Vegetable acceptance: a bittersweet story

Role of taste in acceptance of vegetables

Vera van Stokkom

Vegetable acceptance: a bittersweet story

Role of taste in acceptance of vegetables

Vera L. van Stokkom

Thesis committee

Promotors
Prof. Dr Kees de Graaf
Professor of Sensory Science and Eating Behaviour
Wageningen University & Research

Dr Markus Stieger
Associate Professor, Division of Human Nutrition and Health
Wageningen University & Research

Co-promotor
Prof. Dr Olaf van Kooten
Emeritus Professor Horticultural Supply Chains, Wageningen University & Research
Lector Horticulture, Inholland University of Applied Sciences

Other members
Prof. Dr Edith J.M. Feskens, Wageningen University & Research
Prof. Marion M. Hetherington, University of Leeds, United Kingdom
Dr Herman Peppelenbos, HAS University of Applied Sciences, 's Hertogenbosch
Dr Astrid Postma-Smeets, Netherlands Nutrition Centre, The Hague

This research was conducted under the auspices of the Graduate School VLAG (Advanced studies in Food Technology, Agrobiotechnology, Nutrition and Health Sciences).

Vegetable acceptance: a bittersweet story

Role of taste in acceptance of vegetables

Vera L. van Stokkom

Thesis

submitted in fulfilment of the requirements for the degree of doctor
at Wageningen University
by the authority of the Rector Magnificus,
Prof. Dr A.P.J. Mol,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public
on Friday 14 December 2018 at
4 p.m. in the Aula.

Vera L. van Stokkom
Vegetable acceptance: a bittersweet story**.** Role of taste in acceptance of vegetables,
184 pages.

PhD thesis, Wageningen University, Wageningen, The Netherlands (2018)
With references, with summary in English

ISBN:978-94-6343-376-1
DOI: https://doi.org/10.18174/463833

Content

Chapter 1

General introduction

Consuming vegetables is important for health, however in many countries the consumption is below the quantity that is recommended by the World Health Organization [1]. While many factors are involved in food choice and acceptance, the food product itself might be the most important [2-4]. In particular taste influences acceptance [5, 6], therefore the role of taste in the acceptance of vegetables is explored further in this thesis.

This introductory chapter starts with associations between vegetable consumption and health and vegetable consumption trends. Then the process of taste perception, the influence of innate predispositions on vegetable acceptance and differences in taste preferences between children and adults are described. This chapter ends with an overview of current knowledge about modifying taste as means for increasing vegetable acceptance and a general outline of the subjects of this thesis.

Vegetable consumption and health

The incidence of non-communicable diseases is increasing worldwide [7-9]. Non-communicable diseases are strongly related to lifestyle and are partially preventable [10]. There is convincing evidence that vegetable consumption reduces the risk of non-communicable diseases like hypertension, coronary heart disease and stroke [11]. Vegetable consumption has also been associated with lower all-cause mortality and cardiovascular mortality [12]. A high consumption of green leafy vegetables might be protective against diabetes [13]. The evidence for risk reduction of cancer by vegetable consumption is not yet convincing [11, 14], but there might be a modest preventive effect [15, 16].

In general, vegetables are considered healthy because they are low in energy and contain fibres, vitamins and phytochemicals [17]. There might be a special role in health for cruciferous vegetables, which contain sulphur-containing compounds such as glucosinolates. Breakdown products of glucosinolates, like isothiocyanates, possibly play a role in the prevention of cancer [18].

Vegetable consumption trends

In many countries vegetable consumption is below the recommendation of at least 200 g of vegetables per day [1, 14, 19-25]. Hulshof et al.[26] showed that in the Netherlands, the average consumption of vegetables decreased between 1987/88 (177 g/d) and 1997/1998 (149 g/d). Between 2007/2010 and 2012/2016 children's and adolescents fruit consumption increased and consumption of vegetables was stable in the Netherlands [21]. In the most recent Dutch national food consumption survey from 2012-2016, adults consumed about 130 g/d. In the USA, children's fruit consumption increased while vegetable intake did not change between 2003 and 2010 [22]. In Australia, vegetable consumption by adults slightly decreased between 1999 and 2011. However, this decrease was mostly a result of a decrease in the consumption of potato, which is included in the Australian dietary guidelines [27, 28], but not in the guidelines from the World Health Organization [1]. Children's vegetable consumption was stable between 1995 and 2007 in Australia [20]. Vereecken et al.[25] found that between 2002 and 2010 children's vegetable consumption increased in most countries, nevertheless consumption was below recommendations.

Although there were some positive trends in vegetable consumption, vegetable consumption was still below recommended intakes and strategies for increasing vegetable consumption are needed.

Food choice and sensory properties

Developing effective strategies for increasing vegetable consumption is difficult, as food choice is a complex process and many factors are involved. Different models explaining food acceptance, preferences and choice have been suggested [29, 30]. The physical, social and cultural environment, life style, attitudes and differences in perception are just some of the factors involved in food choice [4, 30-34]. Different strategies aimed at increasing vegetable consumption and acceptance have been investigated focusing on different factors involved in food choice and acceptance. A few examples are the promotion of healthy foods, nutrient labelling, health education and increased exposure, availability or convenience [3, 35-37]. However, it has been suggested that the food product and its sensory properties might be the most influential factor contributing to food choice, acceptance and eating behaviour [2-4].

Sensory properties include visual, olfactory, taste, auditory and textural cues. Sensation is the registering of sensory cues and perception is the interpretation of sensations. Visual and olfactory cues are already perceived before consumption of foods. Once a food is in the oral cavity, olfactory, taste, auditory and textural cues are perceived. Odours are volatile compounds. There are countless different compounds that humans can perceive with olfactory receptors in the nose [38]. Taste is defined as the perception of non-volatile compounds in the oral cavity. The term 'taste' generally refers to five taste modalities: sweet, sour, bitter, umami and salt. It has been suggested that fattiness is the sixth taste quality [39-41]. The oral cavity contains specific taste receptor cells for taste perception. Receptors send signals to the central nervous system where the sensation of taste is formed [41, 42]. Flavour is defined as the combined perception of taste and smell. The perception of texture is different than the perception of smell and taste as those are chemical senses while texture is the perception of structural, mechanical and surface properties of foods [43, 44].

All sensory properties together contribute to the acceptance or rejection of food, but taste might be the most important [5, 6]. For this reason, the role of taste in the acceptance of vegetables is further investigated in this thesis.

Predispositions and taste preferences

Humans are predispositioned to prefer sweet and salty tastes and fattiness, and to reject bitter and sour tastes. These predispositions probably developed because humans needed taste cues for survival. A sensitivity for bitterness probably signals which plans should be avoided as many toxic foods contain bitter tasting compounds. Sourness might not be well accepted because it may signal unripe fruits or spoilage. Parallel to this, humans developed a preference for tastes that provide the body with energy and nutrients [45-47]. Sweetness can signal mono and disaccharides, umami protein content and saltiness sodium content [48].

Nowadays taste preferences and other predispositions are less important for survival. Because sweetness is preferred, and sweetness is often accompanied by energy, taste driven food choices might lead to consumption of foods with high energy. Food products with high energy density are often unhealthy. Healthy foods do not necessarily match innate taste preferences as some phytochemicals can taste bitter [18] and diets with higher dietary quality have been associated with higher bitterness [49]. Moreover, unhealthy foods are perceived as having a better taste [50]. Poelman et al.[51] showed that vegetables are the only foods with (mild) bitter taste. As bitterness is generally not well accepted, it is not surprising that vegetable consumption is low. However, another study showed that few vegetables can be described as very bitter compared to other foods [52]. Thus, while bitterness intensity of some vegetables might be low, bitterness still seems to be associated with a limited acceptance of vegetables [53-55].

To better understand how bitterness and other tastes influence acceptance of different vegetables, there is a need to further explore vegetable taste intensities. Understanding taste differences between vegetables and how these tastes are associated with acceptance can help devise strategies for increasing vegetable acceptance.

Genetic variation and taste preferences

While sourness is generally not well accepted, it has been shown that some children prefer extremely sour tastes [56]. These differences in preferences probably develop as a result of differences in taste sensitivity and perception [34, 41]. Genetic variation can lead to differences in sensitivity and perception, the most well-known example being bitterness sensitivity and perception of 6-n-propylthiouriacil (PROP). It is estimated that 75% of humans are PROP-tasters, and perceive bitterness when tasting PROP, while others do not [34]. Of the PROP-tasters, most perceive PROP as moderately bitter, however a proportion (25%) perceives PROP as intense bitter, the latter group is called supertasters [57]. Sensitivity to bitterness might lead to lower vegetable acceptance [58, 59] and consequently to lower vegetable consumption [60]. However, other studies did not find differences between PROP-tasters and non-tasters in dietary patterns [61, 62] or vegetable consumption [63] and additional research is needed to address these contradictions.

Differences in taste perception and preferences between children and adults
Taste preferences are not static, they change during the course of life. In general, children prefer higher sweetness and saltiness intensities in foods than adults [46, 64, 65]. There is weak evidence that adolescents prefer sour and bitter tastes more than children and little is known about developmental changes in preference for umami [65].

Taste preferences might differ between children and adults because of differences in taste sensitivity. De Graaf and Zandstra[66] showed that children are less able to discriminate between different concentrations of sucrose than adolescents, and adolescents were less sensitive to sucrose than adults. Children might be more sensitive to bitterness [67], which helps explain why adults prefer some bitterness in certain products, like coffee and chocolate and children do not. While predispositions shape preferences, experiences can alter these preferences [45, 47, 67, 68]. Perhaps not only taste sensitivity explains differences in preferences between children and adults, there might also be a learning effect of exposure to food. In later life, taste perception declines which probably involves deterioration of neurological processing of taste [69], but also a decline in olfactory perception or the turnover rate of taste receptor cells might play a role [70, 71]. However, it is not clear if declining taste perceptions leads to preferences for higher taste intensity in older adults [69, 72].

Familiarity, identification and vegetable acceptance
For children, food preference is associated with familiarity. Early experiences are vital to increase familiarity and variety in the diet and to reduce food neophobia [37, 45, 73]. These early experiences largely depend on what parents have available in their home and prepare for their children [74, 75]. As familiarity is important for acceptance, knowing which sensory cues contribute to identification of vegetables is relevant. Different sensory cues might contribute differently to the identification of vegetables. Currently, little is known about how sensory cues contribute to the identification of foods. It has been shown that smell cues play a role in the identification of foods [76-78]. Schiffman[79] showed that removing visual and textural cues impairs identification of vegetables. However, the importance of taste in the identification of vegetables compared to other sensory cues is unknown. Therefore, this thesis explores the contribution of separate sensory cues to the identification of vegetables.

Influence of preparation method on vegetable texture and taste

Vegetables are often consumed after some form of preparation such as cutting, boiling, stir-frying, roasting and steaming. Preparation methods can influence sensory properties of vegetables [54]. Boiling, for example, reduces firmness in some vegetables [80-82]. The most preferred preparation method differs between vegetables [53, 54, 83], but boiling often leads to well accepted vegetables [84, 85]. Granular or tough fibrous textures can negatively influence vegetable acceptance [54, 85, 86] and crunchiness seems to be preferred [85]. In a study by Poelman and Delahunty[84] the influence of preparation methods on texture differed between vegetables, but texture was not associated with acceptance. Taste is also influenced by preparation methods. The influence of preparation methods on taste differs between vegetables [53, 54, 84]. For example, boiling increases sweetness intensity of carrots and zucchini, but decreased sweetness in fennel [54]. However, Bongoni et al.[82] did not find an effect of preparation method on sweetness and bitterness intensity in broccoli.
Preparation methods influence texture and taste differently between vegetables, therefore results of previous studies might not apply to other vegetables. The influence of preparation methods on texture and taste should be further assessed in multiple vegetables. In addition to texture and taste, preparation methods can influence phytochemical content [80-82, 87-90]. Understanding the influence of preparation methods on texture, taste, nutritional quality and acceptance for different vegetables can help recommend different preparation methods most appropriate in terms of taste, texture, nutritional quality and acceptability for different vegetables.

Increasing vegetable acceptance via taste modifications

Taste properties might be the main reason why vegetables are not well accepted [5, 6, 18], therefore modifying taste might be a valid strategy to increase acceptance and is therefore a central focus of this thesis.

Several studies investigated the effect of addition of tastants on acceptance of foods such as orangeade, yoghurt and grapefruit juice and found that sweetness enhancement increases acceptance [91, 92]. However, adding sucrose to fruit puree did not increase intake in another study [93]. Addition of citric acid to enhance sourness did not increase acceptance of orangeade [91], but another study showed that some children prefer extremely sour tastes in gelatines [56].

In vegetables, sweetness enhancement, by dipping vegetables in a sucrose solution, can increase acceptance [92]. Addition of sweeteners, like aspartame, to vegetables can also increase liking [94]. While most vegetables do not have an inherent sour taste, sour seasonings, like vinaigrette, lemon and yoghurt dressings are commonly used in the preparation of vegetables. However, the effect of sourness enhancement on acceptance of vegetables has not been investigated. Addition of monosodium glutamate to enhance umami can increase liking and intake of vegetable soups [95]. Enhancing saltiness increased children's acceptance of green beans [93, 96], but not of a salsify puree [97]. Sharafi et al.[94] showed that misting asparagus, Brussels sprouts and kale with sodium chloride did not increase liking. Offering vegetables with dip can promote intake [98], however in green beans increasing fattiness by addition of butter did not increase intake [93].

Adding tastants to food products does not only enhance the added taste modality but can enhance or suppress other taste modalities and influence flavour. This enhancing or suppressing effect depends on the tastant concentration added. Taste interactions are often symmetrical, so as enhancing sweetness suppresses bitterness, enhancing bitterness suppresses sweetness. In general, high concentrations of added tastants lead to suppression, while low concentrations of added tastants can lead to enhancement of other tastes [99].

