference of color, odor, flavor and overall acceptance were descriptively evaluated by 20 trained panelists (non-smoker, 9 male and 11 female graduate students or staffs aged between 22 to 40 years old from the Department of Food Science, National Chiayi University). After instructive session, five samples (control, blanched, flavored with Japanese style sauce, flavored with cheese, and flavored with Chinese style sauce) were served according to random 3-digit number discrimination test. Bottled water was provided to clear taste between every sample testing. The sensory preference of sample was graded using a 9-point hedonic scale (1- dislike extremely, 9- like extremely).

Statistical Analysis

Data was expressed as the mean ± standard deviation. Student's t-test was used to compare the difference between control (raw) and treatment groups. Sensory acceptances data were analyzed using one-way analysis of variance (ANOVA) and Fisher least significant difference (LSD). The $p < 0.05$ was considered as significant difference. Principle component analysis (PCA) was performed on the correlation matrix of the sensory acceptances. All the statistical analysis was carried out using SPSS Statistics, version 21.0 (IBM Corp., Armonk, NY, USA).

Results and Discussion

Color Characteristics

The color characteristics (lightness and chroma) of broccoli, determined according to the method of CIE system, of raw (control, C), blanched (B), blanched and flavored with Japanese style sauce (F1), with cheese (F2), and with Chinese style sauce (F3) are shown in Figure 1. The L* values of broccoli were in the ranges of 20-30 (Figure 1A). The a* (Figure 1B) and b* (Figure 1C) values were in the ranges from -3 to -13 and from 6 to 20; respectively. The chroma value (C*) (Figure 1D) and hue angle (h°) (Figure 1E), calculated from a* and b* values, were in the ranges of 10.1-24.1 and 108-138, respectively.

Culinary practices, including thermal treatment and seasoning, might affect color characteristics of broccoli. Thermal treatments for long time, such as boiling, frying or over-cooking usually resulted in the conversion of chlorophyll into pheophytin and thus yellowing broccoli. In this study, blanching for 3 min non-significantly affected the lightness of broccoli; while blanching combined with seasonings might turn greenish yellow of broccoli into olive green. Blanching and addition of 1% Japanese style sauce (F1), cheese (F2) or Chinese style sauce (F3) significantly altered the color parameters (a*, C* and h°) ($p < 0.05$) and changed the appearance of broccoli.

