Effect of Taste Enhancement on Consumer Acceptance of Pureed Cucumber and Green Capsicum

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Abstract: Vegetables have low taste intensities, which might contribute to low acceptance. The aim of this study was to investigate the effect of taste (sweetness, sourness, bitterness, umami, and saltiness) and fattiness enhancement on consumer acceptance of cucumber and green capsicum purees. Three concentrations of sugar, citric acid, caffeine, mono-sodium glutamate, NaCl, and sunflower oil were added to pureed cucumber and green capsicum. Subjects ($n = 66$, 35.6 ± 17.7 y) rated taste and fattiness intensity. Different subjects ($n = 100$, 33.2 ± 16.5 years) evaluated acceptance of all pureed vegetables. Taste intensities of vegetable purees were significantly different ($P < 0.05$) between the three tastant concentrations except for umami in both vegetable purees, sourness in green capsicum puree, and fattiness in cucumber puree. Only enhancement of sweetness significantly ($P < 0.05$) increased acceptance of both vegetable purees compared to unmodified purees. In cucumber purees, relatively small amounts of added sucrose (2%) increased acceptance already significantly, whereas in green capsicum acceptance increased significantly only with addition of 5% sucrose. Enhancement of other taste modalities did not significantly increase acceptance of both vegetable purees. Enhancing saltiness and bitterness significantly decreased acceptance of both vegetable purees. We conclude that the effect of taste enhancement on acceptance of vegetable purees differs between tastants and depends on tastant concentration and vegetable type. With the exception of sweetness, taste enhancement of taste modalities such as sourness, bitterness, umami, and saltiness was insufficient to increase acceptance of vegetable purees. We suggest that more complex taste, flavor, or texture modifications are required to enhance acceptance of vegetables.

Keywords: acceptance, capsicum, cucumber, taste, vegetable

Practical Application: Results can be used by cultivators to select and grow vegetable varieties with enhanced taste and flavor. Especially for cucumber, relatively small sweetness enhancement is sufficient to increase acceptance.

Introduction

Diets often do not contain enough vegetables (Alexy, Sichert-Hellert, & Kersting, 2002; Bowen, Klose, Syrette, & Noakes, 2009; Dennison, Rockwell, & Baker, 1998; Van Rossum, De Boer, & Ocke, 2009). Taste is an important driver for food choice (Cox, Melo, Zabaras, & Delahunty, 2012; Kourouniotis et al., 2016). One explanation for the limited acceptance of some vegetables is their bitterness (Birch, 1999; Nicklaus, Boggio, Chabanet, & Issanchou, 2005; Zeinstra, Koelen, Kok, & de Graaf, 2007). However, recent studies have shown that vegetables in general have low taste intensities compared to other foods (Poelman, Delahunty, & de Graaf, 2017; Van Stokkom et al., 2016). It might actually be the low taste intensities that cause the limited acceptance of vegetables, especially since vegetables are not energy dense. The acceptance and intake of other foods with low taste intensities but high energy density, such as potatoes, rice, and pasta, seems to be considerably higher.

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Several studies investigated the effect of taste enhancement on liking of foods and beverages. Taste intensity is often enhanced by addition of tastants (De Graaf & Zandstra, 1999; Liem & de Graaf, 2004; Liem, Westerbeek, Wolterink, Kok, & de Graaf, 2004). Although increasing vegetable consumption is a desirable goal, only few studies focused on the effect of taste enhancement on acceptance of vegetables. Capaldi and Privitera (2008) evaluated broccoli and cauliflower dipped for a short time in a solution containing sucrose. Pleasantness of broccoli and cauliflower increased with increasing sweetness intensity. Sharafi, Hayes, and Duffy (2013) misted asparagus, Brussels sprouts, and kale with solutions containing different concentrations of aspartame, sodium acetate, and sodium chloride to determine the effect of sweetness, sourness, and saltiness enhancement on bitterness suppression. Aspartame was the most effective bitterness suppressor and increased liking for all vegetables. Sodium acetate suppressed bitterness, but only increased liking when sweetness increased. Sodium chloride suppressed bitterness, but did not have an effect on liking. Masic and Yeomans (2013) investigated the effect of taste enhancement on liking of vegetable soups. Monosodium glutamate (MSG) was added to vegetable soups and compared to unmodified vegetable soups. Addition of MSG (1%) increased taste intensity. Soups containing MSG were perceived as saltier and more pleasant compared to soups without MSG, although no effect of MSG addition on savory taste was observed. Bouhlal, Chabanet, Issanchou, and Nicklaus (2013) and Bouhlal,

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Issanchou, Chabanet, and Nicklaus (2014) investigated the impact of salt content on vegetable liking and intake in children. Adding sodium chloride to green beans enhanced saltiness and suppressed bitterness which might be beneficial to increase vegetable intake in children (Bouhlal et al., 2013; Mennella, Pepino, & Beauchamp, 2003). Bouhlal et al. (2014) showed that sodium chloride addition to salsify purees can increase intake in children. In addition to the five basic taste modalities (sweetness, sourness, bitterness, umami, and saltiness), it has been suggested that fattiness is another taste quality (Besnard, Passilly-Degrace, & Khan, 2016; Liu, Archer, Duesing, Hannan, & Keast, 2016; Running, Craig, & Mattes, 2015). Previous studies showed that offering raw broccoli with a regular and light version of a salad dressing as dip increases intake (Fisher et al., 2012), while offering green beans with butter does not (Bouhlal, Issanchou, & Nicklaus, 2011).