The effect of taste enhancement on vegetable acceptance has been studied in only a few vegetables. Additionally, little is known about how the effect of taste enhancement on vegetable acceptance differs between tastants, at what tastant concentration acceptance is optimal and how acceptance of taste modifications differs between adults and children. Therefore, the effect of taste enhancement on acceptance is more thoroughly investigated in this thesis.

Adding tastants, for example sucrose, to vegetables to enhance taste might not be desired from a health perspective. It is valuable to investigate other approaches to enhance taste without the addition of tastants. Combining vegetables with other meal components, for example other vegetables, could be an approach to modify taste perception compared to individual not well accepted vegetables. It is unclear how taste and other sensory properties of combinations of vegetables are different from individual vegetables and how this influences acceptance.

Aim and outline of thesis

The aim of this thesis was to investigate the role of taste in the acceptance of vegetables. Figure 1 provides a simplified overview of factors influencing food acceptance based on the model of Pilgrim[100] and the main subjects of this thesis. The model illustrates that sensation is influenced by the food stimulus (vegetables) and the consumer. Sensation is closely related to perception, which is the interpretation of sensations. Perception subsequently influences acceptance.

To gain insight into the taste of vegetables, this thesis starts with a description of vegetable taste and fattiness intensities of vegetables commonly consumed in the Netherlands in Chapter 2. Additionally, the influence of preparation methods on vegetable taste and fattiness intensities is investigated. In Chapter 3, the role of smell, taste, flavour and texture cues in the identification of vegetables is described. Three studies were performed to further investigate the effect of different vegetable modifications on vegetable taste and acceptance. In Chapters 4 and 5 the effect of taste enhancement on vegetable acceptance of cucumber and green capsicum purees in adults and children is investigated. The influence of combining vegetables with other vegetables on sensory properties and acceptance of vegetables is assessed in Chapter 6. In Chapter 7, main findings are summarized and methodological considerations, practical implications and suggestions for future research are discussed.

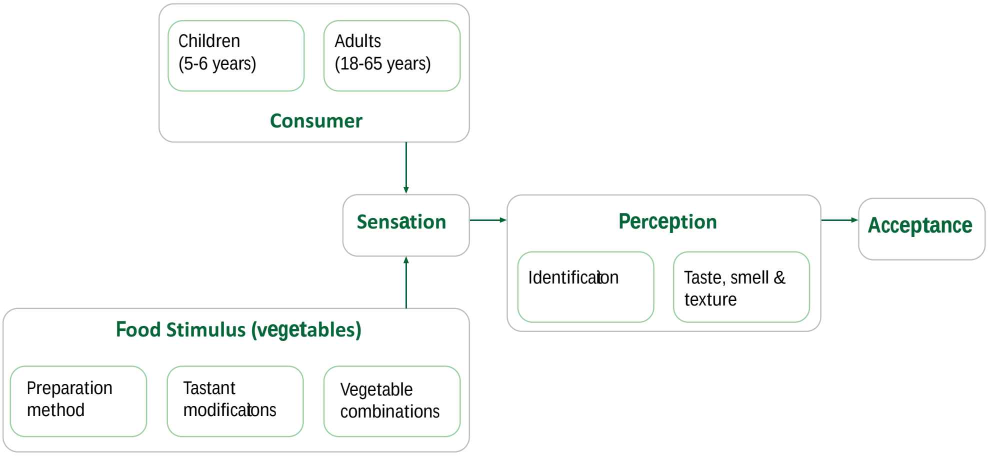


Figure 1. Overview of factors influencing food acceptance adapted from Pilgrim[(100)] and main subjects of this thesis.

References

1. World Health Organization. Healthy Diet. Factsheet N394; 2015.
2. Carrillo E, Varela P, Salvador A, Fiszman S. Main Factors Underlying Consumers' Food Choice: A First Step for the Understanding of Attitudes toward "Healthy Eating". *Journal of Sensory Studies*. 2011;26(2):85-95.
3. Glanz K, Basil M, Maibach E, Goldberg J, Snyder DAN. Why Americans Eat What They Do: Taste, Nutrition, Cost, Convenience, and Weight Control Concerns as Influences on Food Consumption. *Journal of the American Dietetic Association*. 1998;98(10):1118-26.
4. Pollard J, Kirk SF, Cade JE. Factors affecting food choice in relation to fruit and vegetable intake: a review. *Nutrition Research Reviews*. 2002;15(2):373-87.
5. Kourouniotis S, Keast RSJ, Riddell LJ, Lacy K, Thorpe MG, Cicerale S. The importance of taste on dietary choice, behaviour and intake in a group of young adults. *Appetite*. 2016;103:1-7.
6. Cox DN, Melo L, Zabaras D, Delahunty CM. Acceptance of health-promoting Brassica vegetables: the influence of taste perception, information and attitudes. *Public Health Nutrition*. 2012;15(8):1474-82.
7. Fitzmaurice C, Allen C, Barber RM, Barregard L, Bhutta ZA, Brenner H, et al. Global, Regional, and National Cancer Incidence, Mortality, Years of Life Lost, Years Lived With Disability, and Disability-Adjusted Life-years for 32 Cancer Groups, 1990 to 2015 A Systematic Analysis for the Global Burden of Disease Study. *Jama Oncology*. 2017;3(4):524-48.
8. NCD- NRFC. NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in diabetes since 1980: a pooled analysis of 751 population-based studies with 4.4 million participants (vol 387, pg 1513, 2016). *Lancet*. 2017;389(10068):E2-E.
9. Lozano R, Naghavi M, Foreman K, AlMazroa MA, Memish ZA. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010 (vol 380, pg 2095, 2012). *Lancet*. 2013;381(9867):628.
10. Beaglehole R, Bonita R, Horton R, Adams C, Alleyne G, Asaria P, et al. Priority actions for the non-communicable disease crisis. *Lancet*. 2011;377(9775):1438-47.
11. Boeing H, Bechthold A, Bub A, Ellinger S, Haller D, Kroke A, et al. Critical review: vegetables and fruit in the prevention of chronic diseases. *European Journal of Nutrition*. 2012;51(6):637-63.
12. Wang X, Ouyang YY, Liu J, Zhu MM, Zhao G, Bao W, et al. Fruit and vegetable consumption and mortality from all causes, cardiovascular disease, and cancer: systematic review and dose-response meta-analysis of prospective cohort studies. *British Medical Journal*. 2014;349.
13. Carter P, Gray LJ, Troughton J, Khunti K, Davies MJ. Fruit and vegetable intake and incidence of type 2 diabetes mellitus: systematic review and meta-analysis. *British Medical Journal*. 2010;341.
14. World Health Organization. Diet, nutrition and the prevention of chronic diseases: report of a joint WHO/FAO expert consultation. Geneva, Switserland; 2003.

15. Boffetta P, Couto E, Wichmann J, Ferrari P, Trichopoulos D, Bueno-de-Mesquita HB, et al. Fruit and vegetable intake and overall cancer risk in the European Prospective Investigation into Cancer and Nutrition (EPIC). *Journal of the National Cancer Institute*. 2010;102(8):529-37.
16. Health Council of the Netherlands. Dutch Dietary Guidelines 2015. The Hague, The Netherlands; 2015 (2015/24).
17. Slavin JL, Lloyd B. Health Benefits of Fruits and Vegetables. *Advances in Nutrition*. 2012;3(4):506-16.
18. Drewnowski A, Gomez-Carneros C. Bitter taste, phytonutrients, and the consumer: a review. *American Journal of Clinical Nutrition*. 2000;72(6):1424-35.
19. Diethelm K, Jankovic N, Moreno LA, Huybrechts I, De Henauw S, De Vriendt T, et al. Food intake of European adolescents in the light of different food-based dietary guidelines: results of the HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescence) Study. *Public Health Nutrition*. 2012;15(3):386-98.
20. Bowen J, Klose D, Syrette J, Noakes M. Australian children's vegetable intake: findings of the 2007 Australian children's national nutrition and physical activity survey. 2009 (VG07160).
21. Van Rossum CTM, Buurma-Rethans EJM, Vennemann FBC, Beukers M, Brants HAM, de Boer EJ, et al. The diet of the Dutch. Results of the first two years of the Dutch National Food Consumption Survey 2012-2016. Bilthoven: National Institute for Public Health and the Environment, Bilthoven, The Netherlands; 2016 (2016-0082).
22. Kim SA, Moore LV, Galuska D, Wright AP, Harris D, Grummer-Strawn LM, et al. Vital signs: fruit and vegetable intake among children - United States, 2003-2010. *Morbidity and Mortality Weekly Report*. 2014;63(31):671-6.
23. Moore LV, Thompson FE. Adults Meeting Fruit and Vegetable Intake Recommendations - United States, 2013. *Morbidity and Mortality Weekly Report*. 2015;64(26):709-13.
24. Australian Bureau of Statistics. Australian Health Survey: Nutrition First Results - Food and Nutrients, 2011-12. 2014 (4364.0.55.007).
25. Vereecken C, Pedersen TP, Ojala K, Krolner R, Dzielska A, Ahluwalia N, et al. Fruit and vegetable consumption trends among adolescents from 2002 to 2010 in 33 countries. *European Journal of Public Health*. 2015;25 Suppl 2:16-9.
26. Hulshof KF, Brussaard JH, Kruizinga AG, Telman J, Lowik MR. Socio-economic status, dietary intake and 10 y trends: the Dutch National Food Consumption Survey. *European Journal of Clinical Nutrition*. 2003;57(1):128-37.
27. Ridoutt B, Baird D, Bastiaans K, Hendrie G, Riley M, Sanguansri P, et al. Changes in Food Intake in Australia: Comparing the 1995 and 2011 National Nutrition Survey Results Disaggregated into Basic Foods. *Foods*. 2016;5(2):40.
28. National Health and Medical Research Council. Australian Dietary Guidelines. Canberra, Australia; 2013.
29. Sijtsema S, Linnemann A, van Gaasbeek T, Dagevos H, Jongen W. Variables influencing food perception reviewed for consumer-oriented product development. *Critical Reviews in Food Science and Nutrition*. 2002;42(6):565-81.

30. Cardello AV, Meiselman HL. Chapter 1 - Contextual Influences on Consumer Responses to Food Products A2 - In: Methods in Consumer Research, Volume 2: Woodhead Publishing; 2018. p. 3-54.
31. Furst T, Connors M, Bisogni CA, Sobal J, Falk LW. Food choice: a conceptual model of the process. *Appetite*. 1996;26(3):247-65.
32. Mela DJ. Food choice and intake: the human factor. *The Proceedings of the Nutrition Society*. 1999;58(3):513-21.
33. Story M, Neumark-Sztainer D, French S. Individual and environmental influences on adolescent eating behaviors. *Journal of the American Dietetic Association*. 2002;102(3 Suppl):S40-51.
34. Garcia-Bailo B, Toguri C, Eny KM, El-Sohemy A. Genetic variation in taste and its influence on food selection. *OMICS*. 2009;13(1):69-80.
35. Blanchette L, Brug J. Determinants of fruit and vegetable consumption among 6-12-year-old children and effective interventions to increase consumption. *Journal of Human Nutrition and Dietetics*. 2005;18(6):431-43.
36. Knai C, Pomerleau J, Lock K, McKee M. Getting children to eat more fruit and vegetables: a systematic review. *Preventive Medicine*. 2006;42(2):85-95.
37. Cooke L. The importance of exposure for healthy eating in childhood: a review. *Journal of Human Nutrition and Dietetics*. 2007;20(4):294-301.
38. Bushdid C, Magnasco MO, Vosshall LB, Keller A. Humans Can Discriminate More than 1 Trillion Olfactory Stimuli. *Science*. 2014;343(6177):1370-2.
39. Besnard P, Passilly-Degrace P, Khan NA. Taste of Fat: A Sixth Taste Modality? *Physiological Reviews*. 2016;96(1):151-76.
40. Running CA, Craig BA, Mattes RD. Oleogustus: The Unique Taste of Fat. *Chemical Senses*. 2015;40(7):507-16.
41. Liu D, Archer N, Duesing K, Hannan G, Keast R. Mechanism of fat taste perception: Association with diet and obesity. *Progress in Lipid Research*. 2016;63:41-9.
42. Sun-Waterhouse D, Wadhwa SS. Industry-Relevant Approaches for Minimising the Bitterness of Bioactive Compounds in Functional Foods: A Review. *Food and Bioprocess Technology*. 2013;6(3):607-27.
43. Lenfant F, Loret C, Pineau N, Hartmann C, Martin N. Perception of oral food breakdown. The concept of sensory trajectory. *Appetite*. 2009;52(3):659-67.
44. Liu D, Deng Y, Sha L, Abul Hashem M, Gai S. Impact of oral processing on texture attributes and taste perception. *Journal of Food Science and Technology*. 2017;54(8):2585-93.
45. Birch LL. Development of food preferences. *Annual Review of Nutrition*. 1999;19:41-62.
46. Mennella JA, Bobowski NK. The sweetness and bitterness of childhood: Insights from basic research on taste preferences. *Physiology & Behavior*. 2015;152(Pt B):502-7.
47. Breslin PAS. An Evolutionary Perspective on Food and Human Taste. *Current Biology*. 2013;23(9):R409-R18.
48. Van Dongen MV, van den Berg MC, Vink N, Kok FJ, de Graaf C. Taste-nutrient relationships in commonly consumed foods. *British Journal of Nutrition*. 2012;108(1):140-7.
49. Cox DN, Hendrie GA, Lease HJ. Do healthy diets differ in their sensory characteristics? *Food Quality and Preference*. 2018;68:12-8.