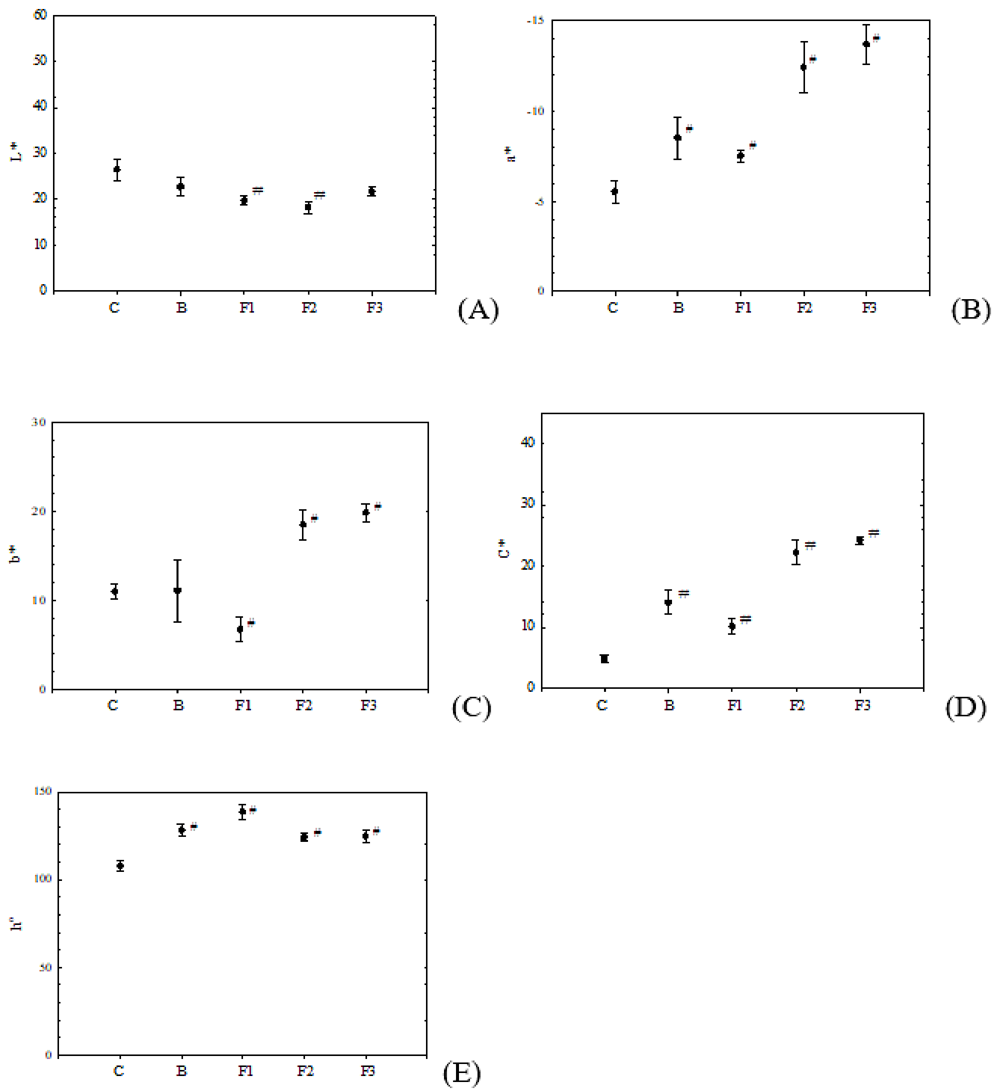

Fig. 1: Color properties of broccoli on (A) lightness (L*), (B) chromaticity a*, (C) chromaticity b*, (D) chroma value (C*) and (E) hue angle (h°)

# $p < 0.05$ compared to the control

Sample codes- C: raw broccoli as control; B: blanched; F1: Japanese style sauce; F2: cheese; F3: Chinese style sauce

Blanching resulted in color change of broccoli from light deep green into deep green and seasoning further turned the appearance into heavy deep green. In a previous study, ho of broccoli increased from 118 to 124 after microwaved for 60 s; and thus color changed from typical green to yellow green.[23] Broccoli blanched with microwave appeared darker than blanched with hot water. In the previous broccoli study of Yuan,[24] no cell disruption leading the release of organic acid for the conversion of chlorophyll (green) into pheophytin (grey-green) was found after 5 or 8 min blanching in boiling water. Similarly, spinach, carrot and cauliflower were cooked in boiling water (1 to 5 ratio, w/v) for 10, 12, and 9 min, respectively, L and b values were not significantly different between raw and boiled vegetables; while boiling enhanced greenness (a value) intensity.[25] In this study, 3 min blanching slightly impacted color appearance of broccoli. Sauce addition, including 1% Japanese style sauce (F1), cheese (F2) or Chinese style sauce (F3), did not alter the portion distribution of chlorophyll and pheophytin; thus, color appearance did not change markedly.

Antioxidant Capacity

Excess oxidative status from diet and living habits leads to unbalanced antioxidant defense system and eventually to chronic diseases. The scavenging capacity of DPPH and ABTS free radicals were generally conducted to evaluate antioxidant potentials of vegetables.[20] Phenolic compounds and polysaccharides in broccoli are excellent components for health-promoting benefits including anticancer, antioxidant, anti-inflammatory and metabolic disorder regulatory effects.[1] Figure 2A showed the effects of blanching or seasonings on phenolic and polysaccharide contents of broccoli. Blanching and seasoning increased phenolic contents, 8.7, 9.1, 8.4 and 10.0 mg/g dw for blanched, F1, F2 and F3, respectively, which is higher than control (8.3 mg/g dw) samples ($p < 0.05$). Compared to control (78 mg/g dw), blanching and seasoning increased polysaccharide contents, 97, 103, 93 and 106 mg/g dw for blanched, F1, F2 and F3, respectively ($p < 0.05$). The effect of seasoning addition on antioxidant capacity, expressed as DPPH and ABTS free radicals scavenging equivalents, were shown in Figure 2B. The Trolox equivalents for ABTS scavenging of seasoning additions, 5.16, 4.52 and 5.27 mg Trolox/100g for F1, F2 and F3, were similar to blanched treatment (5.01 mg Trolox/100g) but significantly higher ($p < 0.05$) than raw broccoli (3.28 mg Trolox/100 g). Blanching and seasoning addition also significantly enhanced DPPH scavenging capacity, 1.56, 1.63, 1.43 and 1.83 mg Trolox/100 g for blanched, F1, F2 and F3 compared to control (1.29 mg Trolox/100g) ($p < 0.05$).

