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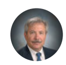

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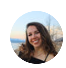

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Microgreens: Consumer sensory perception and acceptance of an emerging functional food crop

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Abstract: Microgreens are an emerging functional food crop with promise for sustainably diversifying global food systems, facilitating adaptations to urbanization and global climate change, and promoting human health. Previous work suggests microgreens have high nutritional quality, low environmental impacts, and broad consumer acceptance. For better reception into the global food system and increased per capita consumption, research is needed to elucidate consumer acceptance of various microgreens species, including factors contributing to their acceptance or lack thereof. Using a consumer panel ($n = 99$), this study evaluated consumer sensory perception and acceptability of six microgreens species (arugula, broccoli, bull's blood beet, red cabbage, red garnet amaranth, and tendril pea), and potential drivers and barriers to consumer acceptance. All microgreens species received high mean liking scores for acceptability by consumers (means ranged from highly acceptable to slightly acceptable), with more distinct differences across microgreens species for flavor and overall acceptability, which appeared to be driven by specific sensory properties. Data from principal component analysis demonstrated that high acceptability scores were associated with higher intent to purchase microgreens and negatively associated with food neophobia. Participants indicated that factors such as knowledge and familiarity of microgreens, cost, access/availability, freshness/shelf life, among other factors, influence their intention to purchase microgreens. These findings suggest that further integration of microgreens into the global food system will be met with high consumer acceptability, but needs to be aligned with enhanced consumer education regarding microgreens, as well as considerations of cost, availability/access, and freshness/shelf life.

Keywords: food bioactives, food systems, human health, micronutrients, sustainability

Practical Application: Researchers investigated consumer sensory perception and acceptability of six microgreens species (arugula, broccoli, bull's blood beet, red cabbage, red garnet amaranth, and tendril pea), and potential drivers and barriers to consumer acceptance. All microgreens tested had high consumer acceptability, but certain factors such as sensory perception and food neophobia impacted their acceptability. Additionally, participants indicated that factors such as knowledge, access and availability, cost, freshness, and shelf life may impact the purchasing of microgreens and thus are important factors to consider for further integration of this emerging functional food crop into the global food system.

1. INTRODUCTION

Microgreens are the young and tender cotyledonary leafy greens (including hypocotyl, if applicable) of most vegetables, grains, and herbs, primarily from the Brassicaceae, Asteraceae, Apiaceae, Amaryllidaceae, Amaranthaceae, Cucurbitaceae, Facaceae, and Lamiaceae families (Choe, Yu, & Wang, 2018; Kyriacou et al., 2016). They are harvested within approximately 10–20 days of seedling emergence, are comprised of cotyledons (i.e., seed leaves), stems, and first true leaves, and are usually harvested at the soil surface (Choe et al., 2018; Mir, Shah, & Mir, 2017). These young greens are known for their variety of colors, textures, and flavors, and thus have recently gained popularity in culinary establishments as garnishes and toppings (Choe et al., 2018), suggesting their potential for enhancing the organoleptic properties of meals and increasing consumer familiarity. Importantly, microgreens are an emerging functional food crop with promise for sustainably diversifying food systems and promoting human, population, environmental, and economic health.

Available data indicate that microgreens are rich sources of micronutrients and bioactive compounds, and that the contents of these compounds may be higher than that of their mature counterparts (Choe et al., 2018; Paradiso et al., 2018; Weber, 2017; Xiao, Lester, Luo, & Wang, 2012). In fact, various microgreen species have been shown in several independent investigations to contain higher levels (up to 260-fold higher in some cases) of certain vitamins (i.e., vitamins C, E, K, and provitamin A/beta-carotene), minerals (i.e., calcium, magnesium, iron, manganese, zinc, selenium, and molybdenum), and bioactive compounds (i.e., carotenoids, total polyphenols, anthocyanins, glucosinolates, and chlorophyll) than mature counterparts (Huang et al., 2016; Paradiso et al., 2018; Pinto, Almeida, Aguiar, & Ferreira, 2015;

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Xiao et al., 2012). These data suggest that microgreens can be utilized as a concentrated source of micronutrients and health-promoting bioactive compounds, though more research is needed to elucidate their nutritional and bioactive compound properties, particularly with respect to the influence of growing practices. For instance, microgreens can be grown commercially in controlled indoor agriculture environments (e.g., greenhouses, vertical farms, warehouses) and in open environments by individuals, with the use of soil or an alternative growing media, and in the presence of natural or artificial light (Renna, Di Gioia, Leoni, Mininni, & Santamaria, 2017). Various preharvest factors may not only influence plant growth but also their levels of micronutrients and bioactive compounds. Considerations should include seed sowing rate due to competition for resources (e.g., nutrients), the use of fertilizers or lack thereof and their nutrient contents, biofortification, and lighting types, wavelengths, and dosage which can influence plant secondary metabolite production and thus the levels of bioactive compounds (Alrifai, Hao, Marcone, & Tsao, 2019; Choe et al., 2018; Mir et al., 2017).

In addition, there is evidence they can be sustainably produced with minimal environmental impacts (e.g., reduced water requirements, food waste, food transport) (Weber, 2017). Because microgreens can be grown year-round in most indoor locales and particularly in controlled environments, they may be useful in facilitating adaptations to population growth, urbanization, and global climate change, while also increasing the availability of high nutritional quality vegetable crops throughout the year (Benke & Tomkins, 2017; Choe et al., 2018; Mir et al., 2017; Weber, 2017). The high nutritional quality of microgreens and potential ease of meal incorporation suggests they can promote fresh vegetable consumption, micronutrient sufficiency, and increased bioactive compound intake for the promotion of human health and to achieve specific health effects as functional foods such as reduced cardiovascular and metabolic disease risk (Huang et al., 2016; Johnson, Litwin, & Seals, 2019).

To further establish microgreens as a major horticultural food crop, further integrate them into the global food system, and evaluate and disseminate their health impacts, understanding consumer acceptability is critical. To date, only one study has evaluated the sensory properties and consumer acceptance of six select microgreens (Xiao et al., 2015), concluding that all microgreens tested had high consumer acceptability. While promising, more research is warranted to further elucidate consumer acceptance of various microgreens species, including factors contributing to their acceptability or lack thereof by individuals and populations. The objective of this study was to evaluate consumer sensory perception and acceptability of six microgreens species (arugula, broccoli, bull's blood beet, red cabbage, red garnet amaranth, and tendril pea), and potential drivers and barriers to consumer acceptance.