To summarize, the effect of taste enhancement on acceptance of various vegetables has been studied extensively. However, to the best of our knowledge, the effect of taste enhancement on acceptance of cucumber and green capsicum has not been studied yet.

The studies described above used different methods to add tastants to vegetables. By using methods such as dipping or misting vegetable texture remains unchanged, but the concentration of added tastant is unknown. Instead of dipping or misting vegetables with tastant solutions, vegetable purees, or soups can be used. By adding tastants to vegetable soups or purees, the concentration of added tastant is known and can be varied over a wide range. The disadvantage of using pureed vegetables is that the texture differs from the texture vegetables have when consumed normally. Texture of foods and vegetables has been shown to contribute to acceptance (Duffy, Hayes, & Feeney, 2017; Nederkoorn, Theibetaen, Tummers, & Roefs, 2018; Zeinstra, Koelen, Kok, & de Graaf, 2010). Previous studies often investigated the effect of taste enhancement of only one or two taste modalities on acceptance. Taste intensity was typically varied by addition of tastants at one or two concentrations. Knowledge is lacking about the effect of enhancement of the five taste modalities and fattiness on acceptance of vegetables and the influence of concentration of added tastants and vegetable type on taste enhancement and acceptance of vegetables. The aim of this study was to investigate the effect of taste (sweetness, sourness, bitterness, umami, saltiness) and fattiness enhancement on vegetable acceptance of cucumber and green capsicum purees. We hypothesized that taste and fattiness enhancement can increase acceptance of vegetable purees and that the effect depends on vegetable type and taste modality. Cucumber and green capsicum were selected since these vegetables belong to the 20 most commonly consumed vegetables in The Netherlands (Van Rossum et al., 2009). These vegetables display very different taste profiles. Cucumber was chosen due to its neutral taste profile whereas green capsicum was selected due to its bitter taste profile (Poelman et al., 2017; Van Stokkom et al., 2016). To our knowledge, the effect of taste enhancement on acceptance has not been studied in cucumber and green capsicum.

Materials and Methods

Subjects

Subjects were recruited in the Wageningen area via social media. Inclusion criteria for participation comprised a good general health, understanding of the Dutch language, and aged between 18 and 65 years. Subjects with food allergies or intolerances, problems with chewing, swallowing, tasting, or smelling were excluded from the study. Pregnant or breastfeeding women were excluded too. Subjects were asked not to wear perfume and not to eat or drink (except water) 1 hr prior to the test session. Subjects received financial compensation for participation in the study. In total $n = 166$ subjects were included in the study (138 females; 28 males). A group of $n = 66$ subjects (54 females; 12 males, 35.8 ± 17.7 years) participated in the sensory evaluation of the vegetable purees. A group of $n = 100$ subjects (84 females; 16 males, 33.2 ± 16.5 years) participated in the hedonic evaluation of the vegetable purees. Medical ethical approval was not required for this study as concluded by the Medical Research Ethics Committee of Wageningen Univ.

Table 1–Composition of cucumber and green capsicum purees with added tastants.

Taste modality	Tastant	Low concentration [% w/w]	Medium concentration [% w/w]	High concentration [% w/w]
Unmodified	–	–	–	–
Sweetness	Sucrose	2.0	5.0	10.0
Sourness	Citric acid	0.05	0.08	0.15
Bitterness	Caffeine	0.05	0.08	0.15
Umami	MSG	0.12	0.30	0.70
Saltiness	Sodium chloride	0.20	0.35	0.50
Fattiness	Sunflower oil	10.0	20.0	30.0

Vegetable preparation

Cucumber (*Cucumis sativus*) and green capsicum (*Capsicum annuum*) were selected as vegetables for this study. Selection was based on four criteria. First, one vegetable should display a relatively neutral taste profile whereas the other vegetable should have a bitter taste profile. In previous studies, cucumber displayed a neutral taste profile while green capsicum was characterized by higher bitterness intensity (Poelman et al., 2017; Van Stokkom et al., 2016). Second, both vegetables should be commonly consumed in The Netherlands. Cucumber is one of the five and green capsicum one of the 20 most commonly-consumed vegetables in The Netherlands (Van Rossum et al., 2009). Third, both vegetables should be consumable cold without further preparation to reduce potential influence of preparation method, such as boiling, and consumption temperature on taste perception. Both cucumber and capsicum are commonly consumed raw (Van Rossum et al., 2009). Fourth, the effect of taste enhancement on acceptance has not been studied yet in cucumber and green capsicum.

Cucumber (variety Lausanna) and green capsicum (variety Pursuit) were obtained from a wholesaler in bulk. Vegetables were rinsed with water, chopped in small pieces with a Robot Coupe CL50, and pureed with an industrial hand mixer (Robot Coupe MP550, Robot-Coupe, France). Vegetable purees were divided over 19 plastic containers. Tastants were added to the purees and dissolved by blending with a hand mixer. For each taste modality (sweetness, sourness, bitterness, umami, saltiness) and for fattiness, tastants (sucrose, citric acid, caffeine, MSG, sodium chloride, and sunflower oil) were added to the purees at low, medium, and high concentrations (Table 1). Sunflower oil contained 0.7% soy lecithin as emulsifier. Added concentrations of tastants were based on reference solutions used for the modified Spectrum Method. In that method, three reference solutions with fixed intensities for each tastant are used to evaluate the intensity of the basic tastes (sweetness, sourness, bitterness, umami, saltiness) on an absolute scale (Martin, Visalli, Lange, Schlich, & Issanchou, 2014). The

Table 2–Self-reported participant characteristics and demographics.