Plant tissue structure disintegration of broccoli by blanching and seasoning addition might be used to explain the increased contents of phenolic compounds and polysaccharide.[26] Moreover, higher phenolic compounds and polysaccharides consequently raised antioxidant capacity of DPPH and ABTS scavenging. Our results showed positive correlation between photochemical contents and antioxidant capacity. The correlation coefficients (r) between phenolic content and DPPH or ABTS were 0.96 and 0.71, respectively; while the correlation coefficients (r) between polysaccharide content and DPPH or ABTS were 0.94 and 0.98.

Place of origin, soil culture, season, temperature and time of process or cooking influenced phenolic contents of vegetables.[27] In this study, blanching increased phenolic contents from 8.3 to 8.7 mg/g dw; while seasoning addition increased phenolic contents to 8.4-10.0 mg/g. Similar enhancing effect of blanching on phenolic contents were reported by Severini,[28] the contents of phenolic compounds in broccoli increased from 10.88 to 11-13 mg/g dw after 30-180 s blanching. Stewart[26] also showed that thermal treatments (steaming or microwave heating) enhanced the proportion of free phenolic compounds in green pea, chili and broccoli. In addition to improving the contents of phenolic compounds, blanching in boiling water for 5 min and microwave at 1000 W for 1.5 min increased DPPH scavenging capacity to 78 and 90%, respectively.[29] Similar to Turkmen's observation, stronger antioxidant effect resulting from higher phenolic compounds induced by thermal treatment was reported by Miglio.[23]

In addition to serve as antioxidants, plant polysaccharides also contribute other physiological functionality, such as immune regulation. Acid pectin polysaccharides, molecular weight ranged 12-400 KDa, from broccoli have been demonstrated to enhance immune activity.[30] Wang[31] found polysaccharides with low molecular weight from broccoli exerted excellent DPPH and ABTS scavenging capacity. In the study of Cao,[32] DPPH and ABTS scavenging capacity were 48~26% and 99~90% for neutral polysaccharide and ascorbic acid at the concentration below 0.6 mg/ml in Brassica rapa, respectively. In this study, polysaccharides were also correlated well with DPPH and ABTS scavenging capacity.

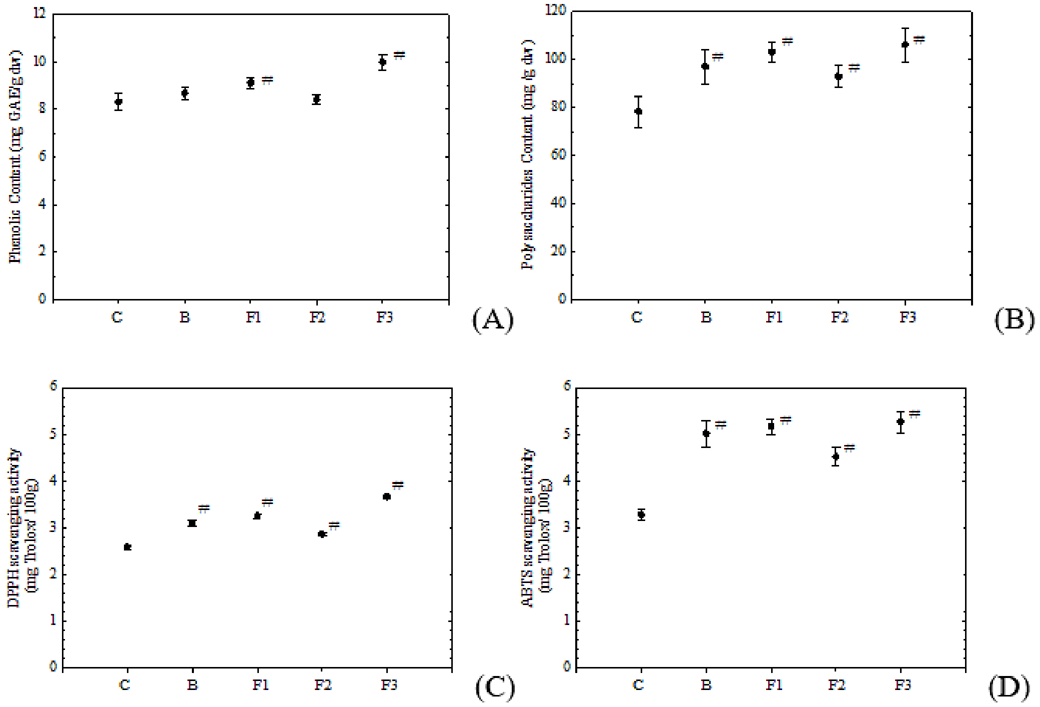

Fig. 2: Phenolic content (A), polysaccharides content (B) and scavenging activity of broccoli on DPPH (C) and ABTS (D) radicals