2. MATERIALS AND METHODS

2.1 Microgreens production

Microgreens were grown in the Colorado State University (CSU) Horticulture Center in Fort Collins, Colorado, USA. Though the health impacts of microgreens were not assessed in the present study, the data from this study will inform future research studies that will evaluate their health impacts. Thus, microgreens were selected based on previous research evaluating their sensory attributes and consumer acceptability, nutritional characteristics, environmental sustainability, and health impacts (Huang et al., 2016; Weber, 2017; Xiao et al., 2012, 2015), as well as researcher interest and input regarding their potential for use as functional foods in reducing disease risk. The microgreen species were chosen due to their potential to provide diversity with respect to their organoleptic properties, as well as micronutrients and bioactive compounds demonstrated to influence human health. The six microgreens species evaluated in the present study belong to the Amaranthaceae, Brassicaceae, and Fabaceae plant families and included arugula (*Eruca sativa*), bull's blood beet (*Beta vulgaris*), broccoli (*Brassica oleracea*), red cabbage (*Brassica oleracea* var *capitate*), red garnet amaranth (*Amaranthus tricolor*), and tendril pea (*Pisum sativum*) (Figure 1). Seeds were purchased from a commercial provider (Johnny's Selected Seeds, Fairfield, ME, USA). Approximately 1.5 cm of coir fiber was layered in each standard 1020 black polystyrene germination tray (26.7 × 53 cm), and seeds were evenly sown at rates shown in Table 1. All trays were covered with black polyethylene sheets for 24 to 48 hr after seeds were sown to increase the germination rate and maintain moisture levels. The seeds were grown under light emitting diode (LED) lamps (Philips, Andover, MA, USA) for 17 hr per day at 62 $\mu mol \cdot m^2 \cdot s^{-1}$. Trays were irrigated twice each day with a hand pump sprayer. Eleven trays of each species were planted and harvested for consumer evaluation, and sowing of microgreen seeds was staggered to achieve the same growth stage at harvest for each day of consumer evaluation. All microgreens were harvested 20 days after sowing with the exception of the tendril peas which were harvested after 10 days due to their faster growth rate.

2.2 Consumer participant population and recruitment

A convenience sample of consumers ($n = 99$) was recruited from CSU and the greater Fort Collins, Colorado area through emails sent through university listservs for faculty, staff, and students, flyer distribution, Nextdoor.com, and word of mouth. Qualified study participants were between the ages 18 to 75 years, had no aversions to leafy green vegetables, were nonsmokers, and were not taking antibiotics or being treated for colds, flu, allergies, or nausea. Inclusion and exclusion criteria were confirmed prior to enrollment in the study using the online survey software Qualtrics (Provo, UT, USA). Participants were provided a salad shaker set as an incentive. Participant characteristics are presented in Table 2. This study was approved by the CSU Institutional Review Board, and written informed consent was obtained prior to participants' inclusion in the study.

2.3 Sample preparation

Microgreens were stored at room temperature 1 day prior to each testing date and were harvested within 1 hr of consumption using a sharp knife or scissors. They were cut evenly at the soil level to prevent inflicting plant tissue damage. All samples were washed thoroughly under running water, and excess water and seed residues were removed using a 2-L salad spinner (Fit & Fresh Salad Spinner, Emsa, Emsdetten, Germany). Following harvest and washing, microgreen samples were refrigerated at 4 °C to maintain freshness, but were moved back to room temperature 10 min prior to serving. Five grams of each microgreen species was placed into white sample containers and labeled with a three-digit random number for blinding purposes. The amount chosen (i.e., 5 g) was based on the previously performed study evaluating sensory properties and consumer acceptance of microgreens (Xiao et al., 2015).

Figure 1–Images of microgreens species evaluated in the consumer sensory perception and acceptability test: arugula (A), broccoli (B), bull's blood beet (C), red cabbage (D), red garnet amaranth (E), and tendril pea (F).

2.4 Evaluation of consumer sensory perception and acceptance

Consumer sensory perception and acceptance evaluation were performed based on methods previously described (Bunning, Kendall, Stone, Stonaker, & Stushnoff, 2010; Xiao et al., 2015). A total of 15 consumer acceptance/sensory evaluation sessions were conducted over a 3-day period with no more than eight participants per session. For each session, a detailed explanation and written instructions on the testing procedure and sensory definitions/descriptors were given to each participant prior to starting the session. Hard copies of the consumer sensory perception and acceptability ballot were distributed to each participant. The intensity perception of microgreens sensory attributes (i.e., aroma, astringency, bitterness, grassy, heat, sourness, and sweetness) were evaluated using a nine-category horizontal line scale with verbal magnitude anchor labels ranging from none (1) to strongest imaginable (9), and overall acceptability, and liking/acceptability of appearance, texture, and flavor were evaluated using a nine-point hedonic scale on a horizontal line with verbal anchor label ranging from highly unacceptable (1) to highly acceptable (9). Line scales were determined to be an appropriate choice for consumer sensory and acceptability evaluation of microgreens because they can be applied to both intensity and hedonic responses (Lawless & Heymann, 2010) and because line scales may provide greater sensitivity than a standard nine-point hedonic scale (Greene, Bratka, Drake, & Sanders, 2006). For both scales (i.e., consumer acceptability and sensory perception), anchor labels were spaced apart equally, and any point selected between two anchor labels was assigned a half value between the two points. Descriptors of sensory attributes provided (Table 3) were based on a previous microgreens sensory descriptive analysis (Xiao et al., 2015). Participants were instructed to cleanse their palates with distilled water and unsalted saltine crackers (Kroger, Cincinnati, OH, USA) between each microgreen species. Participants were seated in a quiet environment and separated from each other using white cardboard privacy screens (School Outfitters, Cincinnati, OH, USA).

Table 1–Vegetable species grown as microgreens and their sowing rate for each standard 1020 tray (26.7 × 53 cm) with coir fiber medium.

Species[a]	Plant family	Average sowing rate per 1020 tray (g)
Arugula (*Eruca vesicaria* (L.) Cav.	Brassicaceae	10
Bull's blood beet (*Beta vulgaris* L.)	Amaranthaceae	23
Broccoli [*Brassica oleraceae* L. (Italica group)], organic	Brassicaceae	13
Red cabbage [*Brassica olaracea* L. (Capitata group)]	Brassicaceae	10.5
Red garnet amaranth (*Amaranthus tricolor* L.), organic	Amaranthaceae	7.5
Tendril pea (*Pisum sativum*), organic	Fabaceae	50

[a]Seeds purchased from Johnny's Selected Seeds, Fairfield, ME, USA.

Table 2–Demographics of consumer participants.