Characteristic	Sensory evaluation group (n = 66) Mean ± SD	Hedonic evaluation group (n = 100) Mean ± SD
Age (y)	35.8 ± 17.7	33.2 ± 16.5
Gender (number female; male)	54; 12	84; 16
BMI (kg/m^2)	22.7 ± 2.9	23.5 ± 4.4
Education level (%)		
Low	16.7	8.0
Intermediate	24.2	22.0
High	59.1	70.0
Vegetable consumption (g/d)	152.5 ± 48.2	153.4 ± 53.6

Consumption frequency cucumber and green capsicum (n)

		Never	<once a year	Yearly	Monthly	Weekly	Daily
Sensory evaluation group	Cucumber	3	1	7	19	30	6
	Green capsicum	1	0	14	35	16	0
Hedonic evaluation group	Cucumber	4	3	13	28	44	8
	Green capsicum	2	2	21	48	27	0

concentrations from the modified Spectrum method were used to ensure that low, medium, and high taste intensities were obtained. Vegetable purees were poured into bottles and stored frozen at −19 °C. Each test day all vegetable purees were defrosted 3 hr prior to the first test session. During test sessions, vegetable purees were kept at 5 °C. Subjects received approximately 15 g of vegetable puree in 25 mL plastic cups with a small plastic spoon.

Study procedure

For the sensory evaluation of vegetable purees, subjects came to the test location at Wageningen Univ., The Netherlands, once for a maximum of 90 min. Subjects were seated in individual sensory booths, received instructions about the experiment, filled in a consent form and questionnaire about demographics and fruit and vegetable consumption using EyeQuestion® (version 3.16.26, Logic8). Subjects (n = 66) received the vegetable purees differing in taste modalities and fattiness in random order during the session. For each taste modality and fattiness, subjects received 3 vegetable purees and an unmodified vegetable puree simultaneously in random order to eliminate order effects. Subjects were asked to rate the taste intensity of the presented taste modality on a 100-mm line scale anchored from weak to strong. This was done for all vegetables purees (five taste modalities and fattiness) in random order. Subjects were naive and did not receive training for the use of the line scale. Between the evaluations of different taste modalities, a 1-min break followed in which subjects could cleanse their palate with water or a cracker. Subjects were instructed to also regularly sip water between samples. For umami, subjects received a solution of MSG in water with a medium intensity (0.3%) to get familiar with umami taste.

For the hedonic evaluation of the vegetable purees, subjects came twice to the test location, Wageningen Univ., The Netherlands, for a maximum of 60 min each session. Subjects were seated in individual sensory booths, received instructions about the experiment, and filled in a consent form and questionnaire about demographics and fruit and vegetable consumption using EyeQuestion® (version 3.16.26, Logic8). Subjects (n = 100) received all 19 vegetable purees (Table 1) of one type of vegetable in random order. Half of the subjects received cucumber purees first, the other half received capsicum purees first. Subjects scored acceptance on a 9-point hedonic scale ranging from extremely dislike to extremely like. Between each sample, a break of 20 s was given in which subjects could cleanse their palate with water or a cracker. In the second session, subjects received 19 samples of the other (2nd) vegetable following the same experimental procedure.

Data analyses

Statistical data analyses were performed using SPSS (IBM SPSS Statistics, version 24). Significance level was set at $P < 0.05$. Descriptive data were generated for demographic and lifestyle variables. For the sensory evaluation, mean perceived intensities (hereafter referred to as intensity) and standard deviations were calculated for each sample. For the hedonic evaluation, categories for acceptance were coded from −4 (extremely dislike) to 4 (extremely like) with 0 corresponding to neither like nor dislike. Means and standard deviation of the acceptance categories and mean differences compared to the unmodified sample were calculated.

Mixed model analysis of variance with the Bonferroni correction was used to analyze differences between taste intensities within a taste modality. Dependent t-test was used for the analysis of taste intensity differences for each taste modality between cucumber samples and green capsicum samples and for the analysis of differences in acceptance between cucumber and green capsicum samples. Mixed model analysis of variance including a random (subject) and fixed factor (sample, 19 levels) was used to analyze differences in acceptance between unmodified vegetables and modified samples followed by Tukey *post hoc* test.

Results

In total, 66 subjects participated in the sensory evaluation group and 100 in the hedonic evaluation group. Vegetable consumption was below recommended intakes of 250 g per day in both subject groups (152.5 ± 48.2 and 153.4 ± 53.6 g/day). Most subjects consumed both vegetables either monthly or weekly (Table 2).