50. Raghunathan R, Naylor RW, Hoyer WD. The Unhealthy = Tasty Intuition and Its Effects on Taste Inferences, Enjoyment, and Choice of Food Products. *Journal of Marketing*. 2006;70(4):170-84.
51. Poelman AAM, Delahunty CM, de Graaf C. Vegetables and other core food groups: A comparison of key flavour and texture properties. *Food Quality and Preference*. 2017;56, Part A:1-7.
52. Martin C, Visalli M, Lange C, Schlich P, Issanchou S. Creation of a food taste database using an in-home "taste" profile method. *Food Quality and Preference*. 2014;36:70-80.
53. Duffy EM, Hayes JE, Feeney EL. Understanding taste and texture perception to enhance vegetable acceptance. *Proceedings of the Nutrition Society*. 2017;76(Oce3):E67-E.
54. Donadini G, Fumi MD, Porretta S. Influence of preparation method on the hedonic response of preschoolers to raw, boiled or oven-baked vegetables. *LWT - Food Science and Technology*. 2012;49(2):282-92.
55. Dinehart ME, Hayes JE, Bartoshuk LM, Lanier SL, Duffy VB. Bitter taste markers explain variability in vegetable sweetness, bitterness, and intake. *Physiology & Behavior*. 2006;87(2):304-13.
56. Liem DG, Westerbeek A, Wolterink S, Kok FJ, de Graaf C. Sour taste preferences of children relate to preference for novel and intense stimuli. *Chemical Senses*. 2004;29(8):713-20.
57. Bartoshuk LM, Duffy VB, Lucchina LA, Prutkin J, Fast K. PROP (6-n-Propylthiouracil) Supertasters and the Saltiness of NaCla. *Annals of the New York Academy of Sciences*. 1998;855(1):793-6.
58. Keller KL, Steinmann L, Nurse RJ, Tepper BJ. Genetic taste sensitivity to 6-n-propylthiouracil influences food preference and reported intake in preschool children. *Appetite*. 2002;38(1):3-12.
59. Kaminski LC, Henderson SA, Drewnowski A. Young women's food preferences and taste responsiveness to 6-n-propylthiouracil (PROP). *Physiology & Behavior*. 2000;68(5):691-7.
60. Bell KI, Tepper BJ. Short-term vegetable intake by young children classified by 6-n-propylthoiuracil bitter-taste phenotype. *The American Journal of Clinical Nutrition*. 2006;84(1):245-51.
61. Drewnowski A, Henderson SA, Cockroft JE. Genetic Sensitivity to 6-n-Propylthiouracil Has No Influence on Dietary Patterns, Body Mass Indexes, or Plasma Lipid Profiles of Women. *Journal of the American Dietetic Association*. 2007;107(8):1340-8.
62. Lumeng JC, Cardinal TM, Sitto JR, Kannan S. Ability to Taste 6-n-Propylthiouracil and BMI in Low-income Preschool-aged Children. *Obesity*. 2008;16(7):1522-8.
63. Yackinous CA, Guinard J-X. Relation between PROP (6-n-propylthiouracil) taster status, taste anatomy and dietary intake measures for young men and women. *Appetite*. 2002;38(3):201-9.
64. Mennella JA, Finkbeiner S, Lipchock SV, Hwang LD, Reed DR. Preferences for salty and sweet tastes are elevated and related to each other during childhood. *PLoS One*. 2014;9(3):e92201.

65. Hoffman AC, Salgado RV, Dresler C, Faller RW, Bartlett C. Flavour preferences in youth versus adults: a review. *Tobacco Control*. 2016;25(Suppl 2):ii32-ii9.
66. De Graaf C, Zandstra EH. Sweetness intensity and pleasantness in children, adolescents, and adults. *Physiology & Behavior*. 1999;67(4):513-20.
67. Mennella JA, Reiter AR, Daniels LM. Vegetable and Fruit Acceptance during Infancy: Impact of Ontogeny, Genetics, and Early Experiences. *Advances in Nutrition*. 2016;7(1):211s-9s.
68. Stein LJ, Cowart BJ, Beauchamp GK. The development of salty taste acceptance is related to dietary experience in human infants: a prospective study. *American Journal of Clinical Nutrition*. 2012;95(1):123-9.
69. Mojet J, Christ-Hazelhof E, Heidema J. Taste perception with age: generic or specific losses in threshold sensitivity to the five basic tastes? *Chemical Senses*. 2001;26(7):845-60.
70. Mojet J, Heidema J, Christ-Hazelhof E. Taste perception with age: generic or specific losses in supra-threshold intensities of five taste qualities? *Chemical Senses*. 2003;28(5):397-413.
71. Fukunaga A, Uematsu H, Sugimoto K. Influences of aging on taste perception and oral somatic sensation. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences*. 2005;60(1):109-13.
72. Methven L, Allen VJ, Withers CA, Gosney MA. Ageing and taste. *Proceedings of the Nutrition Society*. 2012;71(4):556-65.
73. Cooke L, Wardle J. Age and gender differences in children's food preferences. *British Journal of Nutrition*. 2005;93(5):741-6.
74. Savage JS, Fisher JO, Birch LL. Parental influence on eating behavior: conception to adolescence. *The Journal of Law, Medicin and Ethics*. 2007;35(1):22-34.
75. Cullen KW, Baranowski T, Owens E, Marsh T, Rittenberry L, de Moor C. Availability, Accessibility, and Preferences for Fruit, 100% Fruit Juice, and Vegetables Influence Children's Dietary Behavior. *Health Education & Behavior*. 2003;30(5):615-26.
76. Hummel T, Kobal G, Gudziol H, Mackay-Sim A. Normative data for the "Sniffin' Sticks" including tests of odor identification, odor discrimination, and olfactory thresholds: an upgrade based on a group of more than 3,000 subjects. *European Archives Oto-rhino-laryngology*. 2007;264(3):237-43.
77. Hummel T, Sekinger B, Wolf SR, Pauli E, Kobal G. 'Sniffin' sticks': olfactory performance assessed by the combined testing of odor identification, odor discrimination and olfactory threshold. *Chemical Senses*. 1997;22(1):39-52.
78. Sorokowska A, Schriever VA, Gudziol V, Hummel C, Hahner A, Iannilli E, et al. Changes of olfactory abilities in relation to age: odor identification in more than 1400 people aged 4 to 80 years. *European Archives Oto-rhino-laryngology*. 2015;272(8):1937-44.
79. Schiffman S. Food Recognition by Elderly. *Journals of Gerontology*. 1977;32(5):586-92.
80. Miglio C, Chiavaro E, Visconti A, Fogliano V, Pellegrini N. Effects of different cooking methods on nutritional and physicochemical characteristics of selected vegetables. *Journal of Agricultural and Food Chemistry*. 2008;56(1):139-47.

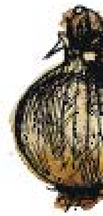
81. Bongoni R, Stieger M, Dekker M, Steenbekkers B, Verkerk R. Sensory and health properties of steamed and boiled carrots (Daucus carota ssp sativus). *International Journal of Food Sciences and Nutrition*. 2014;65(7):809-15.
82. Bongoni R, Verkerk R, Steenbekkers B, Dekker M, Stieger M. Evaluation of Different Cooking Conditions on Broccoli (Brassica oleracea var. italica) to Improve the Nutritional Value and Consumer Acceptance. *Plant Foods for Human Nutrition*. 2014;69(3):228-34.
83. Poelman AAM, Delahunty CM, de Graaf C. Vegetable preparation practices for 5-6 years old Australian children as reported by their parents; relationships with liking and consumption. *Food Quality and Preference*. 2015;42:20-6.
84. Poelman AAM, Delahunty CM. The effect of preparation method and typicality of colour on children's acceptance for vegetables. *Food Quality and Preference*. 2011;22:355-64.
85. Zeinstra GG, Koelen MA, Kok FJ, de Graaf C. The influence of preparation method on children's liking for vegetables. *Food Quality and Preference*. 2010;21(8):906-14.
86. Roininen K, Fillion L, Kilcast D, Lähteenmäki L. Exploring difficult textural properties of fruit and vegetables for the elderly in Finland and the United Kingdom. *Food Quality and Preference*. 2004;15(6):517-30.
87. Pellegrini N, Miglio C, Del Rio D, Salvatore S, Serafini M, Brighenti F. Effect of domestic cooking methods on the total antioxidant capacity of vegetables. *International Journal of Food Sciences and Nutrition*. 2009;60 Suppl 2:12-22.
88. Song L, Thornalley PJ. Effect of storage, processing and cooking on glucosinolate content of Brassica vegetables. *Food and Chemical Toxicology*. 2007;45(2):216-24.
89. Pellegrini N, Chiavaro E, Gardana C, Mazzeo T, Contino D, Gallo M, et al. Effect of Different Cooking Methods on Color, Phytochemical Concentration, and Antioxidant Capacity of Raw and Frozen Brassica Vegetables. *Journal of Agricultural and Food Chemistry*. 2010;58(7):4310-21.
90. Palermo M, Pellegrini N, Fogliano V. The effect of cooking on the phytochemical content of vegetables. *Journal of the Science of Food and Agriculture*. 2014;94(6):1057-70.
91. Liem DG, de Graaf C. Sweet and sour preferences in young children and adults: role of repeated exposure. *Physiology & Behavior*. 2004;83(3):421-9.
92. Capaldi ED, Privitera GJ. Decreasing dislike for sour and bitter in children and adults. *Appetite*. 2008;50(1):139-45.
93. Bouhlal S, Issanchou S, Nicklaus S. The impact of salt, fat and sugar levels on toddler food intake. *British Journal of Nutrition*. 2011;105(4):645-53.
94. Sharafi M, Hayes JE, Duffy VB. Masking Vegetable Bitterness to Improve Palatability Depends on Vegetable Type and Taste Phenotype. *Chemosensory Perception*. 2013;6(1):8-19.
95. Masic U, Yeomans MR. Does monosodium glutamate interact with macronutrient composition to influence subsequent appetite? *Physiology & Behavior*. 2013;116:23-9.
96. Bouhlal S, Chabanet C, Issanchou S, Nicklaus S. Salt content impacts food preferences and intake among children. *PLoS One*. 2013;8(1):e53971.
97. Bouhlal S, Issanchou S, Chabanet C, Nicklaus S. 'Just a pinch of salt'. An experimental comparison of the effect of repeated exposure and flavor-flavor learning with salt or spice on vegetable acceptance in toddlers. *Appetite*. 2014;83C:209-17.

98. Fisher JO, Mennella JA, Hughes SO, Liu Y, Mendoza PM, Patrick H. Offering “Dip” Promotes Intake of a Moderately-Liked Raw Vegetable among Preschoolers with Genetic Sensitivity to Bitterness. *Journal of the Academy of Nutrition and Dietetics*. 2012;112(2):235-45.
99. Keast SJR, Breslin PAS. An overview of binary taste-taste interactions. *Food Quality and Preference*. 2003;14(2):111-24.
100. Pilgrim FJ. The components of food acceptance and their measurement. *American Journal of Clinical Nutrition*. 1957;5(2):171-5.

Chapter 2

Taste intensities of ten vegetables commonly consumed in the Netherlands

Vera L. van Stokkom, Pey Sze Teo, Monica Mars,
Cees de Graaf, Olaf van Kooten, Markus Stieger



Based on publication in Food Research International,
2016. 87: p. 34-41

Abstract

Bitterness has been suggested to be the main reason for the limited palatability of several vegetables. Vegetable acceptance has been associated with preparation method. However, the taste intensity of a variety of vegetables prepared by different methods has not been studied yet. The objective of this study was to assess the intensity of the five basic tastes and fattiness of ten vegetables commonly consumed in the Netherlands prepared by different methods using the modified Spectrum method. Intensities of sweetness, sourness, bitterness, umami, saltiness and fattiness were assessed for ten vegetables (broccoli, carrot, cauliflower, French bean, leek, onion, red bell pepper, cucumber, iceberg lettuce and tomato) by a panel (n = 9) trained in a modified Spectrum method. Each vegetable was assessed prepared by different methods (raw, boiled, mashed and as a cold pressed juice). Spectrum based reference solutions were available with fixed reference points at 13.3 mm (R1), 33.3 mm (R2) and 66.7 mm (R3) for each taste modality on a 100 mm line scale. For saltiness, R1 and R3 differed (16.7 mm and 56.7 mm). Mean intensities of all taste modalities and fattiness for all vegetables were mostly below R1 (13.3 mm). Significant differences ($p < 0.05$) within vegetables between preparation methods were found. Sweetness was the most intensive taste, followed by sourness, bitterness, fattiness, umami and saltiness. In conclusion, all ten vegetables prepared by different methods showed low mean intensities of all taste modalities and fattiness. Preparation method affected taste and fattiness intensity and the effect differed by vegetable type.

Introduction

Vegetables are an essential part of a healthy diet, however the majority of Dutch children and adults do not meet the recommended daily intake of vegetables [(1)]. Especially for children, taste is an important driver for preference and food choice [(2, 3)]. Bitterness has been suggested to cause the rejection of many vegetables [(4, 5)]. It has been shown that humans are predispositioned to have an adverse response to bitter and sour tastes, while they prefer sweet and salty tastes [(6, 7)]. This aversion of bitterness was probably crucial for survival, because bitter tasting plant-based nutrients are often toxic. However, in small amounts, many of these nutrients, such as glucosinolates, have been suggested to contribute to healthy diets [(5)].

Several studies investigated taste profiles of various vegetables using different sensory methodologies. Dinehart et al.[(8)] profiled the taste intensities of asparagus, Brussels sprouts and kale using a Labelled Magnitude Scale. They found that bitterness was the most intensive taste and sweetness and saltiness the least intensive tastes for the tested vegetables. Van Dongen et al.[(9)] determined taste intensities of fifty commonly consumed foods using a modified Spectrum method. Most raw vegetables had a more neutral taste, while vegetable soups were more salty and savoury compared to other foods. Martin et al.[(10)] used an in-home modified Spectrum method to evaluate five basic tastes and fat intensities of 68 vegetables. Vegetables were grouped in two clusters based on taste. The first class contained 46% of the vegetables and was more intense in saltiness, umami, sourness and bitterness than average and less intense in sweetness and fattiness than average. The second class contained 19% of the vegetables and was mainly salty.