Characteristics	Total population (*n* = 99)
Female/male (*n*)	53/46
Age (mean years ± SD, range)	46 ± 16, 19–73
Age categories in years (*n*)	
18–30	18
31–40	24
41–50	14
51–60	17
61–70	22
71–75	4
Race/ethnicity (*n*)	
White	78
Black or African American	3
Hispanic or LatinX	3
Asian	1
Other	3
Two or more races	11
Education (*n*)	
Some college	12
Associate's degree	6
Bachelor's degree	25
Postgraduate	56

Table 3–Descriptors of sensory attributes provided on sensory evaluation ballot.

Sensory attribute	Descriptor of sensory attribute
Aroma	The odor/smell/fragrance/scent
Astringency	Shrinking and puckering of tongue surface, sharpness, acerbity, brininess, tartness, vinegariness, acriditiy
Bitterness	Bitter, pungent, acrid taste
Grassy	Earthy, herbal, or having a flavor of grass
Heat	Peppery, spicy, or pungent
Sourness	Sour taste, causing mouth to pucker
Sweetness	Sweet taste

2.5 Evaluation of food neophobia, leafy green vegetable consumption, and intention to eat microgreens

In order to better characterize the study participants, as well as to identify possible drivers and barriers to microgreen acceptability, sensory perceptions, and intention to purchase microgreens in the future, study participants completed a 10-item questionnaire to ascertain food neophobia where they were asked to rate the level to which they agreed or disagreed on a seven-point scale. High food neophobia is defined as a food neophobia score (FNS) >35, moderate food neophobia is defined as a FNS of 25–35, and a low FNS is defined as <25 (Pliner & Hobden, 1992). Consumption of leafy green vegetables was ascertained from the NHANES Food Frequency Questionnaire (National Cancer Institute [NCI], 2008), and response options ranged from never to 2 or more times per day (three questions). Prior microgreen knowledge and consumption, and intention to purchase microgreens in the future were ascertained via five questions developed for this study. The question set was tested for face and content validity with experts in the fields of nutrition, food science, and public health.

2.6 Statistical analysis

Collected data were stored electronically using Research Electronic Data Capture (REDCap) for secure data management (Harris et al., 2009; Obeid et al., 2013). As a measure of quality control, data were double-entered by two individuals and evaluated for consistency by a third person. Data were analyzed using SAS v9.4 (SAS Institute Inc., Cary, NC, USA). Descriptive statistical analysis was performed, and all data are presented as means ± SEM (unless otherwise stated), and consumer sensory perception and acceptance data are also presented as boxplots with medians, quartiles, and min-max values. Data were analyzed using a linear mixed model, and an adjustment for multiple comparisons was performed using the Tukey method. A *P*-value of 0.05 was used to evaluate statistical significance. Factor analysis was performed using a principal component analysis in XLSTAT (version 2019.4.1, Addinsoft, Inc., New York, NY, USA). The factors that met the criteria of eigen value of >1.0 were retained. The variables that had a loading of ≥0.4 with the factors were noted and further evaluated for positive or negative association based on their loadings.

3. RESULTS AND DISCUSSION

3.1 Consumer sensory perception and acceptance

Mean liking scores are presented in Figure 2 and boxplots with medians, quartiles, and min–max values for appearance, flavor, texture, and overall acceptability are presented in Supplementary Figure 1. Mean intensity rating scores and boxplots with medians, quartiles, and min–max values for sensory perception are presented in Figure 3 and Supplementary Figure 2, respectively. Results indicated that all six microgreens species were considered acceptable by consumers, with mean scores ranging from 6.0 (slightly acceptable) to 7.9 (acceptable). With respect to appearance, microgreens species red in color (bull's blood beet, red cabbage, and red garnet amaranth) were rated as having the highest appearance acceptability (means: 8.4, 8.5, and 8.6, respectively), although broccoli and arugula were rated as acceptable (mean: 8.1 and 8.0, respectively) and tendril pea (mean: 7.7) was rated as moderately acceptable. Flavor acceptability mean liking scores indicate that tendril pea had the highest flavor acceptability (mean: 7.8) while arugula had the lowest (mean: 5.8). For texture, all microgreens were rated as acceptable with minor differences being observed among species (means ranged from 7.1 to 8.0). For overall acceptability, tendril pea exhibited the highest mean liking score (rated as moderately acceptable to acceptable, mean: 7.9) while arugula had the lowest (rated as slightly acceptable, mean: 6.0).

In general, mean liking scores and sensory intensity ratings were similar for bull's blood beet, red cabbage, and red garnet amaranth, while those for broccoli were not consistently similar or dissimilar to other microgreens species. Mean liking scores and sensory intensity ratings for arugula and tendril pea tended to have more divergent values from each other and across species in general.

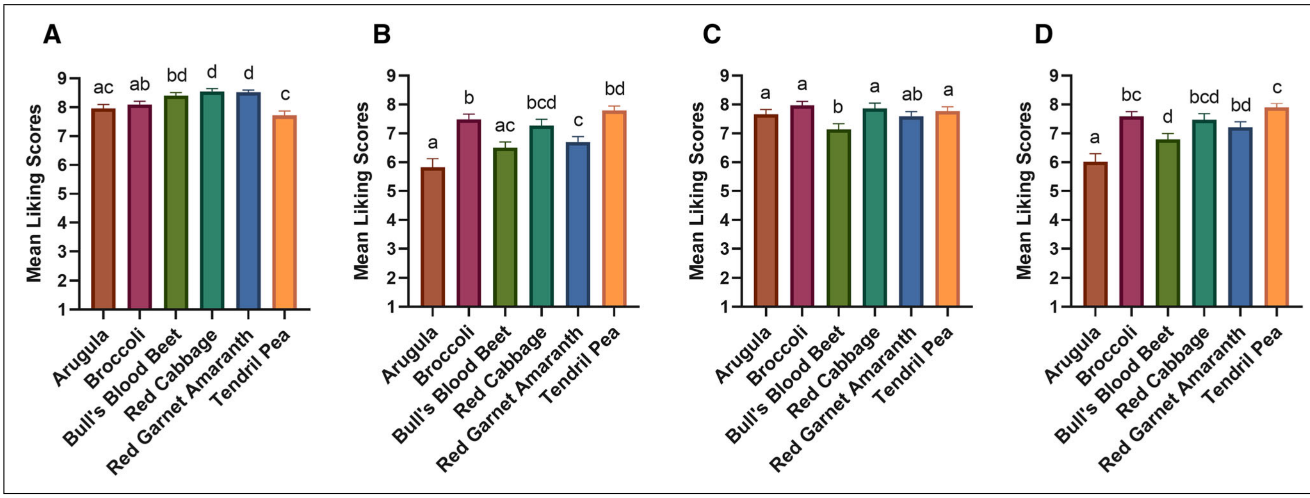

Figure 2–Mean overall liking scores of microgreens samples for appearance (A), texture (B), flavor (C), and overall acceptability (D) (Data are mean ± SEM), Scored on a nine-point hedonic scale on a horizontal line with verbal anchor label ranging from 1 = highly unacceptable, 2 = unacceptable, 3 = moderately unacceptable, 4 = slightly unacceptable, 5 = neither unacceptable nor acceptable, 6 = slightly acceptable, 7 = moderately acceptable, 8 = acceptable, 9 = highly acceptable. Columns with the same letter are not significantly different ($P < 0.05$; analyzed by Tukey's method).