Sensory evaluation of cucumber and green capsicum purees

Table 3 displays mean taste and fattiness intensities and SD (n = 66) for all vegetable purees. Taste and fattiness intensities of the vegetable purees increased significantly ($P < 0.05$) from unmodified to low, medium, and high tastant concentration for each taste modality for both vegetable purees, except between unmodified and low MSG concentration for both vegetable purees, between low and medium MSG concentration for green capsicum, between medium and high sunflower oil concentration for cucumber, and between unmodified and low citric acid for green capsicum

When comparing the taste intensity between cucumber and green capsicum purees, it was found that for the unmodified vegetable purees, sweetness and fattiness intensity did not differ significantly between cucumber and green capsicum. Unmodified green capsicum had significantly higher intensities compared to unmodified cucumber for sourness ($t(65) = 4.429$, $P < 0.01$), bitterness ($t(65) = 4.957$, $P < 0.01$), umami ($t(65) = 3.621$, $P < 0.01$), and saltiness ($t(65) = 3.208$, $P < 0.01$). When comparing the taste intensities between cucumber and green capsicum purees with the same concentration of added tastants, it was observed that sourness low ($t(65) = -2.818$, $P < 0.01$), sourness medium ($t(65) = -3.569$, $P < 0.01$), sourness high ($t(65) = -2.108$, $P < 0.05$), umami high ($t(65) = -3.158$, $P < 0.01$), and saltiness high ($t(65) = -2.723$, $P < 0.01$) were significantly higher for cucumber purees compared to green capsicum purees. Bitterness intensity at medium tastant concentration was significantly higher in green capsicum purees compared to cucumber purees ($t(65) = 2.229$, $P < 0.05$). The other taste intensities did not differ significantly between cucumber and green capsicum purees.

Acceptance of cucumber and green capsicum purees

Table 4 shows the mean acceptance of unmodified vegetable purees and purees with low, medium, and high concentrations of added tastants. Mean acceptance of cucumber purees varied from –3.2 to 0.9. Mean acceptance of green capsicum purees ranged from –3.1 to 0.6. As a consequence of the taste intensity modifications, acceptance of both vegetable purees varied over a broad range from "dislike very much" which corresponds to –3.0 to "like slightly" which corresponds to 1.0. Many vegetable purees (21 out of 38 samples; 55% of samples) displayed mean acceptance scores between –0.5 and 0.5 corresponding to "neither like nor dislike."

Acceptance for sweetness low, sourness low, saltiness low, and saltiness high was significantly higher for cucumber purees than for green capsicum purees ($t(99) = 3.62$, $P < 0.01$; $t(99) = 2.69$, $P < 0.01$, $t(99) = 3.27$, $P < 0.01$; $t(99) = 2.67$, $P < 0.01$). Acceptance for bitterness medium was significantly lower for cucumber purees than for green capsicum purees ($t(99) = -2.79$, $P < 0.01$). For the other samples, there were no significant differences in acceptance between cucumber and green capsicum purees.

Figure 1 shows mean differences in acceptance between vegetables purees with added tastants and unmodified purees for cucumber and green capsicum purees for the five taste modalities and fattiness. Acceptance differed significantly between unmodified vegetable purees and purees with added tastants for cucumber [$F(18,1782) = 42.17$, $P < 0.01$] and green capsicum [$F(18,1782) = 31.12$, $P < 0.01$]. For the cucumber purees, acceptance of low sweetness was significantly higher than acceptance of unmodified cucumber puree (+1.0), whereas acceptance of all three bitterness intensities (–1.4, –2.4, –3.1), high umami (–1.1), and high saltiness (–0.8) were significantly lower than acceptance of unmodified cucumber puree. For green capsicum purees, acceptance of medium sweetness (+1.0) and high sweetness (+0.8) was significantly higher than acceptance of unmodified green capsicum, whereas acceptance of all 3 bitterness intensities (–0.9, –1.7, –2.7) and high saltiness (–1.0) was significantly lower than acceptance of unmodified green capsicum puree (Figure 1).

Discussion

Our results demonstrate that taste enhancement can significantly increase or decrease acceptance, strongly depending on the type of added tastant, its concentration, and type of vegetable to which the tastants is added.

Sweetness enhancement and acceptance

A higher sweetness intensity significantly increased acceptance of cucumber and green capsicum purees compared to unmodified vegetable purees, which is consistent with the existing literature (Capaldi & Privitera, 2008; Sharafi et al., 2013). In cucumber, a relatively small level of sweetness enhancement corresponding to the addition of 2% sucrose was already sufficient to increase acceptance significantly compared to the unmodified vegetable. In contrast, in green capsicum purees a medium level of sweetness enhancement corresponding to the addition of 5% sucrose was needed to achieve an increase in acceptance. This suggests that in cucumber, a vegetable with a relatively neutral taste profile, a shift in acceptance is reached by addition of less sucrose compared to green capsicum puree, a vegetable with a higher bitterness (Poelman et al., 2017; Van Stokkom et al., 2016).

Enhancing taste does not only result in an increase of the added taste, but might also result in a different perception of other taste modalities due to taste–taste interactions. Keast and Breslin (2003) showed that low sweetness can increase bitterness. Since unmodified green capsicum displayed a significant higher bitterness compared to unmodified cucumber, it is possible that bitterness was increased by the presence of sweetness in green

Table 3–Mean taste and fattiness intensities of cucumber and green capsicum purees for unmodified, low, medium, and high tastant concentrations ($n = 66$).