# p < 0.05 compared to the control

Sample codes- C: raw broccoli as control; B: blanched; F1: Japanese style sauce; F2: cheese; F3: Chinese style sauce

Sensory Evaluation

The sensory preference included color, odor, flavor, and overall acceptance of broccoli prepared with blanching or seasoning addition is listed in Table 1. Blanching significantly enhanced color preference of broccoli than other treatments; while seasoning addition improved odor and flavor acceptance. The color preference of broccoli followed the pattern: blanched (6.95) > flavored (5.90-6.35) > Raw (control, 5.70). Compared to raw and blanched broccoli, seasoning addition enhanced both odor (6.35-6.53) and flavor preference (6.69-6.88). With the averages of 5.90-6.95, the color preference was acceptable for blanched and flavoring addition broccoli. Overall acceptance declined in the order of flavorings (6.05-6.74) > blanching (4.84) > raw (2.37). As described above, lightness (L*) and chroma (a*, b*), determined by CIE system, slightly changed (Figure 1); however, the preference was in the acceptable range (scores 6-7). Blanching might eliminate the intensity of grassy flavor, bitter and astringency and seasonings with sour, oil and soy sauce improved the preference of flavor, taste and overall acceptance. Moreover, blanching or flavorings sustained the contents of bioactive compounds (phenolic compounds and polysaccharides) and antioxidant capacity (DPPH and ABTS scavenging effect). From the above data, it can be concluded that blanching in boiling water for 3 min and seasoning addition of broccoli were considered beneficial for antioxidant capacity and sensory acceptance.

Principal Component Analysis (PCA) was conducted to evaluate sensory preference (color, flavor, taste and overall acceptance) and grouped into two main components, PC1 and PC2. The values of Kaiser-Meyer-Olkin (KMO) (0.744) and Bartlett's test ($p < 0.05$) indicated PCA model was appropriate to distinguish sensory preference. PCA data were shown in Table 2: Eigen value of PC1 and PC2 was 2.785 and 0.932; while variance contribution rate (% of variance) of PC1 and PC2 was 66.91 and 26.01%, respectively; cumulative variance contribution rate was 92.92%. Load factors of PC1 were 0.890, 0.966 and 0.968 for odor, flavor and overall acceptance, respectively, but only 0.114 for color preference. The load factors of PC2 for color, odor, flavor and overall acceptance were 0.991, 0.221, 0.046 and 0.082, respectively. While load factor closes to 1 indicating the factor contributed more principle component, the value is near to 0 indicating no significant correlation between factor and principle component. High load factor of odor, flavor and overall acceptance of PC1 (Table 2) suggested strong correlation; on the other hand, high load factor (0.991) of PC2 for color indicated color is the major contributed factor for PC2. From the data of PC1 and PC2, acceptance scores of odor, flavor and overall were 3.467-3.659 in PC1 and acceptance score of color was 1.717 in PC2. Weight ratios calculated from sensory scores from PC1, were 4.5, 30.9, 32.6 and 32.0% for color, odor, flavor and overall acceptance, respectively; while weight ratios calculated from PC2 were 76.9, 15.0, 3.0 and 5.3% for color, odor, flavor and overall acceptance, respectively. Moreover, PC overall scores were calculated according to the following equation:

PC overall score = PC1score * % of variance PC1 / % of variance (PC1+PC2) + PC2 score *% of variance PC2 /% of variance (PC1+PC2)