Not only taste but also preparation method and nutrient content can influence vegetable acceptability. Studies have shown that children prefer boiled and steamed vegetables over other preparation methods and that vegetables with a medium firm texture are preferred compared to very soft or very firm vegetables [(11-13)]. Nutrient content of vegetables can differ depending on the preparation methods used [(14, 15)]. As nutrient content has been linked to taste [(5, 9, 16)], it is plausible that preparation method alters taste. Humans prefer high energy dense foods and the low energy density of vegetables might contribute to the limited acceptability of vegetables [(17)]. Preparation method can alter vegetable texture and might influence acceptance by altering perceived energy density [(11, 17, 18)].

To the best of our knowledge, the taste and fattiness intensities of the most commonly consumed vegetables in the Netherlands and the influence of different preparation methods on taste and fattiness intensity has not been studied yet. Altering the preparation method is an easy way for parents to influence sensory properties of vegetables and may help optimize vegetable acceptance by children. The aim of the current study is to describe the taste and fattiness intensity of ten vegetables commonly consumed in the Netherlands using a modified Spectrum method and to investigate the effect of preparation method on taste and fattiness intensity.

Methods

Participants

Participants were selected based on their taste recognition, taste discrimination, concentration and sensory profiling abilities. The trained panel that analysed the taste and fattiness intensity of ten vegetables most commonly consumed in the Netherlands consisted of nine participants (n = 9), two males and seven females (mean age 36.3 ± 13.3 years) with a normal BMI (18.5-25 kg/m^2). All participants signed an informed consent form and received financial compensation for participation in the study. The study has been approved by the Human Ethics Review Committee of Wageningen University under number NL47315.081.13.

Training and the modified Spectrum method

The panel received intensive training using a modified Spectrum method to evaluate the intensity of sweetness, bitterness, umami, sourness, saltiness and fattiness in food products. Training of the panel consisted of two sessions per week for a period of six months. Each (training) session lasted 60-90 min. Each panellist received a minimum of 63 h of training in total. Panellists were training using basic tastant solutions, modified commercially available products and commercially available reference products. For each taste modality three reference solutions with fixed intensities on a 100 mm line scale were used during training and product profiling (13.3 mm (R1), 33.3 mm (R2) and 66.7 mm (R3)). For saltiness, the position of R1 and R3 on the 100 mm line scale differed (16.7 mm and 56.7 mm). Reference solutions contained different concentrations of sucrose (sweetness), citric acid (sourness), caffeine (bitterness), monosodium glutamate (MSG) (umami) and sodium chloride (saltiness) dissolved in Evian mineral water (Table 1). After the training with the reference tastant solutions, the panellists were trained in taste and fattiness evaluations of several food products which were modified with varying intensities of sapid taste substances (mashed potato (modified with NaCL and MSG), gelatine dessert (modified with sucrose), agar (modified with caffeine and citric acid) white rice (modified with MSG) and vanilla custard (modified with mascarpone)). This part of the training was completed when group consensus was reached about the taste intensities of the tastant solutions and modified commercially available products. In the next step of the training of the panellists, five reference products for fattiness and additional reference products for each taste modality were discussed and rated. This part of the training was completed when consensus about the taste and fattiness intensities of the commercially available reference products was reached. Based on the training, reference products were placed on the line scale at fixed points. Panellists were trained to recognise the fixed points of the reference solutions and reference products until they were able to accurately assess the references with the corresponding intensities of the fixes points. Training also included special sessions concerning umami, bitterness, fattiness and saltiness-umami discrimination. These additional training sessions included the profiling of taste intensities of (semi) solid foods. Reference solutions and reference products were available during profiling sessions and their position on the line scale was marked. Similar modified Spectrum methods have been used previously [10].

Table 1. Modified Spectrum method: composition and position of reference solutions and reference foods used on the intensity scale (100 mm).

Taste modality	Position reference solutions	Concentration g/L	References foods	% on scale
Sweetness (Sucrose)	R1 13.3	20	Biscuit	20
	R2 33.3	50	Custard	33
	R3 66.7	100	Cake	50
			Marshmallow	67
			Condensed milk	88
Sourness (Citric acid)	R1 13.3	0.5	Rye bread	15
	R2 33.3	0.8	Butter milk	38
	R3 66.7	1.5	Biogarde (yoghurt)	50
			Pickle	78
			Citric acid	97
Bitterness (Caffeine)	R1 13.3	0.5	Grapefruit juice	57
	R2 33.3	0.8	Dark chocolate	70
	R3 66.7	1.5		
Umami (Monosodium glutamate)	R1 13.3	1.2	Seaweed	28
	R2 33.3	3.0	Surimi	43
	R3 66.7	7.0	Parmesan cheese	69
			Soy sauce	94
Saltiness (Sodium chloride)	R1 16.7	2.0	Cracotte	14
	R2 33.3	3.5	Pringles	48
	R3 56.7	5.0	Old cheese	75
			Soy sauce	94
Fattiness	-		Cracker	9
			Custard	55
			Cream cheese	72
			White chocolate	73
			Butter	97

Panel performance

Panel performance measures (discriminative power, agreement and reproducibility) were monitored regularly during training and profiling sessions and feedback was given when necessary. Feedback was given to the panellists based on their individual ability to reproduce their results, their evaluations of the reference solutions and reference products and their use of the 100 mm line scale compared to the whole panel. In general, the panel had high reliability and discriminatory power with fair agreement and was able to produce a constant mean with a low standard deviation in repetitive sessions for a particular food item. A detailed description of the panel selection, training and performance was published elsewhere [19].

Sensory profiling took place in a sensory laboratory with individual testing booths at Wageningen University. Panellists were presented with a maximum of ten samples per session. Every session consisted of three randomized replicates per sample and lasted a maximum of 90 minutes.

Vegetable selection and preparation
Ten vegetables were selected based on consumption frequency in the Netherlands reported in the Dutch national food consumption survey [20]: broccoli, carrot, cauliflower, French bean, leek, onion, red bell pepper, cucumber, iceberg lettuce and tomato. Every week (in total four weeks), two or three vegetables were obtained from a wholesaler (Bakker Barendrecht, The Netherlands) and sensory profiling was executed within four days after obtaining the vegetables. Vegetables were stored at 6˚C. One hour prior to sensory testing, vegetables were kept at room temperature. Vegetables were assessed for several preparation methods (raw, boiled, mashed, juice and cold mash). In total 35 samples were assessed since preparation methods were not the same for all vegetables (Table 2). For each vegetable different preparation methods were used as boiling was not desired for certain vegetables (cucumber, iceberg lettuce and tomato). Standardized procedures were applied for the different preparation methods based on a cooking book [21] and expert knowledge. All vegetables were prepared unseasoned, so without any additions of condiments, salt, spices or oil to prevent modification of the taste modalities, and to make the different preparation methods as comparable as possible.

Table 2. Vegetable type, classification, origin, variation and description of preparation method.

Vegetable	Epic-classification and Latin names	Country of origin	Variation	Preparation method
Broccoli	Cabbage *Brassica oleracea*	Spain	Parthenon	Raw Juice Boiled – 8 min in boiling water (212 g vegetable/500 g water) Mashed - boiled, drained and 30 s blend
Carrot	Root vegetable *Daucus carota*	Spain	Naval	Raw Juice Boiled – 10 min in boiling water (220 g/500 g)[B] Mashed - boiled, drained and 30 s blend

Table 2 continues

Vegetable	Epic-classification and Latin names	Country of origin	Variation	Preparation method
Cauliflower	Cabbage *Brassica oleracea*	Spain	Meridien	Raw Juice[A] Boiled – 8 min in boiling water (212 g /500 g) Mashed – Boiled, drained and 30 s blend
French bean	Fruiting vegetable *Phaseolus vulgaris*	Egypt	Elhama	Boiled – 10 min in boiling water (224 g/500 g) Mashed - boiled, drained and 30 s blend
Leek[C]	Stalk vegetable *Allium ampeloprasum L.*	The Netherlands	Vitaton	Raw Juice Boiled – 8 min in boiling water (238 g/500 g) Mashed – boiled, drained and 30 s blend
Onion	Onion, garlic *Allium oepg L.*	The Netherlands	Centro	Raw Juice Boiled – 10 min in boiling water (238 g/500 g) Mashed – boiled, drained and 30 s blend
Red bell pepper	Fruiting vegetable *Capsicum annuum*	Spain	Lazaro	Raw Juice Boiled – 5 min in boiling water (226 g/500 g) Mashed – boiled, drained and 30 sec. blend
Cucumber	Fruiting vegetable *Cucumis sativus*	The Netherlands	Proloog	Raw Juice Cold mash - 30 s blend
Iceberg lettuce	Leafy vegetable *Lactuca satica L.*	Spain	Botiola	Raw Juice Cold mash - 30 s blend
Tomato	Fruiting vegetable *Solanum lycopersicum L.*	Morocco	Pitenza	Raw Juice Cold mash - 30 s blend

[A] TOP BV produced vegetable juices with a Cold Press type CP01 at a maximum pressure of 200 bar.
[B] Ratio vegetable/water was calculated taking shrinkage into account.
[C] One week between the harvests. No significant differences were observed between batches.

After preparation, the boiled and mashed vegetables were kept warm using a bain-marie container (60˚C). The raw vegetables, juices and cold mash vegetables were presented at room temperature. Portions of around 15 g were put into plastic cups labelled with three digit codes before consumption. During a session all preparation methods of two or three vegetables were offered to the panellists in a random order.

Statistical data analyses

Data were processed using IBM SPSS Statistics version 22. Means and SD over panellists per vegetable were calculated. Statistical data analysis was performed for all vegetables together and separately per preparation methods. Analysis of variance was performed using the GLM procedure to determine significant taste intensity differences between preparation methods averaged over all vegetables, within a vegetable and to evaluate panel performance. Differences between preparation methods overall vegetables and for differences between preparation methods within vegetables were investigated with Tukey post-hoc tests. Pearson's correlation coefficients were calculated to investigate associations between taste and fattiness intensities. Principle component analysis (PCA) was used to map the sensory profiling of the vegetables for different preparation methods. In addition, cluster analysis was performed to identify groups of vegetables based on taste and fattiness intensity. Statistical significance was set at $p < 0.05$.

Results

Taste and fattiness intensities averaged over vegetables per preparation method

For all taste modalities and fattiness, 90% of the samples had intensities below R1 (13.3 mm) (Table 3, Figure 1).

Table 3. Mean intensities and standard deviations per taste modality and fattiness per preparation method averaged overall vegetables. *letters A-C indicate significant differences ($p = 0.05$) between preparation methods per taste modality and fattiness. Same letters mean no significant difference between means.

Preparation	Sweetness	Sourness	Bitterness	Umami	Saltiness	Fattiness
Raw	9.2 ± 5.8^{B}	8.1 ± 9.3^{B}	8.4 ± 13.6^{B}	4.4 ± 6.0^{C}	2.1 ± 2.9^{BC}	3.1 ± 4.8^{D}
Boiled	12.0 ± 6.6^{A}	5.1 ± 6.5^{C}	4.6 ± 7.8^{B}	5.3 ± 5.7^{BC}	2.9 ± 4.6^{AB}	10.2 ± 13.2^{B}
Mashed	13.5 ± 7.5^{A}	5.3 ± 6.5^{C}	4.5 ± 8.3^{B}	6.8 ± 7.7^{AB}	4.1 ± 6.0^{A}	11.1 ± 13.2^{A}
Juice	12.5 ± 9.8^{A}	10.2 ± 12.0^{B}	18.5 ± 28.0^{A}	7.8 ± 9.5^{A}	2.8 ± 4.1^{AB}	4.2 ± 5.6^{CD}
Cold mash	9.0 ± 4.7^{B}	14.7 ± 13.5^{A}	3.4 ± 2.7^{B}	7.8 ± 8.6^{A}	1.8 ± 2.2^{C}	5.0 ± 4.2^{C}

Preparation method significantly influenced the taste modalities sweetness ($F(4,89) = 15.55$, $p < 0.01$), sourness ($F(4,89) = 23.42$, $p < 0.01$), bitterness, ($F(4,89) = 29.92$, $p < 0.01$) , umami ($F(4,89) = 12.18$, $p < 0.01$), saltiness ($F(4,89) = 8.29$, $p < 0.01$) and fattiness ($F(4,89) = 129.64$, $p < 0.01$). Raw and cold mash were significantly less sweet. Boiled and mashed were significantly less sour than all other preparation methods. The cold mash preparation method was significantly more sour, and juice was significantly more bitter than all other preparation methods. The raw preparation method was significantly less umami than the mashed, juice and cold mash preparation methods. The mashed preparation method was significantly higher in fattiness than all other preparation methods.