Vegetable taste modality	Unmodified puree Mean ± SD	Low tastant concentration Mean ± SD	Medium tastant concentration Mean ± SD	High tastant concentration Mean ± SD	F-value
Cucumber					
Sweetness	14 ± 15^{A}	35 ± 19^{B}	71 ± 18^{C}	84 ± 21^{D}	$F(3,195) = 235.82$, $P < 0.01$
Sourness	15 ± 14^{A}	40 ± 23^{B}	55 ± 24^{C}	76 ± 19^{D}	$F(3,195) = 167.78$, $P < 0.01$
Bitterness	22 ± 17^{A}	47 ± 25^{B}	56 ± 27^{C}	81 ± 20^{D}	$F(3,195) = 131.76$, $P < 0.01$
Umami	30 ± 20^{A}	29 ± 19^{A}	39 ± 22^{B}	72 ± 22^{C}	$F(3,195) = 71.19$, $P < 0.01$
Saltiness	14 ± 14^{A}	35 ± 18^{B}	58 ± 18^{C}	75 ± 18^{D}	$F(3,195) = 219.34$, $P < 0.01$
Fattiness	20 ± 18^{A}	46 ± 22^{B}	59 ± 21^{C}	65 ± 23^{C}	$F(3,195) = 89.51$, $P < 0.01$
Green capsicum					
Sweetness	14 ± 13^{A}	41 ± 22^{B}	69 ± 21^{C}	86 ± 14^{D}	$F(3,195) = 305.33$, $P < 0.01$
Sourness	28 ± 24^{A}	31 ± 22^{A}	43 ± 22^{B}	70 ± 23^{C}	$F(3,195) = 71.44$, $P < 0.01$
Bitterness	37 ± 24^{A}	47 ± 24^{B}	65 ± 25^{C}	75 ± 24^{D}	$F(3,195) = 62.43$, $P < 0.01$
Umami	43 ± 24^{A}	35 ± 21^{A}	42 ± 25^{A}	61 ± 25^{B}	$F(3,195) = 19{,}21$, $P < 0.01$
Saltiness	20 ± 19^{A}	35 ± 23^{B}	53 ± 23^{C}	69 ± 21^{D}	$F(3,195) = 98.01$, $P < 0.01$
Fattiness	19 ± 15^{A}	45 ± 23^{B}	58 ± 21^{C}	68 ± 23^{D}	$F(3,195) = 91.30$, $P < 0.01$

Letters A to D indicate significant differences ($P < 0.05$) in taste intensity between different concentrations of added tastants for each taste modality.

Table 4–Mean acceptance of unmodified and low, medium, and high tastant concentration vegetable purees measured on a 9-point hedonic scale coded from −4 (dislike extremely) to +4 (like extremely).

Taste	Intensity	Cucumber Acceptance mean ± SD	Green capsicum Acceptance mean ± SD	Significance of difference in acceptance between cucumber and green capsicum purees
Unmodified	-	-0.1 ± 1.5	-0.4 ± 1.8	$t(99) = 1.45, P = 0.15$
Sweetness	Low	0.9 ± 1.6^{A}	0.2 ± 1.9^{A}	$t(99) = 3.62, P < 0.01$
	Medium	0.6 ± 2.1^{A}	0.6 ± 2.2^{A}	$t(99) = -0.31, P = 0.76$
	High	0.4 ± 2.3^{A}	0.5 ± 2.3^{A}	$t(99) = -0.56, P = 0.57$
Sourness	Low	0.3 ± 1.4^{A}	-0.3 ± 1.8^{AB}	$t(99) = 2.69, P < 0.01$
	Medium	-0.1 ± 1.5^{AB}	-0.1 ± 1.9^{A}	$t(99) = 0.14, P = 0.89$
	High	-0.6 ± 2.0^{B}	-0.9 ± 2.1^{B}	$t(99) = 1.04, P = 0.30$
Bitterness	Low	-1.5 ± 1.6^{A}	-1.3 ± 1.6^{A}	$t(99) = -1.12, P = 0.27$
	Medium	-2.5 ± 1.5^{B}	-2.0 ± 1.6^{B}	$t(99) = -2.79, P < 0.01$
	High	-3.2 ± 1.0^{C}	-3.1 ± 1.1^{C}	$t(99) = -1.11, P = 0.27$
Umami	Low	0.0 ± 1.4^{A}	-0.2 ± 1.7^{A}	$t(99) = 1.13, P = 0.26$
	Medium	-0.4 ± 1.7^{AB}	-0.3 ± 1.8^{A}	$t(99) = -0.62, P = 0.53$
	High	-1.2 ± 2.0^{B}	-1.2 ± 1.9^{B}	$t(99) = -0.28, P = 0.78$
Saltiness	Low	0.1 ± 1.6^{A}	-0.6 ± 1.8^{A}	$t(99) = 3.27, P < 0.01$
	Medium	-0.5 ± 1.8^{AB}	-0.8 ± 2.0^{AB}	$t(99) = 1.67, P = 0.10$
	High	-0.9 ± 2.0^{B}	-1.4 ± 2.0^{B}	$t(99) = 2.67, P < 0.01$
Fattiness	Low	0.1 ± 1.7^{A}	-0.3 ± 1.9^{A}	$t(99) = 1.98, P = 0.05$
	Medium	0.3 ± 1.8^{A}	0.3 ± 1.8^{A}	$t(99) = -0.05, P = 0.96$
	High	-0.2 ± 1.8^{A}	-0.1 ± 1.9^{A}	$t(99) = -0.14, P = 0.89$

Letters A to D indicate significant differences in acceptance between intensities within a taste modality within a type of vegetable. Mean acceptance scores were compared between cucumber and green capsicum purees using dependent *t*-tests. Level of significance of comparison of the means is shown.

capsicum, but not in cucumber. During the sensory evaluation, subjects were asked to rate the taste intensity of the enhanced taste modality only. Therefore, it was not possible to assess the effect of sweetness enhancement on bitterness or to assess any other taste–taste interactions, which is a limitation of this study.