Table 1: Sensory acceptances of raw, blanched and seasoned broccoli

	Raw (C)	Blanched (B)	F1	F2	F3
Color	5.70 ± 2.11^{bc}	6.95 ± 1.23^{a}	5.90 ± 1.33^{c}	6.35 ± 1.14^{b}	6.05 ± 1.47^{b}
Odor	4.06 ± 1.71^{c}	5.47 ± 1.23^{b}	6.53 ± 1.12^{a}	6.47 ± 1.55^{a}	6.35 ± 1.84^{ab}
Flavor	2.31 ± 1.20^{c}	5.25 ± 1.18^{b}	6.69 ± 1.1^{a}	6.88 ± 1.67^{a}	6.75 ± 2.11^{a}
Overall acceptance	2.37 ± 1.34^{d}	4.84 ± 1.26^{c}	6.05 ± 1.61^{b}	6.74 ± 1.33^{a}	6.11 ± 2.23^{ab}

Data in the same row with different superscripts are significantly different ($p < 0.05$)
Sample codes- C: raw broccoli as control; B: blanched; F1: Japanese style sauce; F2: cheese; F3: Chinese style sauce

Table 2: PCA data (Eigen value, variance contribution rate, cumulative variance contribution rate, load factor and acceptance scores (weight ratio)) of raw, blanched and seasoned broccoli

	PC1	PC2	Score (weight ratio)		
Eigen value	**2.785**	**0.932**	**PC1**	**PC2**	**PC overall**
% of variance	66.91	26.01			
Color	0.114	0.991	0.508±0.125 (4.5%)	1.717±0.424 (76.9%)	0.847 ± 0.209 (9.7%)
Odor	0.890	0.221	3.467±1.282 (30.9%)	0.335±0.124 (15.0%)	2.590±0.958 (29.7%)
Flavor	0.966	0.046	3.659±1.680 (32.6%)	0.068±0.031 (3.0%)	2.654±1.218 (30.5%)
Overall acceptance	0.968	0.082	3.597±1.547 (32.0%)	0.118±0.051 (5.3%)	2.623±1.128 (30.1%)

PC overall scores related to color, odor, flavor and overall acceptance were 0.847, 2.590, 2.654 and 2.623; while weight ratios were 9.7, 29.7, 30.5 and 30.1%, respectively.

PC1, PC2 and PC overall scores calculated from load factor and weight ratio of sensory characteristics (Table 2) of broccolis were listed in Table 3. All the scores, PC1, PC2 and PC overall scores, of blanching and seasoning addition were significantly higher than those of raw materials.

PC overall scores for seasoning addition samples were 9.81-10.79, which was significantly higher than those scores of blanched (8.15) and raw broccoli (4.91). From the above data, it can be concluded again: odor, flavor and overall acceptance were the major contributors of PC1. During blanching, the perception intensity of grassy smell, bitterness and astringency can be removed and thus enhanced sensory acceptance. While flavoring with vinegar/oil or soy sauces also strengthened acceptance. The major contributor of PC2 was color; however, pigments of broccoli were not disturbed by short-time blanching and seasonings and thus color preference was not affected in this study. Compared the percentage of variance of PC1 (66.91%) to PC2 (26.01%), PC1 played more important role for acceptance. In this study, the sensory scores (Table 1) of all the samples treated with seasonings were in the range of 6.05-6.11 indicated consumers accepted all the seasoning treatments (1 was highly undesirable and 9 was highly desirable).

With PC1 and PC2 serving as independent variances, linear regression analysis at 95% confidence interval was performed to evaluate sensory acceptance scores of various treatments (raw, blanched and seasoned). CoePlot of raw, blanched and seasoned broccoli were shown in Figure 3A-C. Beta-standardized regression coefficient (0.4 to 0.6) of PC1 indicated positive correlation between preferences of odor, flavor and overall of blanched and flavored samples and overall sensory scores. While β-standardized regression coefficient (-0.2 to -0.4) of PC2 suggested color acceptance was negatively correlated to overall sensory scores.

Several studies investigated how sensory active compounds affected sensory trials. The interactions between sensory active compounds (glucosinolate, isothiocyanates, phenolics and polysaccharides) in vegetables (3 cultivars of broccoli, 5 of Brussels sprout, 3 of cauliflower, and 4 of kohlrabi, both raw and cooked) and sensory characteristics were analyzed by Wieczorek.[33] Results of PCA showed bitterness concentrations (glucosinolates) negatively correlated to sensory acceptance and sweetness positively correlated to desirability. Cooking increased phenolics and polysaccharides concentrations but decreased glucosinolate levels, which thus enhanced overall sensory acceptance. Polysaccharides may improve consumers' acceptance of cooked vegetables by masking bitterness perception.[34] To compared with previously published report,[35] the levels of bitterness compounds in vegetables (Brussels sprouts, kale and asparagus) positively correlated to hedonic scales (r= 0.45) but negatively