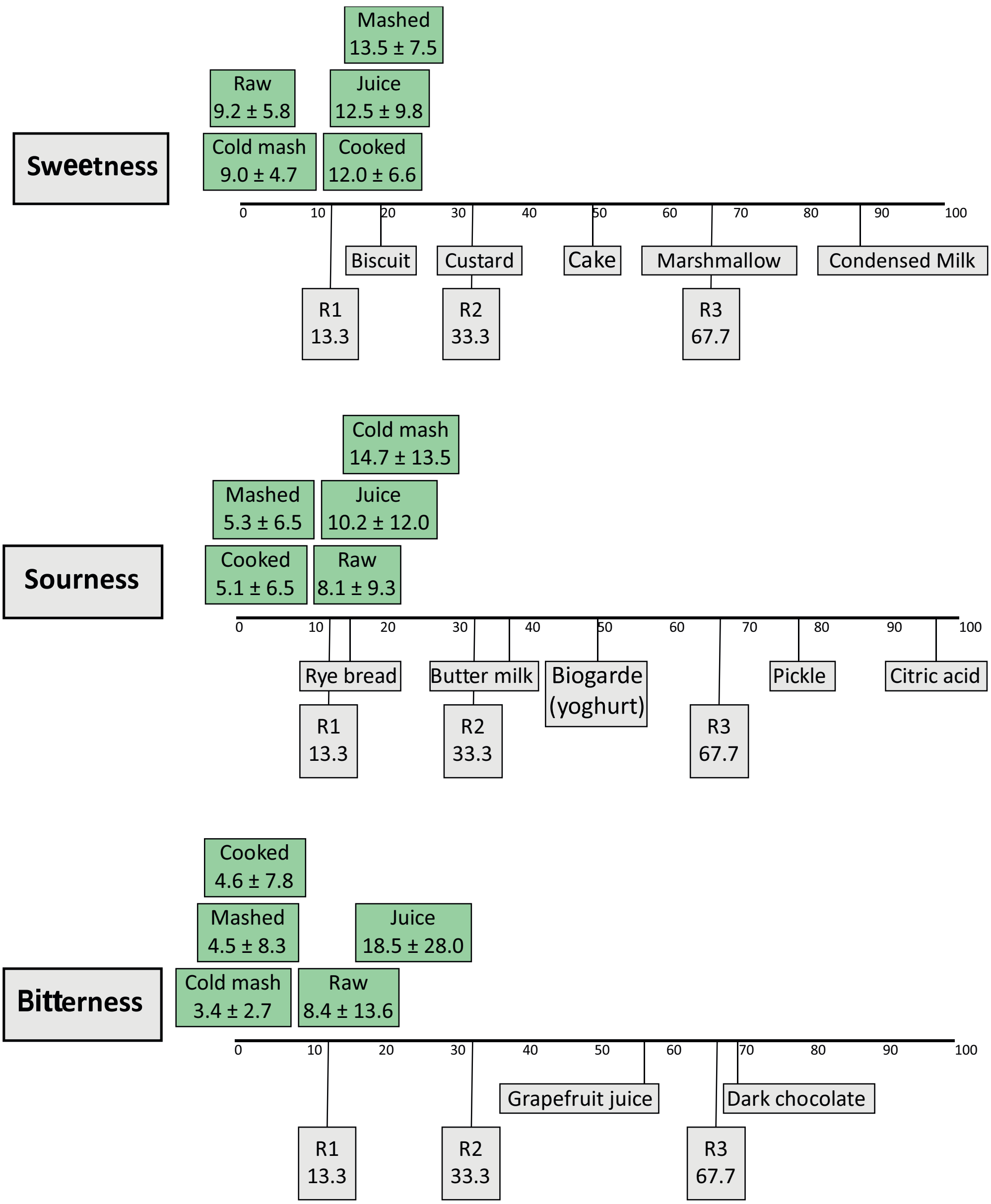


Figure 1 continues

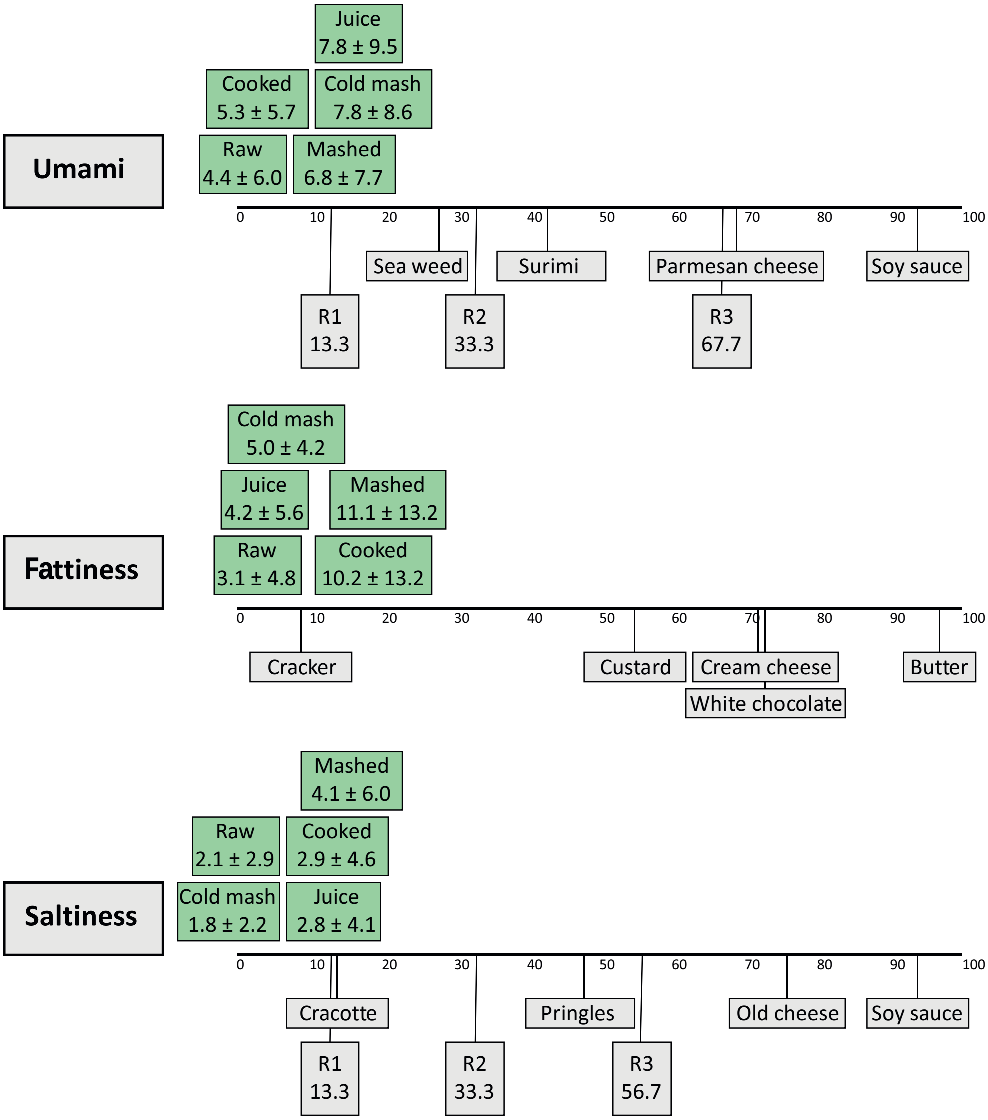


Figure 1. Mean tastes and fattiness intensities of ten vegetables commonly consumed in the Netherlands averaged over type of preparation method with fixed intensities of reference solutions and reference products.

Taste and fattiness intensities per vegetable per preparation method

Taste intensities differed significantly between preparation methods within vegetables (Table 4). F-values per taste modality per vegetable are reported in Table A1, Appendix A.

For broccoli, carrot, cauliflower and red bell pepper, sweetness was significantly higher in juices compared to raw preparation method. For tomato, all preparations differed significantly for sourness. For cauliflower, leek and onion, bitterness was significantly higher in juices than all other preparation methods. Juices were significantly more umami than raw vegetables for carrot, cucumber and tomato. Mashed and boiled preparations were higher in fattiness than all other preparations for most vegetables.

Table 4. Means and standard deviations of ten vegetables commonly consumed in the Netherlands per preparation method. *letters A-D indicate significant differences ($p < 0.05$) between preparation methods within one vegetable. Same letters mean no significant difference between means.

Vegetable	**Sweetness** *Mean ± SD*	**Sourness** *Mean ± SD*	**Bitterness** *Mean ± SD*	**Umami** *Mean ± SD*	**Saltiness** *Mean ± SD*	**Fattiness** *Mean ± SD*
Broccoli						
Raw	6.2 ± 5.2^{B}	6.3 ± 7.3^{A}	9.3 ± 5.8^{A}	6.4 ± 7.7^{A}	2.3 ± 3.1^{A}	1.7 ± 2.0^{C}
Boiled	11.5 ± 5.3^{A}	5.7 ± 7.3^{A}	4.7 ± 4.0^{B}	7.3 ± 7.9^{A}	5.9 ± 8.9^{A}	11.4 ± 15.5^{AB}
Mashed	11.2 ± 5.1^{A}	5.3 ± 7.0^{A}	5.0 ± 4.9^{B}	8.9 ± 8.5^{A}	4.2 ± 4.6^{A}	14.6 ± 15.8^{A}
Juice	11.2 ± 6.2^{A}	6.6 ± 6.7^{A}	12.8 ± 9.4^{A}	9.8 ± 12.7^{A}	5.2 ± 6.8^{A}	5.7 ± 6.7^{BC}
Carrot						
Raw	16.1 ± 6.7^{C}	2.0 ± 1.8^{A}	2.0 ± 2.2^{A}	2.5 ± 2.2^{B}	1.7 ± 1.9^{A}	2.8 ± 4.8^{B}
Boiled	19.5 ± 7.2^{BC}	1.4 ± 1.6^{A}	0.8 ± 9.0^{A}	4.8 ± 5.3^{AB}	2.2 ± 3.7^{A}	10.5 ± 13.9^{AB}
Mashed	23.3 ±.8.8^{B}	1.4 ± 1.7^{A}	1.4 ± 1.3^{A}	6.3 ± 6.6^{AB}	3.0 ± 5.2^{A}	13.4 ± 15.0^{A}
Juice	30.1 ± 7.6^{A}	1.2 ± 1.3^{A}	1.7 ± 1.9^{A}	9.8 ± 9.7^{A}	3.3 ± 4.4^{A}	8.5 ± 7.8$^{A B}$
Cauliflower						
Raw	7.6 ± 5.1^{C}	3.6 ± 4.6^{A}	3.6 ± 3.5^{B}	3.4 ± 3.6^{A}	2.1 ± 3.0^{A}	3.7 ± 5.7^{B}
Boiled	10.0 ± 4.2^{BC}	3.8 ± 4.7^{A}	4.1 ± 4.2^{B}	5.0 ± 4.3^{A}	2.0 ± 2.4^{A}	11.6 ± 15.0^{AB}
Mashed	12.3 ± 5.4^{AB}	3.3 ± 3.7^{A}	2.9 ± 3.0^{B}	5.3 ± 5.9^{A}	2.7 ± 4.1^{A}	13.1 ± 14.7^{A}
Juice	14.2 ± 8.0^{A}	3.7 ± 5.1^{A}	11.5 ± 15.7^{A}	6.5 ± 5.5^{A}	3.9 ± 5.2^{A}	7.6 ± 8.5^{AB}
French bean						
Boiled	7.5 ± 4.4^{A}	3.3 ± 5.1^{A}	1.9 ± 1.5^{A}	3.7 ± 4.7^{A}	1.8 ± 2.1^{A}	4.4 ± 3.3^{A}
Mashed	9.1 ± 5.7^{A}	3.8 ± 5.7^{A}	2.0 ± 1.7^{A}	6.5 ± 8.1^{A}	2.3 ± 3.2^{A}	5.8 ± 3.9^{A}

Table 4 continues

Vegetable	Sweetness *Mean ± SD*	Sourness *Mean ± SD*	Bitterness *Mean ± SD*	Umami *Mean ± SD*	Saltiness *Mean ± SD*	Fattiness *Mean ± SD*
Leek						
Raw	5.1 ± 3.4^{B}	4.2 ± 5.8^{A}	16.7 ± 12.4^{B}	1.8 ± 1.9^{B}	1.5 ± 2.3^{A}	3.0 ± 4.7^{B}
Boiled	9.1 ± 4.5^{A}	4.3 ± 5.9^{A}	10.1 ± 15.7^{B}	6.1 ± 6.3^{A}	3.5 ± 5.0^{A}	12.3 ± 15.7^{A}
Mashed	9.0 ± 4.0^{A}	7.7 ± 7.9^{A}	8.5 ± 14.3^{B}	6.3 ± 6.2^{A}	3.8 ± 5.2^{A}	15.2 ± 16.2^{A}
Juice	4.1 ± 3.4^{B}	5.5 ± 7.3^{A}	54.4 ± 28.1^{A}	2.1 ± 2.2^{B}	1.6 ± 2.0^{A}	2.4 ± 2.5^{B}
Onion						
Raw	8.9 ± 4.6^{AB}	7.7 ± 9.9^{A}	31.0 ± 28.5^{B}	2.8 ± 3.9^{AB}	3.4 ± 4.1^{A}	3.4 ± 6.5^{BC}
Boiled	9.4 ± 5.2^{A}	4.4 ± 6.8^{A}	4.5 ± 8.0^{C}	4.5 ± 5.7^{AB}	2.2 ± 2.5^{A}	9.2 ± 11.2^{AB}
Mashed	12.1 ± 5.5^{A}	4.9 ± 7.7^{A}	7.1 ± 14.9^{C}	7.3 ± 10.5^{A}	9.7 ± 10.7^{A}	9.7 ± 10.7^{A}
Juice	5.8 ± 4.9^{B}	9.7 ± 9.1^{A}	74.5 ± 21.1^{A}	2.5 ± 3.0^{B}	2.7 ± 2.8^{A}	1.5 ± 2.1^{C}
Red Bell pepper						
Raw	14.5 ± 5.0^{B}	10.2 ± 6.1^{B}	4.8 ± 5.3^{A}	5.4 ± 6.5^{A}	2.7 ± 4.4^{A}	4.6 ± 8.6^{A}
Boiled	16.8 ± 6.0^{AB}	12.8 ± 7.6^{AB}	5.9 ± 8.1^{A}	5.9 ± 6.2^{A}	2.9 ± 4.2^{A}	11.8 ± 15.8^{A}
Mashed	17.8 ± 7.0^{AB}	11.1 ± 6.2^{AB}	4.5 ± 4.8^{A}	6.8 ± 9.0^{A}	2.6 ± 4.3^{A}	12.6 ± 15.0^{A}
Juice	20.4 ± 9.1^{A}	15.7 ± 5.7^{A}	5.4 ± 5.1^{A}	7.6 ± 8.1^{A}	3.1 ± 4.8^{A}	5.5 ± 6.3^{A}
Cucumber						
Raw	6.0 ± 3.7^{A}	6.5 ± 5.6^{A}	2.9 ± 2.6^{A}	0.6 ± 0.4^{B}	1.5 ± 2.2^{A}	2.5 ± 2.8^{AB}
Cold mash	7.1 ± 3.6^{A}	7.8 ± 5.8^{A}	2.3 ± 2.7^{A}	1.9 ± 3.6^{AB}	1.7 ± 2.4^{A}	4.0 ± 3.9^{A}
Juice	6.3 ± 4.8^{A}	7.1 ± 3.8^{A}	2.4 ± 2.3^{A}	4.0 ± 7.1^{A}	1.6 ± 1.6^{A}	1.7 ± 2.4^{B}
Iceberg lettuce						
Raw	10.2 ± 5.7^{A}	4.7 ± 4.9^{A}	3.3 ± 2.2^{A}	1.9 ± 2.6^{A}	0.9 ± 1.7^{A}	1.7 ± 1.9^{B}
Cold mash	12.1 ± 5.3^{A}	4.7 ± 4.5^{A}	3.9 ± 2.4^{A}	4.5 ± 7.0^{A}	1.3 ± 2.2^{A}	5.3 ± 4.5^{A}
Juice	11.6 ± 5.8^{A}	5.0 ± 4.9^{A}	4.2 ± 2.4^{A}	6.2 ± 11.3^{A}	1.6 ± 2.5^{A}	2.3 ± 3.7^{B}
Tomato						
Raw	7.9 ± 2.6^{A}	26.4 ± 7.2^{B}	3.0 ± 2.2^{A}	14.3 ± 6.5^{B}	2.6 ± 2.9^{A}	4.5 ± 3.2^{AB}
Cold mash	7.7 ± 3.5^{A}	31.0 ± 7.9^{AB}	3.9 ± 2.9^{A}	16.6 ± 5.6^{AB}	2.3 ± 2.2^{A}	5.6 ± 4.4^{A}
Juice	9.3 ± 4.7^{A}	35.1 ± 12.2^{A}	2.8 ± 2.1^{A}	20.3 ± 7.9^{A}	2.2 ± 4.4^{A}	2.7 ± 3.2^{B}