Next to increasing taste intensity, adding sugar also increases energy density. In general, humans prefer energy-dense foods (Birch, 1999; Ventura & Worobey, 2013) and increasing energy density has been suggested to be an effective strategy to increase food intake; however, results are inconsistent (Caton et al., 2013; De Wild, de Graaf, & Jager, 2013; Gibson & Wardle, 2003; Hausner, Olsen, & Moller, 2012). In addition, enhancing fattiness intensity did not significantly increase acceptance. In the current study, subjects only tasted a small amount of vegetable purees (max 15 g per sample, average intake was around 5 g). Therefore, it is likely that energy played no or only a minor role in the increase of acceptance by enhancing sweetness by adding sucrose.

Sourness enhancement and acceptance

Low and medium concentrations of added citric acid in cucumber purees were perceived significantly more sour compared to low and medium concentrations of added citric acid in green capsicum purees. In green capsicum, the unmodified and low concentration of added citric acid were not perceived significantly different. This might be due to the more intense taste of the unmodified green capsicum which might have suppressed sourness, and therefore discrimination between tastes might have been more difficult. Subjects used for the sensory evaluation of the vegetable purees did not receive any training on the use of the line scale nor on the evaluation of the five taste modalities and fattiness. The lack of training leads to differences in the use of the line scales causing additional variability in the data set. It can also not be excluded that some subjects might have confused sourness with other taste modalities. The benefit of using naive subjects for the sensory evaluation of the vegetable purees is that they are more representative for consumers compared to trained and experienced subjects. Low concentration of added citric acid did not increase nor decrease acceptance significantly in neither vegetable compared to the unmodified purees. Consumers might just not like very sour vegetables. However, there were differences between cucumber and green capsicum. Low sourness was significantly more accepted in cucumber than in green capsicum purees. Low sourness might have enhanced bitterness in green capsicum, as Keast and Breslin (2003) showed that low sourness intensity can enhance bitterness. High concentrations of added citric acid were not well accepted in both vegetables even though Keast and Breslin (2003) suggested that high sourness also suppresses bitterness. Mojet, Heidema, and Christ-Hazelhof (2004) demonstrated that enhancing sourness did not cause a difference in perception of any of the other taste modalities. As mentioned earlier, a limitation of this study is that we did not quantify the effect of tastant addition on perception of other taste modalities, but assessed only the intensity of the corresponding and enhanced taste modality. Therefore, we do not know the effect of sourness enhancement on perception of other taste modalities in vegetables.

Bitterness enhancement and acceptance

Addition of caffeine can decrease sweetness and increase bitterness perception (Mojet et al., 2004). Bitterness is not well accepted (Birch, 1999; Drewnowski, 1997). As expected, enhancing bitterness decreased acceptance for both vegetables significantly. The stronger the bitterness, the lower the acceptance. Thus, simply enhancing taste intensity does not increase acceptance but strongly depends on the modality of the enhanced taste. In this study, we did not determine 6-n-propylthiouriacil (PROP) taster status of subjects. We used $n = 166$ healthy subjects without taste or swallowing problems (self-reported). We speculate that subjects included super PROP tasters, PROP tasters, and non-PROP tasters. The study did not aim to cluster subjects based on their PROP taster status. Bitter compounds of vegetables are often beneficial for human health. While the food industry tries to reduce bitterness in vegetables by selective breeding to increase vegetable acceptance,