These findings are comparable to that previously observed (Xiao et al., 2015) with respect to bull's blood beet and red amaranth. In the study by Xiao et al., researchers found that those two species exhibited similar acceptability and intensity scores and were generally rated as good/excellent for acceptability. In the present study, bull's blood beet and red garnet amaranth also exhibited similar mean liking scores and sensory perception intensity ratings, with the exception for aroma and grassy, which were perceived as higher for red garnet amaranth (means: 3.5 and 6.2, respectively) than bull's blood beet (means: 2.4 and 5.5, respectively). In their study, bull's blood beet was rated more favorably compared to other microgreens species, whereas it was rated less acceptable for texture, flavor, and overall acceptability than several other species such as broccoli and tendril pea in our study. Nonetheless, our findings indicate that all species were rated as being anywhere from slightly acceptable to highly acceptable.

We observed that arugula had the lowest mean liking scores for flavor and overall acceptability, and the highest intensity ratings for astringency, bitterness, sourness, and heat. In consideration of the interindividual variability noted (Supplementary Figure 1), arugula had the highest level of variability for sourness, flavor, and overall acceptability, indicating several individuals found it to be acceptable as well as several who found it to be unacceptable. Though arugula is a cruciferous vegetable along with broccoli and red cabbage, the latter two microgreens species were rated more favorably for mean liking scores and the aforementioned sensory properties. Cruciferous vegetables contain glucosinolates and isothiocyanates that are known to have bitter and acrid flavors (Drewnowski & Gomez-Carneros, 2000), and it is possible that the levels of these compounds are greater in arugula microgreens than broccoli and red cabbage microgreens. Additionally, these data show that there is high variability in how individuals perceive the flavor and specific sensory attributes of arugula, and therefore selection of arugula microgreens for consumption should be more personalized for consumer acceptability. Higher concentrations of these compounds have been observed in young plants compared with the mature plant (Drewnowski & Gomez-Carneros, 2000), an important factor when considering growing practices (e.g., modulation of LED lighting) for enhancing the levels of these health-promoting compounds (Alrifai et al., 2019), particularly with respect to consumer acceptability of microgreens. Though not evaluated in the present study, research is currently underway in our laboratory to examine the bioactive compounds present in the six microgreens evaluated in the present study, and the influence of maturity. Future studies should evaluate the consumer acceptability and sensory perceptions of microgreens compared to their mature counterparts, and with microgreens in which the bioactive compounds differ under various growing conditions.

3.2 Sex comparisons of consumer sensory perception and acceptance

Participant sex differences in mean liking scores and sensory perception intensity ratings of microgreens are presented in Tables 4 and 5, respectively. On average, compared to males, females rated the appearance (female mean: 8.4; male mean: 7.5; $P = 0.001$) and texture (female mean: 8.1; male mean: 7.2; $P = 0.009$) of arugula more favorably (acceptable in females vs. moderately acceptable in males). Interestingly, females perceived arugula to have a higher ($P = 0.04$) heat intensity (mean: 7.2, moderately strong) than males (mean: 6.5, slightly strong/moderately strong). Females also rated broccoli microgreens (mean 8.4, acceptable) higher ($P = 0.002$) than males for appearance (mean: 7.7, moderately acceptable/acceptable). In terms of overall acceptability, females rated bull's blood beet and red garnet amaranth microgreens more favorably (female means: 7.3 and 7.6, respectively, acceptable to moderately acceptable) than males (means: 6.2 and 6.8, respectively, moderately acceptable to slightly acceptable) ($P = 0.007$ for bull's blood beet and 0.048 for red garnet amaranth). Sex differences in chemosensory perceptions have been observed in several animal and human studies, with males appearing to be less sensitive to certain flavors than females (Barragan et al., 2018; Martin & Sollars, 2017; Spence, 2018; Tepper et al., 2017). Genetics and sex hormones appear to play a central role, though research has also demonstrated a lack of sex differences in chemosensory perception (Barragan et al., 2018; Martin & Sollars, 2017; Spence, 2018; Tepper et al., 2017). The findings of the present study suggest that for certain acceptability and sensory properties females may perceive certain microgreens more favorably than males; however, more research is needed.