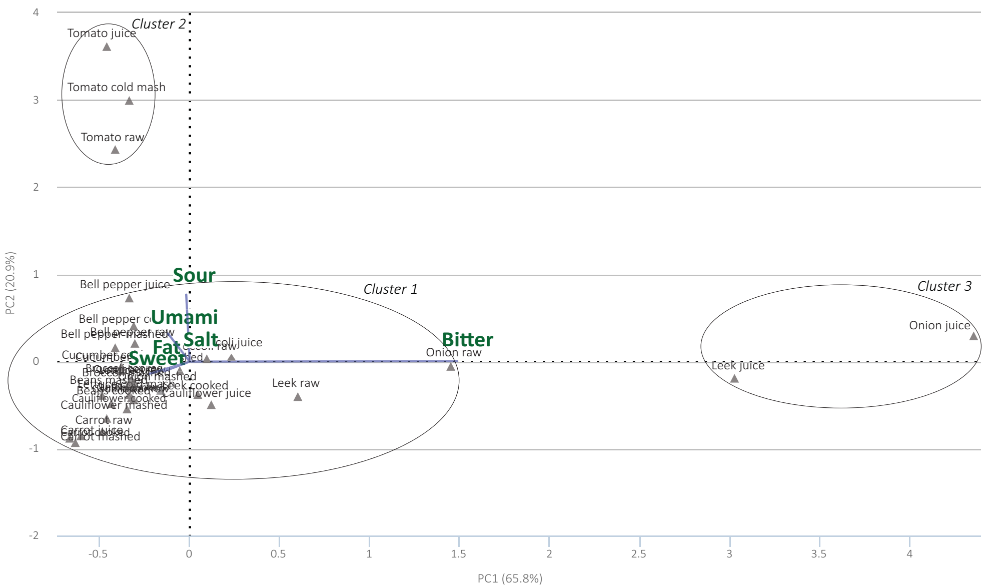


Figure 2. PCA biplot of vegetables per preparation method (covariance matrix) together with visualization of three vegetable clusters.

Cluster analysis

A biplot representation of the PCA and visualization of three clusters of vegetables are shown in Figure 2.

The most discriminative taste modalities were bitterness (PC1, 65.8%) and sourness (PC2, 21%). Sweetness was significantly correlated with fattiness ($r = 0.43$, $p < 0.01$) and inversely correlated with bitterness ($r = -0.35$, $p < 0.05$). Sourness was correlated with umami ($r = 0.78$, $p < 0.01$). Umami and saltiness were correlated ($r = 0.36$, $p < 0.05$) and saltiness and fattiness were correlated ($r = 0.53$, $p < 0.01$).

Cluster analysis indicated three main clusters of vegetables based on taste and fattiness intensities. The three clusters account for 86.7% of the variance. Cluster 1 represented most vegetables (86%) and was the most dispersed cluster of which sweetness was the most intensive taste. Cluster 2 contained 9% of the vegetables and was more intensive for umami and sour compared to the other clusters. All preparations of tomato were in cluster 2. Cluster 3 contained 6% of the vegetables (onion juice and leek juice) of which the most intensive taste was bitterness.

Discussion

The present study systematically assessed taste and fattiness intensities of ten vegetables commonly consumed in the Netherlands and the influence of different preparation methods on taste and fattiness intensity using a modified Spectrum method. Results showed that most vegetables had very low intensities of the five basic tastes and fattiness, typically below R1 (13.3 mm). Preparation method had a significant effect on the intensity of all taste modalities and fattiness. Bitterness and sourness were the taste intensities discriminating the most between vegetables.

Vegetable taste intensities

Although bitterness has often been described as the main reason for the rejection of vegetables, we observed that sweetness was the most intensive taste, followed by sourness, bitterness, fattiness, umami and saltiness. Three clusters of vegetables based on taste intensities were identified. Most vegetables (86%) were in one cluster and did not show pronounced differences in taste or fattiness intensities. Previous studies using a modified Spectrum method have shown that many foods, including vegetables, have low taste intensities [9, 10]. However, results about the most intensive taste of vegetables show differences between studies. Dinehart et al.[8], reported that bitterness was the most intense taste for asparagus, Brussels sprouts and kale, followed by sourness and sweetness. Similar to our results, saltiness had the lowest intensity. Asparagus was also one of the very bitter foods in the study of Martin et al.[10]. Also, broccoli, cauliflower and green bean (6% of all tested vegetables) were mainly bitter, all other tastes were below average in this food group. Martin et al.[10] described two more vegetable groups: one included 47% of all vegetables and was more intense in saltiness, umami, sourness and bitterness than average and one was a more salty group and included 19% of all vegetables. The results from Dinehart et al.[8] and Martin et al.[10] are different than the results from the current study, since sweetness was the most intensive taste for all vegetables in the current study. In our study, there were only a few vegetables with intensities for umami, sourness and bitterness above R1 (tomato, bell pepper, leek and onion) and non for saltiness. Martin et al.[10] used an in-home design which might have led to higher than average intensities of saltiness. Participants might have added condiments, vinaigrette or salt during the preparation of the vegetables at home, leading to higher saltiness and possibly higher umami intensities and a decrease of other tastes. Another explanation for the taste intensity differences between studies is the possibility that different varieties of vegetables were used.

It has been shown that there are nutrient differences between varieties of the same vegetable [22-25]. These nutrient variations might cause differences in taste intensities between vegetable varieties. Martin et al.[10] , Dinehart et al.[8] and van Dongen et al.[9] did not specify the vegetable varieties used. Martin et al.[10] found correlations between saltiness and umami and saltiness and fattiness ($r = 0.66$, $p < 0.01$; $r = 0.53$, $p < 0.01$) showed the same direction as our results (saltiness-umami $r = 0.36$, $p < 0.05$ and saltiness-fattiness $r = 0.64$, $p < 0.01$).

Influence of preparation method on taste and fattiness intensity

Our study showed significant taste intensity differences between preparation methods. The effect of preparation method on taste differed per vegetable. Boiling decreased taste intensity for some vegetables, mainly in vegetables where the raw preparation method and the juice had higher intensities compared to boiled and mashed preparation methods. This decrease in taste intensity could be caused by the leaching of taste related nutrients in the water during boiling [18, 26, 27]. Poelman et al.[18] and Bongoni et al.[12] found that nutrients probably leach in the water during boiling leading to a decrease of sweetness in broccoli. However, in our study, raw vegetables and vegetable juices with low taste intensities had higher taste intensities for the boiled and mashed preparation methods. There are three possible explanations for this increase in taste intensity: taste-related compounds are generated by heating, there is an effect of temperature on taste perception or textural changes influence perceived taste intensities.

After boiling some vegetables have an increase of their total antioxidant capacity (TAC) probably due to the formation of antioxidant compounds [14, 15], which could lead to increased taste intensity compared to raw vegetables. The increase or decrease of nutrients in vegetables after cooking is probably related to vegetable type [15]. The difference in taste intensity between cold and warm preparation methods might also have to do with tasting temperature. Boiled and mashed vegetables were offered at a temperature around 50˚C, while raw, cold mash and juices were offered at room temperature. Some studies have shown that temperature can have an effect on taste intensity. Heating possibly increases sweetness, although results are not always consistent [28, 29]. Increased taste intensity between cold and warm preparation methods might be caused by textural changes. Zeinstra et al.[11] compared the liking for several preparation methods and found that boiling was the most preferred preparation method. The preference for boiled vegetables might be due to the perceived increased fattiness intensity, which could signal higher energy density and higher energy density foods are preferred in general over low energy density foods [11, 17, 30].

The results from the current study show that for some vegetables, juices have significantly higher taste intensities than vegetables prepared by other methods. Vegetable juices might have higher availability of taste compounds compared to solid-like vegetables. Nowadays, vegetable juices have become a popular way to consume vegetables due to its convenience. Sweetness intensity was increased in juices, which might contribute to the popularity of vegetable juices. However, bitterness increased as well which might be a reason why fruits are often added to vegetable juices. Although vegetable juice consumption may contribute to increased vegetable intake, they cannot replace whole vegetables due to the removal of fibrous material during preparation and should therefore be seen as a supplement to whole vegetables [(31)]. Stir-frying and similar preparation methods were not included in this study due to the necessity of adding butter or oil during preparation, possibly resulting in altered tastes and fattiness intensities.

Low taste intensities and vegetable acceptance

Generally, the intensities for all vegetables and for all preparation methods were low. Therefore, it might be the lack of taste that causes low acceptability for vegetables in the Netherlands as opposed to the suggested high bitterness of some vegetables. This hypothesis is supported by earlier studies that have shown that palatability of vegetables improves by adding taste or flavour, such as salt, sugar or other components [(32-35)]. Interestingly, the two most consumed vegetables in the Netherlands, onion and tomato [(1)] displayed the most intense and most discriminating tastes in our study. This might be the reason for their frequent consumption.

Panel performance

The trained panel had difficulties assessing the taste modalities and fattiness due to the low intensities for most vegetables. The modified Spectrum method provides intensity scales which are not product specific but cover a broad and supposedly absolute range of intensities instead. This makes agreement within the panel especially for products with low intensities more difficult. Vegetable specific scales are likely to be more sensitive to analyse particular vegetables. However, a disadvantage of those relative scales is that it is not possible to compare different food groups on an absolute scale. More specific training in vegetables could lead to higher agreement between panellists. For all tastes, the panel was able to discriminate between the different samples.

Conclusions

This study provides insights in the five basic taste and fattiness intensities of ten vegetables commonly consumed in the Netherlands for several preparation methods. By investigating the taste for different preparation methods with a modified Spectrum method, it became apparent that all included vegetables have low taste intensities in general. Preparation method can be used to influence vegetable taste and fattiness intensities. The results indicate that the lack of vegetable taste might be involved in the low acceptability of vegetables rather than bitter taste of vegetables commonly consumed in the Netherlands.

Acknowledgements

We like to thank Bakker Barendrecht, The Netherlands, for providing us with vegetables, TOP BV, The Netherlands, for producing the vegetable juices and Astrid van Langeveld and Korrie Pol of Wageningen University for their support with the panel. This study was carried out with the financial support of the Centre of Expertise Greenport, ’s-Hertogenbosch, The Netherlands.

References

1. Van Rossum CT, De Boer EJ, Ocke MC. Dutch National Food Consumption Survey-Young Children 2005/2006. *Annals of Nutrition and Metabolism.* 2009;55:521-2.
2. Drewnowski A. Sensory control of energy density at different life stages. *The Procedings of the Nutrition Society.* 2000;59(2):239-44.
3. Drewnowski A. Sensory preferences for fat and sugar in adolescence and adult life. *Annals New York Academy of Sciences.* 1989;561:243-50.
4. Ames BN, Profet M, Gold LS. Dietary pesticides (99.99% all natural). *Proceedings of the National Academy of Sciences U S A.* 1990;87(19):7777-81.
5. Drewnowski A, Gomez-Carneros C. Bitter taste, phytonutrients, and the consumer: a review. *American Journal of Clinical Nutrition.* 2000;72(6):1424-35.
6. Steiner JE, Glaser D, Hawilo ME, Berridge KC. Comparative expression of hedonic impact: affective reactions to taste by human infants and other primates. *Neuroscience and Biobehavioral Reviews.* 2001;25(1):53-74.
7. Birch LL. Development of food preferences. *Annual Review of Nutrition.* 1999;19:41-62.
8. Dinehart ME, Hayes JE, Bartoshuk LM, Lanier SL, Duffy VB. Bitter taste markers explain variability in vegetable sweetness, bitterness, and intake. *Physiology & Behavior.* 2006;87(2):304-13.
9. Van Dongen MV, van den Berg MC, Vink N, Kok FJ, de Graaf C. Taste-nutrient relationships in commonly consumed foods. *British Journal of Nutrition.* 2012;108(1):140-7.
10. Martin C, Visalli M, Lange C, Schlich P, Issanchou S. Creation of a food taste database using an in-home “taste” profile method. *Food Quality and Preference.* 2014;36:70-80.
11. Zeinstra GG, Koelen MA, Kok FJ, de Graaf C. The influence of preparation method on children’s liking for vegetables. *Food Quality and Preference.* 2010;21(8):906-14.
12. Bongoni R, Verkerk R, Steenbekkers B, Dekker M, Stieger M. Evaluation of Different Cooking Conditions on Broccoli (Brassica oleracea var. italica) to Improve the Nutritional Value and Consumer Acceptance. *Plant Foods for Human Nutrition.* 2014;69(3):228-34.
13. Bongoni R, Stieger M, Dekker M, Steenbekkers B, Verkerk R. Sensory and health properties of steamed and boiled carrots (Daucus carota ssp sativus). *International Journal of Food Sciences and Nutrition.* 2014;65(7):809-15.
14. Pellegrini N, Chiavaro E, Gardana C, Mazzeo T, Contino D, Gallo M, et al. Effect of Different Cooking Methods on Color, Phytochemical Concentration, and Antioxidant Capacity of Raw and Frozen Brassica Vegetables. *Journal of Agricultural and Food Chemistry.* 2010;58(7):4310-21.
15. Bernhardt S, Schlich E. Impact of different cooking methods on food quality: Retention of lipophilic vitamins in fresh and frozen vegetables. *Journal of Food Engineering.* 2006;77(2):327-33.
16. Schiffman SS, Dackis C. Taste of Nutrients - Amino-Acids, Vitamins, and Fatty-Acids. *Perception & Psychophysics.* 1975;17(2):140-6.
17. Drewnowski A. The role of energy density. *Lipids.* 2003;38(2):109-15.