Table 3: PC1, PC 2 and PC overall scores of raw, blanched and seasoned broccoli

	PC1	PC2	PC overall
Raw	6.08±2.79	1.89±0.64	4.91±2.10
Blanched	10.38±3.00*	2.41±0.39*	8.15±2.22*
F1	12.89±3.14*#	2.23±0.44*#	9.91±2.33*#
F2	14.06±2.78*#	2.40±0.36*	10.79±2.05*#
F3	12.74±4.52*#	2.26±0.54*	9.81±3.37*#

The sample codes are the same as in Table 1
* compared with control (Raw) ($p < 0.05$)
# compared with blanching treatment ($p < 0.05$)

correlated to acceptance (r= -0.28).Besides, perception intensity of bitterness and acceptance were significantly negative correlated (r= -0.22, $p < 0.01$); while perception intensity of sweetness and acceptance were significantly correlated (r= 0.34,p < 0.01). Unpleasant tastes including bitterness, astringent and grassy flavor deterred vegetable consumption.[35] Incorporation of vegetable puree into desserts and salty dishes was suggested to increase vegetable intakes.[36] In this study, palatability improved by blanching and seasoning addition might provide an alternative approach to promote vegetable consumption.

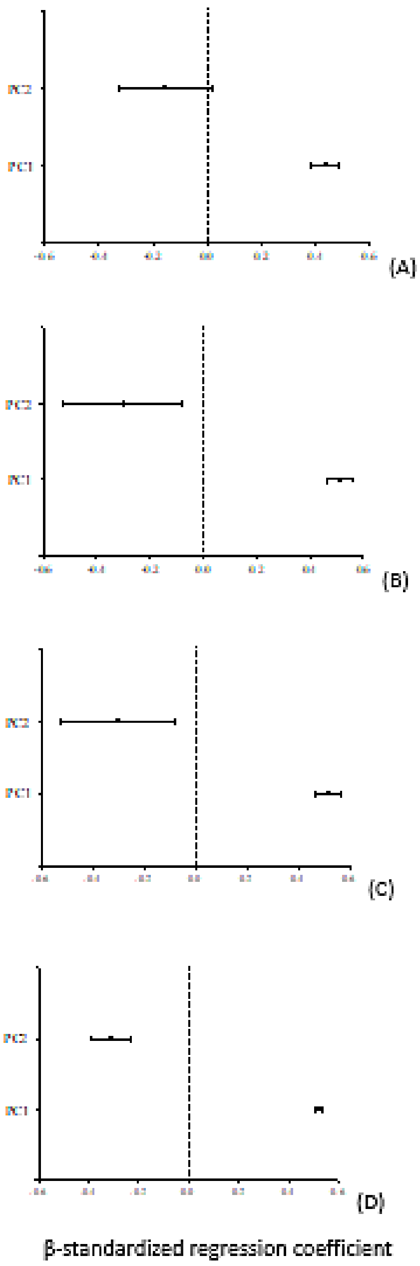

Fig. 3: PCA-CoePlot – control (A), blanched (B), seasoned (C) and overall acceptance (D)

Conclusion

Vegetable intake is associated with healthy promotion. However, bitterness of broccoli deterred sensory desirability and furthermore impacted its consumption. It is important to development a strategy to reduce broccoli waste. Cooking and flavor enhancement were proposed to overcome undesirable taste barrier and improve vegetable consumption. As compared to untreated broccoli, this study demonstrated blanching and sauce additions of 1% Japanese style sauce (F1), cheese (F2) or Chinese style sauce (F3) not only remained color acceptance and but also significantly improved antioxidant capacity and sensory preference. With better consumer's acceptance, our results can provide a strategy to school and government for reducing vegetable waste.

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Conflict of Interest

The author(s) do not have any conflict of interest.

Data Availability Statement

All data is provided in full in the tables and figures section of this paper.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Author Contributions

- **Pei-Yu Tien:** Methodology, investigation, data curation, validation.
- **Pei-Fen Yang:** Methodology, investigation, data curation.
- **Yih-Ming Weng:** Data curation, formal analysis, writing - review & editing.
- **Zer-Ran Yu:** Conceptualization, data curation, methodology, statistical analysis.
- **Be-Jen Wang:** Conceptualization, supervision, writing - review & editing.

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