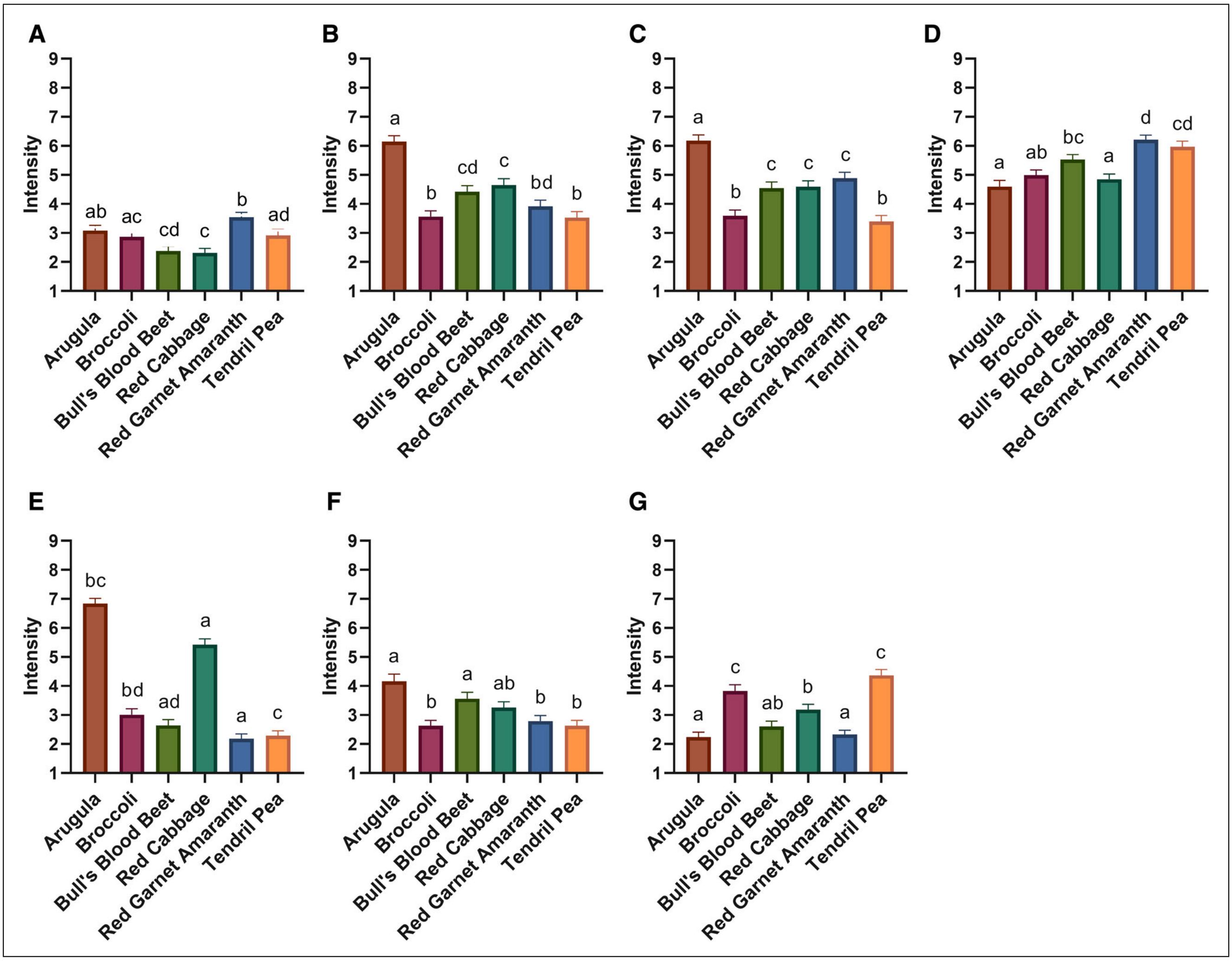

Figure 3–Mean intensity scores of microgreens samples for aroma (A), astringency (B), bitterness (C), grassy (D), heat (E), sourness (F), and sweetness (G) (Data are mean ± SEM). Scored on a nine-category horizontal line scale with verbal magnitude anchor labels ranging from 1 = none, 2 = extremely weak, 3 = moderately weak, 4 = slightly weak, 5 = neither weak nor strong, 6 = slightly strong, 7 = moderately strong, 8 = extremely strong, 9 = strongest imaginable. Columns with the same letter are not significantly different ($P < 0.05$; analyzed by Tukey's method).

3.3 Food neophobia, leafy green vegetable consumption, and microgreen knowledge and consumption

The tendency to avoid unfamiliar foods, or food neophobia, was assessed to better characterize the study participants, as well as to understand its potential impact on consumer sensory perceptions and acceptability of microgreens. Food neophobia scores are presented in Table 6 and indicate that overall the consumer population included had low neophobia (FNS < 25).

The frequency of leafy green vegetable consumption is presented in Table 6. Overall, participants reported eating raw greens one to two times per week, lettuce salads two times per week, and lettuce salads made with dark green vegetables one to two times per week. No sex differences were noted for these parameters.

When asked about their familiarity with microgreens (presented in Table 6), mean scores for the entire population studied corresponded with being "a little familiar to somewhat familiar," with no sex differences. The sources of microgreens familiarity reported by consumer panelists included farmers' markets ($n = 37$), grocery stores ($n = 29$), restaurants ($n = 31$), article in print or online ($n = 30$), friends/family ($n = 25$), other sources such as Community Supported Agriculture, CSU research communications, university dining hall, and in a presentation or class ($n = 18$), while some had never seen/heard about microgreens before ($n = 17$). Overall, frequency of microgreen consumption was reported to be "rarely to sometimes," with no sex differences observed (presented in Table 6). Finally, when asked how likely they were to purchase microgreens in the future, mean scores for the entire population corresponded with being neutral to more or less likely, and no sex differences were observed (presented in Table 6). Examples of reasons impacting likelihood of purchasing in the future included price, availability/access, nutrient content, quality/freshness/shelf life, health benefits, taste, knowledge about them (what they are, how to use them, health and sustainability benefits, etc.), sustainability implications, and the ability to grown them at home.

3.4 Principal component analysis

To explore possible barriers and drivers to microgreen acceptability external to the microgreens themselves, factor analysis was performed using a principal component analysis. The analysis lead to 24 factors that had an eigen value of >1.0, accounting for 67% of the variance explained by those 24 factors. The first four

Table 4–Sex comparisons in mean consumer liking scores of microgreen samples.

Microgreen	Appearance	Texture	Flavor	Overall acceptability
Arugula				
Females	8.4 ± 0.1	8.1 ± 0.2	5.7 ± 0.4	6.0 ± 0.4
Males	7.5 ± 0.2*	7.2 ± 0.3*	5.9 ± 0.5*	6.1 ± 0.4
Broccoli				
Females	8.4 ± 0.1	8.0 ± 0.2	7.6 ± 0.2	7.7 ± 0.2
Males	7.7 ± 0.2*	7.9 ± 0.2	7.3 ± 0.3	7.4 ± 0.3
Bull's blood beet				
Females	8.6 ± 0.1	7.5 ± 0.2	6.8 ± 0.2	7.3 ± 0.2
Males	8.2 ± 0.2	6.8 ± 0.3	6.1 ± 0.3	6.2 ± 0.3*
Red cabbage				
Females	8.6 ± 0.1	8.2 ± 0.2	7.5 ± 0.3	7.7 ± 0.3
Males	8.6 ± 0.2	7.5 ± 0.3	7.1 ± 0.4	7.3 ± 0.3
Red garnet amaranth				
Females	8.6 ± 0.1	7.9 ± 0.2	7.0 ± 0.2	7.6 ± 0.2
Males	8.6 ± 0.1	7.3 ± 0.3	6.3 ± 0.3	6.8 ± 0.3*
Tendril pea				
Females	7.7 ± 0.2	7.9 ± 0.2	8.1 ± 0.1	8.1 ± 0.1
Males	7.7 ± 0.2	7.6 ± 0.3	7.5 ± 0.3	7.7 ± 0.3

Notes: Data are mean ± SEM. Scored on a nine-point hedonic scale on a horizontal line with verbal anchor label ranging from 1 = highly unacceptable, 2 = unacceptable, 3 = moderately unacceptable, 4 = slightly unacceptable, 5 = neither unacceptable nor acceptable, 6 = slightly acceptable, 7 = moderately acceptable, 8 = acceptable, 9 = highly acceptable.
*Significantly different than females ($P \leq 0.05$; analyzed by Tukey's method).