18. Poelman AAM, Delahunty CM, de Graaf C. Cooking time but not cooking method affects children's acceptance of Brassica vegetables. *Food Quality and Preference.* 2013;28(2):441-8.
19. Teo PS, van Langeveld AWB, Pol K, Siebelink E, de Graaf C, Martin C, et al. Training of a Dutch and Malaysian sensory panel to assess intensities of basic tastes and fat sensation of commonly consumed foods. *Food Quality and Preference.* 2018;65:49-59.
20. Van Rossum CTM, Fransen HP, Verkaik-Kloosterman J, Buurma-Rethans EJM, Ocke MC. Dutch National Food Consumption Survey 2007-2010: diet of children and adults aged 7 to 69 years. *National Institute for Public Health and the Environment*, Bilthoven, The Netherlands; 2011 (350050006/2011).
21. Henderson HHF. Het nieuwe kookboek. Kosmos Z&K Uitgevers, Utrecht, The Netherlands; 1999.
22. Abu-Reidah IM, Arraez-Roman D, Lozano-Sanchez J, Segura-Carretero A, Fernandez-Gutierrez A. Phytochemical Characterisation of Green Beans (Phaseolus vulgaris L.) by Using High-performance Liquid Chromatography Coupled with Time-of-flight Mass Spectrometry. *Phytochemical Analysis.* 2013;24(2):105-16.
23. Baldwin EA, Scott JW, Einstein MA, Malundo TMM, Carr BT, Shewfelt RL, et al. Relationship between sensory and instrumental analysis for tomato flavor. *Journal of the American Society for Horticultural Science.* 1998;123(5):906-15.
24. Padilla G, Cartea ME, Velasco P, de Haro A, Ordas A. Variation of glucosinolates in vegetable crops of Brassica rapa. *Phytochemistry.* 2007;68(4):536-45.
25. Tieman D, Bliss P, McIntyre LM, Blandon-Ubeda A, Bies D, Odabasi AZ, et al. The chemical interactions underlying tomato flavor preferences. *Current Biology.* 2012;22(11):1035-9.
26. Miglio C, Chiavaro E, Visconti A, Fogliano V, Pellegrini N. Effects of different cooking methods on nutritional and physicochemical characteristics of selected vegetables. *Journal of Agricultural and Food Chemistry.* 2008;56(1):139-47.
27. Pellegrini N, Miglio C, Del Rio D, Salvatore S, Serafini M, Brighenti F. Effect of domestic cooking methods on the total antioxidant capacity of vegetables. *International Journal of Food Sciences and Nutrition.* 2009;60 Suppl 2:12-22.
28. Talavera K, Ninomiya Y, Winkel C, Voets T, Nilius B. Influence of temperature on taste perception. *Cellular and Molecular Life Sciences.* 2007;64(4):377-81.
29. Schiffman SS, Sattely-Miller EA, Graham BG, Bennett JL, Booth BJ, Desai N, et al. Effect of temperature, pH, and ions on sweet taste. *Physiology & Behavior.* 2000;68(4):469-81.
30. Drewnowski A. Why do we like fat? *Journal of the American Dietetic Association.* 1997;97(7 Suppl):S58-62.
31. Wootton-Beard PC. Improving public health?: The role of antioxidant-rich fruit and vegetable beverages. *Food Research International.* 2011;44:3135-48.
32. Sharafi M, Hayes JE, Duffy VB. Masking Vegetable Bitterness to Improve Palatability Depends on Vegetable Type and Taste Phenotype. *Chemosensory Perception.* 2013;6(1):8-19.

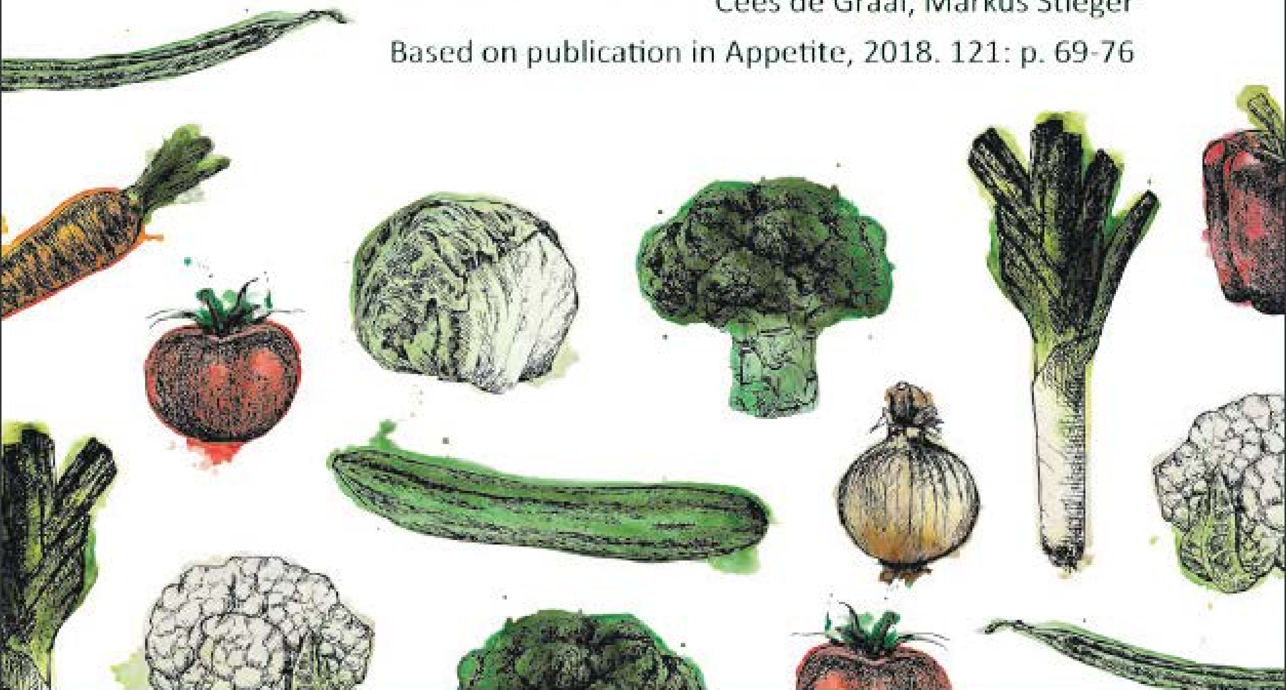
33. Capaldi ED, Privitera GJ. Decreasing dislike for sour and bitter in children and adults. *Appetite.* 2008;50(1):139-45.
34. Fisher JO, Mennella JA, Hughes SO, Liu Y, Mendoza PM, Patrick H. Offering "Dip" Promotes Intake of a Moderately-Liked Raw Vegetable among Preschoolers with Genetic Sensitivity to Bitterness. *Journal of the Academy of Nutrition and Dietetics.* 2012;112(2):235-45.
35. Bouhlal S, Issanchou S, Nicklaus S. The impact of salt, fat and sugar levels on toddler food intake. *British Journal of Nutrition.* 2011;105(4):645-53.

Chapter 3

The role of smell, taste, flavour and texture cues in the identification of vegetables

Vera L. van Stokkom, Annelies E. Blok, Olaf van Kooten,
Cees de Graaf, Markus Stieger

Based on publication in Appetite, 2018. 121: p. 69-76



Abstract

It has been shown that the identification of many foods including vegetables based on flavour cues is often difficult. The effect of providing texture cues in addition to flavour cues on the identification of foods and the effect of providing taste cues only on the identification of foods have not been studied. The aim of this study was to assess the role of smell, taste, flavour and texture cues in the identification of ten vegetables commonly consumed in the Netherlands (broccoli, cauliflower, French bean, leek, bell pepper, carrot, cucumber, iceberg lettuce, onion and tomato). Participants (n = 194) were randomly assigned to one of four test conditions which differed in the sensory cues available for vegetable identification: taste, smell (orthonasal), flavour (taste and smell) and flavour-texture (taste, smell and texture). Blindfolded participants were asked to identify the vegetable from a list of 24 vegetables. Identification was the highest in the flavour-texture condition (87.5%). Identification was significantly lower in the flavour condition (62.8%). Identification was the lowest when only taste cues (38.3%) or only smell cues (39.4%) were provided. For four raw vegetables (carrot, cucumber, onion and tomato) providing texture cues in addition to flavour cues did not significantly change identification suggesting that flavour cues were sufficient to identify these vegetables. Identification frequency increased for all vegetables when perceived intensity of the smell, taste or flavour cue increased. We conclude that providing flavour cues (taste and smell) increases identification compared to only taste or only smell cues, combined flavour and texture cues are needed for the identification of many vegetables commonly consumed in the Netherlands.

Introduction

The daily recommended intake of vegetables is met by less than 15% of adults and less than 3% of children in the Netherlands. Median vegetable consumption in the Netherlands is 103-140 g/d for adults and 60-92 g/d for children [(1)]. These values are far below the recommended daily intake of at least 200 g/d for adults and 150 g/d for children [(2)]. Similar consumption patterns have been observed in other countries [(3-5)].

The dislike for the taste of vegetables, specifically for bitterness, has been suggested to cause low vegetable consumption [(6-9)]. However, it was recently demonstrated that vegetables display low taste and flavour intensities compared to other foods [(10-14)]. Van Stokkom et al.[(14)] determined the taste intensities of ten vegetables commonly consumed in the Netherlands using a modified Spectrum method. In the modified Spectrum method, a sensory profiling method, three reference solutions representing fixed intensities for each taste modality are used by trained panellists to evaluate the intensity of each taste (sweetness, sourness, bitterness, umami, saltiness) on an absolute intensity scale. In general, the intensities of all taste modalities for most vegetables were very low. Sweetness was the most intense taste, followed by sourness and bitterness. It is therefore likely that other sensory properties such as appearance, smell, flavour and texture, influence acceptance of vegetables.

To assess the influence of sensory cues provided for the identification of foods, Schiffman[(15)] studied the effect of combined removal of visual cues by blindfolding and textural cues by pureeing, on identification of 20 commonly consumed foods, including 10 vegetables. The absence of visual and textural cues means that only flavour cues (taste and smell) were provided for the identification of the foods. Identification of foods in young adults (students, 18-22 years) and elderly (67-93 years) was considerably impaired when only flavour cues were provided. Identification by students ranged from 4% to 67% from cabbage to corn. Identification by elderly ranged from 0% to 69% from broccoli to tomato. Students identified most foods better than elderly when flavour cues were provided for identification. These results suggest that visual and texture cues might be important for identification of foods. Schiffman[(15)] quantified the identification of foods under one experimental condition only i.e. when flavour cues were provided. The effect of providing texture cues in addition to flavour cues on identification was not investigated by Schiffman[(15)], nor anyone else. Smell cues play a role in identification of foods, as shown by previous studies which used sniffing sticks to assess identification of smell and mainly focussed on differences in identification ability between different ages and sexes [(16-18)]. However, it remains unclear how the influence of smell in identification relates to the influence of other sensory cues. To summarize, currently knowledge is lacking on the contribution of specific sensory cues on the identification of vegetables.

The aim of this study is to assess the role of smell, taste, flavour and texture cues in the identification of ten vegetables commonly consumed in the Netherlands. We hypothesize that each of the sensory cues contributes differently to the identification of vegetables and that identification depends on the preparation method and type of vegetable.

Methods

Participants

Adults were recruited through social media, flyers and a list of individuals available at the Division of Human Nutrition, Wageningen University. Inclusion criteria comprised a good general health, understanding of the Dutch language and aged between 18 and 65 years. Participants with allergies or intolerances to vegetables were excluded from participation, as well as participants experiencing problems with chewing, swallowing, tasting or smelling. Pregnant or breast-feeding women were excluded from the study. Participants were asked not to wear perfume and not to eat or drink (except water) one hour prior to the test session. Participants received financial compensation for participation in the study. One participant was removed from the dataset since the nose clip fell off multiple times in the taste condition. In total 194 participants were included in the study (147 females, 47 males, 37.8 ± 16.6 years). Ethical approval was not required for the study according to the Medical Research Ethics Committee of Wageningen University. The study was registered under number 16/02.

Study design

Participants (n = 194) were randomly assigned to one of four test conditions using a between subjects design: smell (n = 48), taste (n = 49), flavour (n = 48) and flavour-texture (n = 49). Participants were blindfolded in all four test conditions and asked to identify ten vegetables from a list of 24 vegetables in each of the conditions. In the smell condition, participants sniffed non-pureed vegetables (identification based on orthonasal smell cues). In the taste condition, participants tasted pureed vegetables while wearing a nose clip to eliminate smell cues (identification based on taste cues). In the flavour condition, participants tasted pureed vegetables without a nose clip (identification based on orthonasal and retronasal smell and taste cues). In the flavour condition, participants did not sniff the vegetables before tasting. In the flavour-texture condition, participants tasted non-pureed vegetables (identification based on smell, taste, texture and auditory cues).