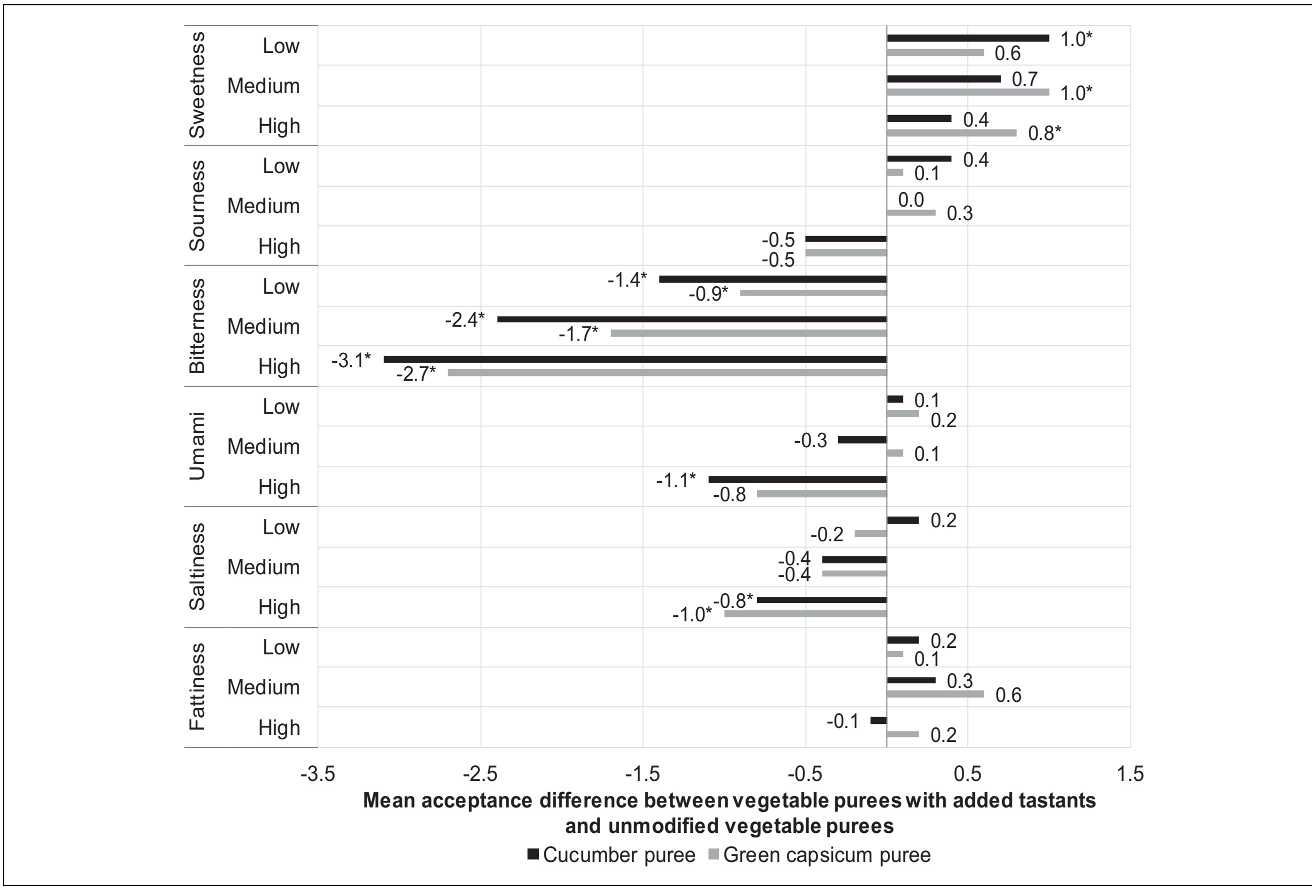

Figure 1–Mean difference in acceptance between purees with added tastants and unmodified purees for cucumber (black) and green capsicum purees (gray) ($n = 100$) for sweetness, sourness, bitterness, umami, saltiness, and fattiness. * indicates significant differences ($P < 0.05$) in acceptance compared to unmodified vegetable purees.

this might influence vegetable quality negatively. It has been suggested that efforts should be made to increase the amount of healthy compounds in vegetables, but that could also increase bitterness (Drewnowski & Gomez-Carneros, 2000). Our results show that increasing bitterness reduces consumer acceptance of vegetables indicating that strategies should be developed to enhance acceptance of bitterness. For example, matching bitter vegetables with other foods in a meal which suppress bitterness might be a methodology that could be used to enhance acceptance of vegetables.

Umami enhancement and acceptance

Addition of MSG at low concentrations did not lead to significant differences in umami intensity compared to the unmodified vegetable purees, possibly because of unfamiliarity of the consumers with umami taste sensations. As mentioned earlier, subjects used for the sensory evaluation did not receive any training. A solution of MSG was provided during the sensory evaluation to illustrate umami taste to the subjects. There was a significant difference in umami intensity between medium and high concentrations of added MSG compared to unmodified and low concentrations of added MSG in cucumber purees, and only high concentration of added MSG compared to the other MSG concentrations and unmodified green capsicum purees. High umami enhancement significantly reduced acceptance compared to the unmodified sample in cucumber purees ($P < 0.05$) and tended to reduce acceptance in green capsicum purees (not significant; $P = 0.07$) which is surprising since it has been shown that MSG can increase the palatability of many foods. Umami is not an uncommon taste of vegetables (Beauchamp, 2009; Masic & Yeomans, 2013; Yamaguchi & Ninomiya, 2000). Masic and Yeomans (2013) added 1% MSG to vegetable soups which resulted in increased pleasantness ratings. In our study, the highest MSG concentration (0.7%) decreased acceptance of the vegetable purees. Masic and Yeomans (2013) used soups which contained several ingredients (carrots, onions, olive oil, water, and a spice mixture). It is unclear whether the 1% MSG would also increase pleasantness ratings when just one vegetable were provided or a puree of vegetable. These differences between our and Masic and Yeomans (2013) suggest that the effect of umami enhancement on acceptance depends on vegetable type.

Saltiness enhancement and acceptance

It is common practice to add seasonings or salt to vegetables (Ahern et al., 2013; Birch, 1999; Drewnowski, 1997; Leshem, 2009; Martin et al., 2014). Enhancing saltiness by salt addition can suppress bitterness (Bouhlal et al., 2013; Bouhlal et al., 2011; Keast & Breslin, 2003; Mennella et al., 2003). On the contrary, Mojet et al. (2004) showed that adding NaCl to food can decrease sweetness and increase bitterness, sourness, and umami resulting in a more negative taste profile. Enhancing saltiness did not increase acceptance in our study. In fact, the higher the saltiness intensity, the lower the acceptance of the vegetable purees. One could argue that too much salt was added even for the low concentration of added NaCl (0.2%). In the study of Bouhlal et al. (2013), 0.6% and 1.2% NaCl were added to green beans and pasta. For green beans, at 0.6% NaCl concentration intake increased the most, while for pasta this was observed at 1.2%. A concentration of 0.6% NaCl was most liked for both foods. The salt concentrations Bouhlal et al. (2013) used were higher than the highest concentration we used (0.5%). Moreover, our results show that acceptance decreased when NaCl concentration increased. The differences between these findings might be due to the different methods used to increase saltiness. Bouhlal et al. (2013) added salt after boiling and stirred to distribute salt in the vegetable–salt mixture, which might have led to differences in salt concentration between bites. Another possibility is that preferred saltiness intensity depends on type of vegetable used.