factors were considered due to their scientific associations and meaningfulness (Supplemental Table 1 and Figure 4). There were 17 variables that had high loadings (≥0.4) on factor 1. The data indicate that individuals with low food neophobia were also likely to have higher raw green, lettuce, and dark green lettuce consumption, to be familiar with microgreens and to consume them more frequently, to have a higher intent to purchase microgreens in the future, and to find arugula, bull's blood beet, red garnet amaranth, and tendril pea microgreens more acceptable. There were nine variables that had high loadings on factor 2. The data show that individuals who had high overall acceptability scores for broccoli were also likely to have high overall acceptability scores for bull's blood beet, red cabbage, red garnet amaranth, and tendril pea, but were not likely to have seen or heard of microgreens at the farmer's market, grocery store, restaurant, or online. There were four variables that had high loadings on factor 3. The data indicate that age was related to frequency of raw green, lettuce salad, and dark green lettuce consumption. There were three variables that had high loadings on factor 4. These data demonstrate that age, sex, and race/ethnicity were related to food neophobia. Although these data are not causative, they do suggest that individuals who are open to trying new foods, that is have low food neophobia, tend to find certain microgreens tested in the present study more acceptable. The data also suggest that consumer acceptability of microgreens may influence whether a consumer will purchase microgreens when presented with the opportunity. Of note, typical lettuce- and/or dark green-based salad consumption may influence knowledge, familiarity, and consumption of microgreens, suggesting that education regarding how to incorporate microgreens into nonsalad-based foods and meals will be important.

To explore the relationship between overall microgreen sensory intensity and microgreen overall acceptability, factor analysis was performed using a principal component analysis. The analysis lead to four factors that had an eigen value of >1.0, accounting for 73% of the variance explained by those four factors. The factors were evaluated, and the first factor was considered due to its scientific associations and meaningfulness (Supplemental Table 2 and Figure 5A). There were eight variables that had high loadings (≥0.4) on factor 1. The data show that higher overall acceptability was positively related to appearance, flavor, and texture acceptability, and negatively related to astringency, bitterness, heat, and sourness of microgreens. With respect to sensory properties associated with reduced liking and consumer acceptability, similar observations have been noted for other food types such as less-liked/commonly consumed berries (e.g., cranberries and lingonberries which are known for their tart/sour flavors) (Laaksonen, Knaapila, Niva, Deegan, & Sandell, 2016) and edible insects (Sogari, Menozzi, & Mora, 2019). These data are important as taste, rather than perceived nutrition or health value, has been suggested to exert a greater influence on food selection (Drewnowski & Gomez-Carneros, 2000).

To explore which sensory attributes are related to consumer acceptability of each distinct microgreen species, factor analysis was performed using a principal component analysis (Supplemental

Table 5–Sex comparisons in mean consumer intensity ratings of microgreen sample sensory attributes.

Microgreen	Aroma	Astringency	Bitterness	Grassy	Heat	Sourness	Sweetness
Arugula							
Females	3.0 ± 0.3	6.4 ± 0.3	6.3 ± 0.3	4.6 ± 0.3	7.2 ± 0.2	4.1 ± 0.4	2.0 ± 0.2
Males	3.1 ± 0.3	5.8 ± 0.3	6.1 ± 0.3	4.6 ± 0.3	6.5 ± 0.3*	4.2 ± 0.4	2.5 ± 0.3
Broccoli							
Females	3.0 ± 0.3	3.6 ± 0.3	3.7 ± 0.3	4.9 ± 0.3	3.1 ± 0.3	2.6 ± 0.3	4.2 ± 0.3
Males	2.7 ± 0.2	3.5 ± 0.3	3.4 ± 0.3	5.2 ± 0.3	2.9 ± 0.3	2.7 ± 0.3	3.4 ± 0.3
Bull's blood beet							
Females	2.4 ± 0.2	4.4 ± 0.3	4.5 ± 0.3	5.4 ± 0.3	2.8 ± 0.3	3.6 ± 0.3	2.7 ± 0.3
Males	2.4 ± 0.2	4.5 ± 0.3	4.6 ± 0.3	5.7 ± 0.2	2.5 ± 0.3	3.5 ± 0.3	2.5 ± 0.3
Red cabbage							
Females	2.3 ± 0.2	4.7 ± 0.3	4.6 ± 0.3	4.9 ± 0.3	5.5 ± 0.3	3.2 ± 0.3	3.5 ± 0.3
Males	2.4 ± 0.2	4.6 ± 0.3	4.6 ± 0.3	4.8 ± 0.2	5.3 ± 0.3	3.4 ± 0.3	2.9 ± 0.3
Red garnet amaranth							
Females	3.7 ± 0.3	3.7 ± 0.3	4.6 ± 0.3	6.2 ± 0.2	2.4 ± 0.3	2.9 ± 0.3	2.5 ± 0.2
Males	3.4 ± 0.2	4.2 ± 0.3	5.2 ± 0.3	6.2 ± 0.2	2.0 ± 0.2	2.7 ± 0.3	2.2 ± 0.2
Tendril pea							
Females	3.2 ± 0.3	3.4 ± 0.3	3.4 ± 0.3	5.9 ± 0.3	2.5 ± 0.3	2.7 ± 0.3	4.7 ± 0.3
Males	2.6 ± 0.3	3.7 ± 0.3	3.4 ± 0.3	5.9 ± 0.3	2.1 ± 0.2	2.5 ± 0.3	4.0 ± 0.3

Notes: Data are mean ± SEM. Scored on a nine-category horizontal line scale with verbal magnitude anchor labels ranging from 1 = none, 2 = extremely weak, 3 = moderately weak, 4 = slightly weak, 5 = neither weak nor strong, 6 = slightly strong, 7 = moderately strong, 8 = extremely strong, 9 = strongest imaginable.
*Significantly different than females ($P \leq 0.05$; analyzed by Tukey's method).

Table 6–Food neophobia, leafy green vegetable consumption, and microgreen knowledge and consumption for all consumers with sex comparisons.

		Sex	
Variable	All	Females	Males
Food neophobia score	23.1 ± 0.9	23.9 ± 1.3	22.2 ± 1.4
How often did you eat raw greens (such as spinach, turnip, collard, mustard, chard, or kale)?	6.9 ± 0.2	7.0 ± 0.3	6.7 ± 0.3
How often did you eat lettuce salads (with or without other vegetables?	7.0 ± 0.2	7.2 ± 0.3	6.9 ± 0.3
How often were the lettuce salads you ate made with dark green leaves?	6.8 ± 0.2	6.8 ± 0.3	6.8 ± 0.3
How familiar are you with microgreens?	2.6 ± 0.1	2.6 ± 0.2	2.6 ± 0.2
How frequently have you consumed microgreens?	2.3 ± 0.1	2.3 ± 0.1	2.30 ± 0.1
How likely are you to purchase microgreens in the future?	4.7 ± 0.1	4.8 ± 0.2	4.6 ± 0.2

Notes: Data are mean ± SEM. There were no significant differences. Leafy green vegetable consumption: 1 = never, 2 = 1–6 times per year, 3 = 7–11 times per year, 4 = 1 time per month, 5 = 2–3 times per month, 6 = 1 time per week, 7 = 2 times per week, 8 = 3–4 times per week, 9 = 1 time per day, 10 = 2 or more times per day. Familiarity with microgreens: 1 = not at all familiar, 2 = a little familiar, 3 = somewhat familiar, 4 = familiar, 5 = very familiar. Frequency of microgreen consumption: 1 = never, 2 = rarely, 3 = sometimes, 4 = often. Intention to purchase microgreens: 1 = extremely unlikely, 2 = unlikely, 3 = more or less unlikely, 4 = neutral, 5 = more or less likely, 6 = very likely, 7 = extremely likely.

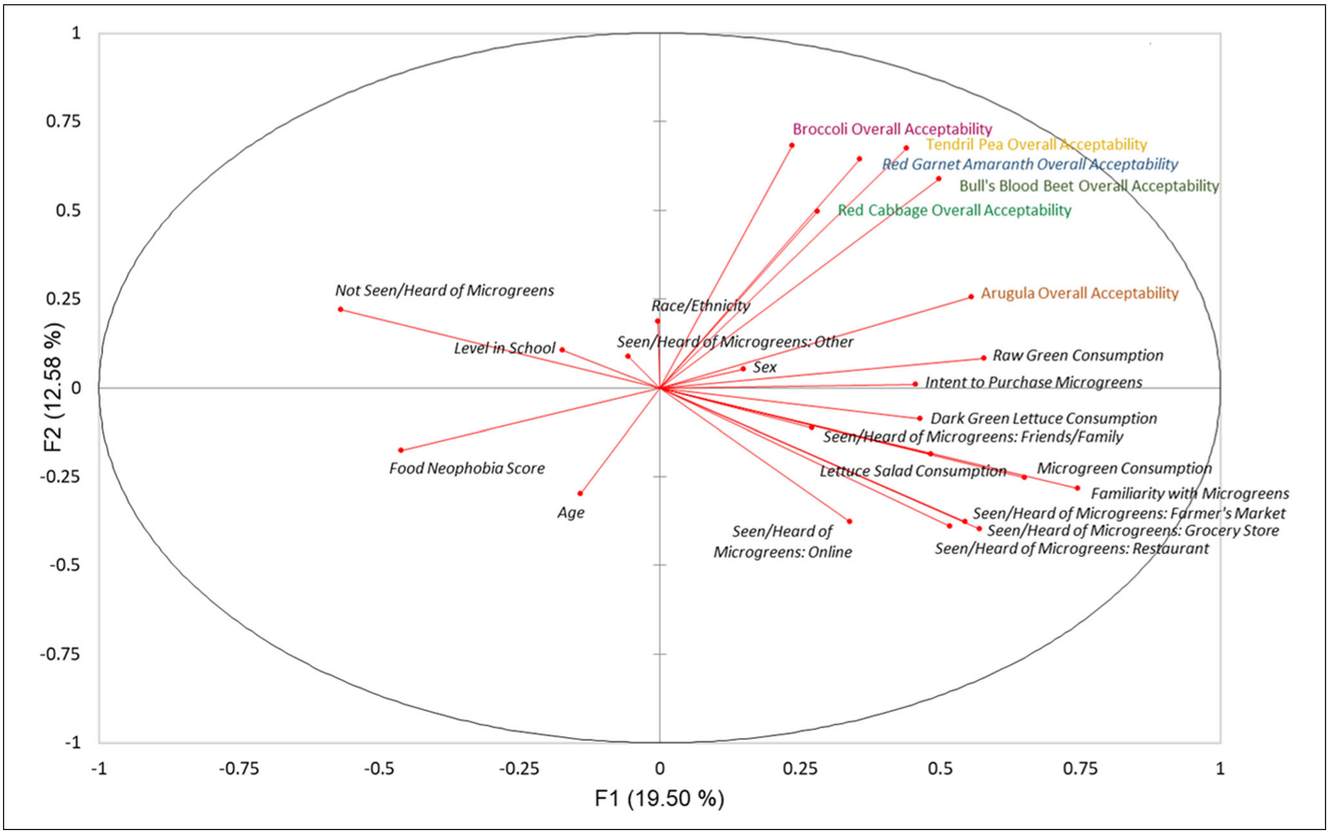

Figure 4–Principal component analysis of microgreen consumer acceptability, food neophobia, leafy green vegetable and microgreen consumption, and intention to eat microgreens.

Table 3 and Figure 5B). The analysis lead to three factors that had an eigen value of >1.0, accounting for 93% of the variance explained by those three factors. The first two factors were considered due to their scientific associations and meaningfulness. Arugula, bull's blood beet, and red cabbage had negative scores on factor 1, while broccoli, red garnet amaranth, and tendril pea had positive scores (explaining 50.1% of the variation observed among sensory and acceptability scores), with high negative loadings for astringency, bitterness, sourness, and heat, and positive loadings for grassy, sweetness, flavor, texture, and overall acceptability. Factor 2 explained 58.1% of the variation observed among sensory and acceptability scores. Arugula and red garnet amaranth had positive scores on factor 2, while broccoli, bull's blood beet, red cabbage, and tendril pea had negative scores, with a high negative loading for sweetness, and high positive loadings for aroma, bitterness, appearance acceptability, and texture acceptability. Overall, these data indicate that broccoli and tendril pea had the highest flavor, texture, and overall acceptability, which may be due to their sweet and grassy sensory attributes, and low bitter, astringent, sour, and heat sensory attributes. They also suggest that arugula had the lowest acceptability scores, which may be due to its bitter, astringent, sour, and heat sensory attributes.