Fattiness enhancement and acceptance

No significant differences in acceptance were observed between vegetables purees differing in concentration of added sunflower oil. It might be that fatty taste or fatty mouthfeel provided by the sunflower oil was unexpected in cucumber and green capsicum purees and therefore less accepted. Fattiness was the only sensory attribute related to the addition of sunflower oil assessed by the subjects. We acknowledge that in our study we cannot disentangle whether fat taste, fat texture, or both contributed to the observed effects. By adding sunflower oil to vegetable purees, energy content increased. As mentioned earlier, subjects only tasted a small amount of vegetable purees (max 15 g per sample, average intake was around 5 g). Therefore, it is likely that energy played no or only a minor role on the acceptance of vegetable purees with sunflower oil. A recent review showed that the effect of energy density on vegetable intake and acceptance is unclear due to inconsistent results from different studies (Holley, Farrow, & Haycraft, 2017).

Acceptance of vegetable purees

To summarize, the effect of taste enhancement on acceptance of vegetable purees differed between tastants and depends on tastant concentrations and vegetable type. This study demonstrated that with the exception of sweetness, taste enhancement of individual taste modalities such as saltiness, umami, sourness, and bitterness was insufficient to increase acceptance of cucumber and green capsicum purees. It is possible that more complex modifications of the taste profile or the flavor profile of the vegetables purees are required to enhance acceptance of vegetables. Furthermore, texture modifications might be used to enhance acceptance of vegetables. In the current study, vegetables were pureed, so strong texture cues were absent whereas texture could contribute to enhancing acceptance. When preparing vegetables, often spices and seasoning are added which do not enhance a single taste modality but provide a more complex and probably more pleasant flavor profile to the vegetable. During consumption, vegetables are commonly consumed together with sauces which also do not enhance a single taste modality but provide a more complex flavor and texture profile to the vegetables. We speculate that the enhancement of a single taste modality did not match expectations of consumers and that more complex taste, flavor, and texture combinations are needed to increase acceptance for vegetables further.

Taste enhancement method

Cucumber and green capsicum were offered in a pureed form which is not a common way to consume these vegetables. This might have led to relatively low acceptance scores. However, unmodified cucumber and green capsicum purees had acceptance scores of –0.1 and –0.4, respectively, indicating subjects neither liked nor disliked the unmodified cucumber puree. Many vegetable purees (21 out of 38 samples; 55% of samples) displayed mean acceptance scores between –0.5 and 0.5 corresponding to "neither like nor dislike." Preparation method is important for the acceptance of vegetables, especially familiarity with the preparation method influences acceptance (Poelman & Delahunty, 2011; Zeinstra et al., 2010). Zeinstra et al. (2010) showed that young adults (18 to 25 years) like uniformity in vegetables and dislike granular texture and brown color. Smashed preparations were not well liked, but steamed and boiled were liked (carrots, French beans). Bouhlal et al. (2013), Capaldi and Privitera (2008), and Sharafi et al. (2013) offered vegetables as a whole, this way the exact concentrations of added tastants were unknown, but texture integrity maintained. By pureeing vegetables, we were able to add different concentrations of tastants in a controlled manner. Pureeing itself is unlikely to have modified taste, as Van Stokkom et al. (2016) showed that taste intensities do not significantly differ between vegetables consumed as a whole and pureed. Our samples were uniform, as they were pureed but the texture might have made vegetable purees less attractive compared to unpureed raw vegetables. It is possible that next to taste, addition of sunflower oil effected texture (Le Calvé et al., 2015; Mela, 1988). We recommend future studies to not only include a descriptive analysis of all taste properties to assess taste–taste interactions, but also to include texture properties. As acceptance only significantly increased between the unmodified vegetables and some sweetness intensities for both vegetables, the mean differences compared to the unmodified sample were higher towards the negative side. This indicates that it is more challenging to increase acceptance of vegetables purees by enhancing taste than it is to decrease acceptance.

Conclusions

The effect of taste enhancement on acceptance of cucumber and green capsicum purees differed per tastant, concentration of tastant, and vegetable type. Only enhancement of sweetness increased acceptance of cucumber and green capsicum purees, at different concentrations of added sucrose. For cucumber purees, less sweetness enhancement was needed to increase acceptance compared to green capsicum purees, probably because cucumber displayed a relatively neutral taste profile whereas green capsicum exhibited higher intensities of sourness, bitterness, umami, and saltiness. Enhancement of all other taste modalities and fattiness was insufficient to increase acceptance of vegetable purees. We suggest that more complex taste, flavor, or texture modifications are required to enhance acceptance of vegetables. Results can be used by cultivators to grow vegetable varieties with more taste and flavor, especially since in cucumbers relatively small taste enhancements effects are sufficient to increase acceptance. Future studies could investigate whether food combinations based on taste and texture are an effective strategy to increase vegetable acceptance, for example, combining a neutral tasting vegetable with a stronger tasting vegetable or food.

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Authors' Contributions

V.L. van Stokkom designed the study, collected test data, interpreted the results, and drafted the manuscript. M. Stieger designed the study, interpreted the results, and drafted the manuscript. O. van Kooten designed the study and drafted the manuscript. C. de Graaf designed the study, interpreted the results, and drafted the manuscript.

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