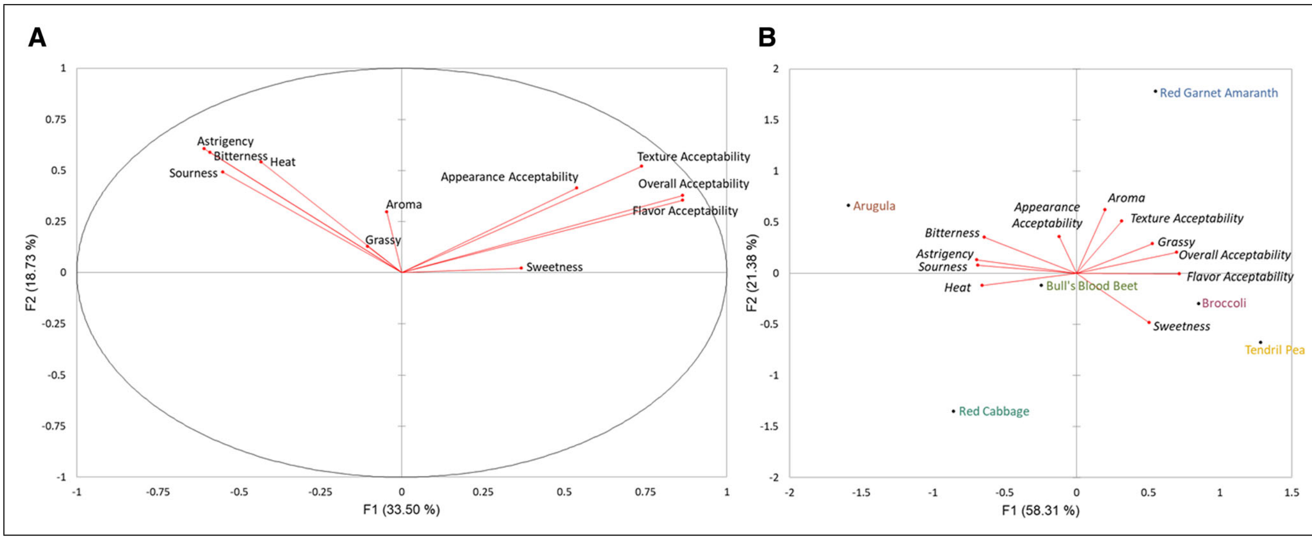

Figure 5–Principal component analysis of consumer perceptions of sensory intensity and acceptability for microgreens combined (A) and for each microgreen species (B).

3.5 Industry Relevance

The findings of this study are important to horticultural and food industries as they suggest that consumers find various microgreens species acceptable for consumption. Importantly, the overall findings of the study suggest that consumer education regarding microgreens, a modifiable factor contributing to consumer intention to purchase microgreens, will be key so that knowledge of them will not be a limiting factor. Additional important considerations should include cost and freshness of the microgreens, as well as expansion of their availability. Sensory attribute information could be used to correctly market microgreen species, blends, and restaurant menu options such that consumers may be more likely to purchase microgreens that suit their palate, thus encouraging consumption. Though taste and flavor are the major factors influencing consumer food purchases (Drewnowski & Gomez-Carneros, 2000), providing additional information about their nutritional characteristics may provide further purchasing encouragement to health-conscious consumers (Asioli et al., 2017). With the recent shift in consumer concern about environmental sustainability (Asioli et al., 2017), it would be of benefit to consider packaging for microgreens that preserves freshness while reducing the environmental footprint. Of the microgreens species tested, broccoli, red cabbage, and tendril pea had the highest overall acceptability with similar trends for taste and texture acceptability. All microgreens were rated favorably for appearance acceptability and therefore could be used to enhance the visual properties of prepared meals, but needs to be balanced with desired flavor profiles (e.g., arugula and red cabbage for heat/spicy).

4. CONCLUSION

The six microgreens species evaluated in the present study received high acceptability scores by study participants, with more distinct differences across microgreens species being observed for flavor and overall acceptability, which appeared to be driven by specific sensory properties. With respect to possible drivers and barriers to consumer acceptability of the microgreens tested, specific sensory attributes and food neophobia were most associated with consumer acceptability of microgreens, and intention to purchase microgreens in the future. Knowledge and familiarity of microgreens were identified as major factors driving the intent to purchase microgreens in the future, although other factors such as availability and price were important. The findings of the present study suggest that further assimilation of microgreens into the global food system, including marketing channels, will be met with high consumer acceptability overall. Important considerations should include enhanced consumer education concerning microgreens (nutritional properties, meal incorporation, and sustainability implications), cost, access/availability, and freshness/shelf life. Research is needed to evaluate consumer acceptability and sensory perceptions in other populations and geographic locations.

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AUTHOR CONTRIBUTIONS

S. Newman, M. Bunning, L. Bellows, M. Foster, A. Heuberger, J. Prenni, H. Thompson, M. Uchanski, T. Weir, and S. Johnson acquired the funding and contributed to the conceptualization of the research. K. Michell, H. Isweiri, S. Newman, M. Bunning, L. Bellows, and S. Johnson designed the study and interpreted the results. K. Michell, H. Isweiri, and S. Newman grew the microgreens with assistance from M. Dinges. K. Michell, M. Dinges, and L. Grabos collected and entered the data. S. Rao, T. Weir, and S. Johnson performed statistical analysis and helped with data interpretation. K. Michell and S. Johnson drafted the initial manuscript. All authors commented on and edited subsequent drafts, and reviewed and approved the final version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Supplemental Figure 1. Boxplots with median, quartiles and min–max values of overall liking scores of microgreens samples for appearance (A), texture (B), flavor (C), and overall acceptability (D). Scored on a 9-point hedonic scale on a horizontal line with verbal anchor label ranging from 1 = highly unacceptable, 2 = unacceptable, 3 = moderately unacceptable, 4 = slightly unacceptable, 5 = neither unacceptable nor acceptable, 6 = slightly acceptable, 7 = moderately acceptable, 8 = acceptable, 9 = highly acceptable. See Figure 2 for significant differences among groups.

Supplemental Figure 2. Boxplots with median, quartiles and min–max values of intensity scores of microgreens samples for aroma (A), astringency (B), bitterness (C), grassy (D), heat (E), sourness (F), and sweetness (G). Scored on a 9-category horizontal line scale with verbal magnitude anchor labels ranging from 1 = none, 2 = extremely weak, 3 = moderately weak, 4 = slightly weak, 5 = neither weak nor strong, 6 = slightly strong, 7 = moderately strong, 8 = extremely strong, 9 = strongest imaginable. See Figure 3 for significant differences among groups.

Supplemental Table 1. Principal component analysis factor loadings for consumer acceptability of microgreens, food neophobia, leafy green vegetable and microgreen consumption, and intention to eat microgreens.

Supplemental Table 2. Principal component analysis factor loadings for consumer sensory perception and acceptability of all microgreens combined.

Supplemental Table 3. Principal component analysis factor loadings for consumer sensory perception and acceptability ratings.