Vegetable selection and preparation

The ten vegetables most frequently consumed in the Netherlands were selected for the study [(1)]: broccoli (*Brassica oleracea var. Italica,* variety Ironman), cauliflower (*Brassica oleracea var. botrytis,* variety Easytop), French bean (*Phaseolus vulgaris,* variety unknown), leek (*Allium ampeloprasum* L., variety Harston), bell pepper

(*Capsicum annuum,* variety Davos), carrot (*Daucus carota*, variety Evora), cucumber (*Cucumis sativus,* variety Proloog), iceberg lettuce (*Lactuca sativa* L., variety unknown), onion (*Allium cepa* L., variety Alfa) and tomato (*Solanum lycopersicum* L., variety Arvento). Fresh vegetables were bought at a local supermarket and stored at 4°C for a maximum of three days. Some vegetables were boiled and offered warm, other vegetables were offered raw, depending of the more common way to consume the vegetable [19]. Broccoli, cauliflower, French bean and leek were boiled before preparation of the purees or one-bite portions. Boiling times (time in boiling water) and vegetable / water ratio were for broccoli and cauliflower 8 min, 212/500 g, French bean 10 min, 224/500 g and leek 8 min, 238/500 g. Bell pepper, carrot, cucumber, onion and tomato were prepared at the start of the test day and stored at 7°C during the test day. Vegetable purees were prepared by pureeing vegetables with a hand blender until a homogenous, smooth consistency was obtained (± 30 s / 200 g). Carrots were first chopped using a food processor and pureed afterwards. Broccoli, cauliflower, French bean and leek samples were stored in bowls in a water bath at 60°C after preparation for a max of 3.5 h. Therefore, preparation of these vegetables was performed twice a day, as well as preparation of lettuce. Serving temperature of the boiled vegetables was 50 ± 5°C. Raw vegetables were served at room temperature. Vegetables were presented to the blindfolded participants by the researcher either as one-bite portions (smell and texture conditions) or as a puree (taste and flavour conditions). Sample size was ~10 g. All vegetable samples were offered in non-transparent plastic containers (50 ml) covered with a lid. In the smell condition, blindfolded participants were asked to identify the vegetable by sniffing two one-bite portions from the foam container. In the taste and flavour conditions, blindfolded participants received ~10 g of vegetable puree from the researcher on a spoon. In the flavour-texture condition, blindfolded participants received a one-bite portion from the researcher on either a fork or a spoon, depending on the vegetable.

Test procedure

Participation in the study consisted of one test session of approximately 45 min at the University of Applied Sciences Inholland Delft or Wageningen University. Upon arrival at the test location, participants signed an informed consent and completed a questionnaire to examine fulfilment of the inclusion criteria. When participants were eligible, participants received detailed instructions including how to ask to try the vegetable a second time and how to indicate when they were ready. Participants were instructed to wear the blindfolds until the investigator gave permission to remove them. Participants were told not to mention any answers out loud. After the instruction, participants were placed in a quiet test room and completed a general questionnaire about population characteristics on a laptop or tablet computer (EyeQuestion® version 3.16.26, Logic8). Additionally, the questionnaire contained questions on vegetable consumption frequency of the target vegetables as well as the other vegetables on the 24-item list. Choice options for consumption frequency were ‘never’, ‘less than once a year’, ‘yearly (1-11 times a year)’, ‘monthly (1-3 times a month)’, ‘weekly (1-6 times a week)’ and ‘daily’. After completion of the general questionnaire participants were blindfolded and participants in the taste condition had a nose pin placed on their nose. After receiving a sample once or twice, the sample was discarded and participants could remove their blindfolds. Using a laptop or tablet computer, participants were asked to identify the vegetable from a list of 24 vegetables frequently consumed in the Netherlands. Next to the ten vegetables that were actually presented, choice options included asparagus, beetroot, Brussels sprout, celery, chicory, corn, eggplant, endive, mushrooms, peas, radish, red cabbage, spinach and zucchini. The 24 options were placed in alphabetical order. Participants subsequently rated overall perceived intensity of the smell, taste or flavour on a 100 mm line scale anchored with ‘weak’ and ‘strong’ at the ends. In the smell condition, participants rated the perceived intensity of the smell of the vegetable. In the taste condition, participants rated the perceived intensity of the taste of the vegetable. In the flavour and flavour-texture conditions, participants rated the perceived intensity of the flavour of the vegetable. For the sake of clarity, in the following the respective perceived intensities assessed under the four conditions are referred to as intensity. A break of 20 s was given between samples, during which participants could drink some water or eat an unsalted cracker to cleanse the palate. In the smell condition, participants were provided coffee beans to neutralise their nasal palate. The ten vegetables were presented, either pureed or not, in semi-random order. Onion was always the last sample to avoid potential carry-over effects due to the strong odour and lingering taste of onions.

Statistical data analyses

Data analyses were performed using IBM SPSS Statistics version 21, using a significance level of $p < 0.05$. Population characteristics were presented as percentages or means with standard deviations. Kruskal-Wallis *H* tests and Mann-Whitney *U* tests were performed to verify whether age, BMI and weekly vegetable consumption were the same across conditions and test locations, respectively. Correct frequencies of identification (%) were calculated per condition for each vegetable, hereafter identification frequency. A three-way log-linear analysis was performed to determine whether frequencies of identification depended on test conditions and vegetables. Separate Chi-square tests on frequency of identification were performed for the four test conditions averaged over the ten vegetables. In addition, Chi-square tests on frequency of identification were performed to assess significant differences between frequencies of identification in different conditions per vegetable. Yates continuity corrections were applied for 2x2 contingency tables. Spearman correlation coefficient was determined for the correlation between frequency of identification (%) and consumption frequency of vegetables. Point biserial correlation coefficient [20] was determined for age and vegetable identification.

Mean smell, taste and flavour intensities for each vegetable were calculated per condition. A mixed model analysis of variance was performed to assess the main effect of test condition on intensity rating with intensity as a repeated measures variable and condition as a variable measured between participants. Maulchy's test indicated that sphericity was violated for the main effect of vegetable type, $\chi^2(44) = 84.410$, $p < 0.001$. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.908$). Significant differences in intensities between conditions within a vegetable were determined by a one-way independent analysis of variance. Games-Howell post hoc tests were performed, since the assumption of equal variances was violated. Differences in intensities between vegetables averaged over the conditions were determined by repeated measures analysis of variance. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(44) = 135.696$, $p < 0.001$. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.844$). Pearson's correlation coefficients were determined for identification frequency and intensity.

Results

Participant characteristics

Demographic characteristics of the participants and consumption frequency of the ten vegetables are summarized in Table 1 and 2. Age, BMI and weekly vegetable consumption did not differ significantly between test conditions or locations.

Table 1. Self-reported participant characteristics (n = 194).

Characteristic	**Mean ± SD, percentage (%)**
Age (years)	37.8 ± 16.6
Gender (% male)	24.0 %
Test location (% in Wageningen)	67.5 %
BMI (kg/m2)	23.7 ± 4.1
Smoker	2.6 %
Education level (%)	
Low (no or only primary school)	0.5 %
Intermediate (high school)	26.8 %
High (university)	72.7 %
Fruit consumption frequency (portions/day)	1.5 ± 0.9
Vegetable consumption (g/day)	162 ± 59

Table 2. Self-reported consumption frequencies (*n* = 194) of ten vegetables commonly consumed in the Netherlands. Not all percentages add up to 100% due to rounding.

Consumption frequency (% of participants)	Never	Less than once a year	Yearly	Monthly	Weekly	Daily
Broccoli	-	1.5	13.9	55.2	29.4	-
Cauliflower	4.1	5.2	39.7	44.3	6.7	-
French bean	-	-	11.9	55.2	33.0	-
Leek	2.1	1.5	20.1	49.0	26.8	0.5
Bell pepper	1.5	1.0	2.1	21.6	68.0	5.7
Carrot	1.0	1.0	10.8	43.8	38.7	4.6
Cucumber	2.6	2.1	7.7	22.7	56.7	8.2
Lettuce	-	-	4.6	24.2	64.9	6.2
Onion	0.5	0.5	2.6	10.3	68.6	17.5
Tomato	0.5	0.5	1.5	13.4	68.6	15.5

Vegetable identification

Vegetables were significantly less often identified in the smell and taste conditions compared to the flavour condition [$\chi^2(1)=51.360$, $p < 0.001$ and $\chi^2(1)= 57.457$, $p < 0.001$] (Figure 1). Vegetables were identified significantly more often in the flavour-texture condition compared to all other test conditions [$\chi^2(1)=238.991$, $\chi^2(1)= 251.467$ and $\chi^2(1) = 77.517$, $p < 0.001$ for the smell, taste and flavour conditions].

Boiled vegetables were on average less frequently identified than raw vegetables (45.3% versus 64.9%). Identification frequency significantly increased between the taste and flavour-texture condition for boiled and raw vegetables. For raw vegetables, identification frequency significantly increased between the taste and flavour condition. For most boiled vegetables, there was no significant increase in identification frequency between the taste and flavour condition (Figure 2).

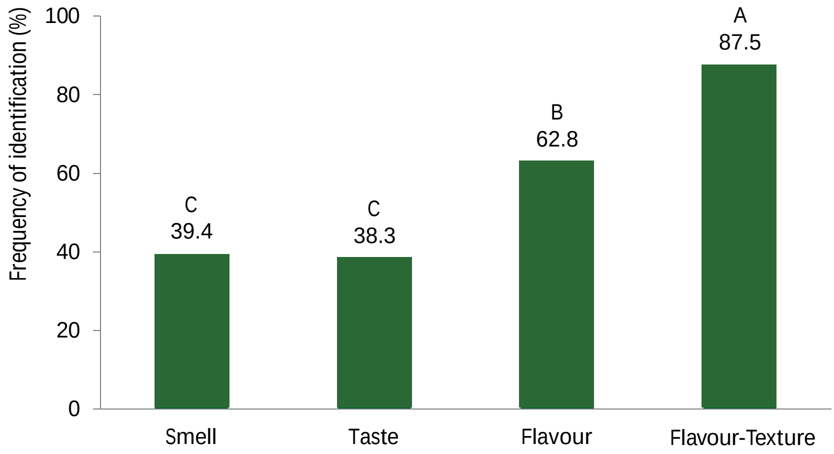


Figure 1. Frequency of identification (%) per condition averaged over ten vegetables commonly consumed in the Netherlands. In the smell condition, participants (*n* = 48) sniffed non-pureed vegetables (identification based on smell cues). In the taste condition, participants (*n* = 49) tasted pureed vegetables while wearing a nose clip (identification based on taste cues). In the flavour condition, participants (*n* = 48) tasted pureed vegetables without a nose clip (identification based on smell and taste cues). In the flavour-texture condition, participants (*n* = 49) tasted non-pureed vegetables (identification based on smell, taste and texture cues). Significant differences between conditions are indicated by letters A-C ($p < 0.001$). Same letters indicate no significant difference between frequencies of identification.

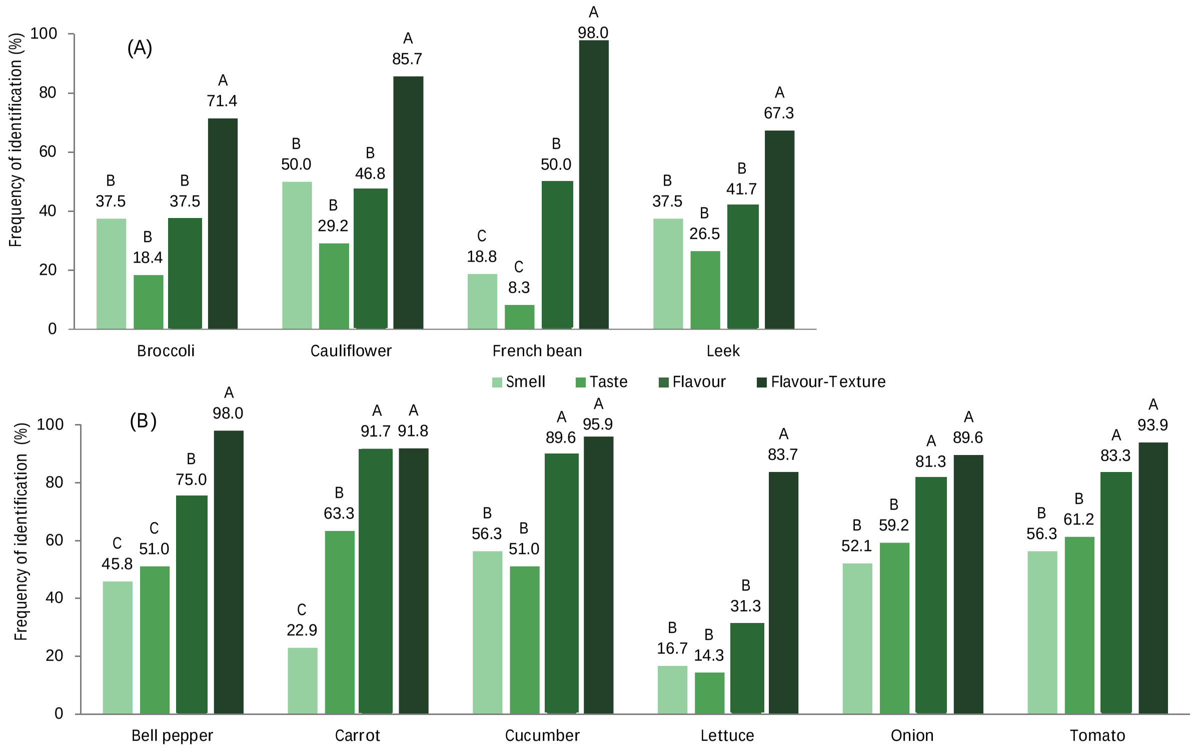


Figure 2. Frequency of identification (%) of ten vegetables commonly consumed in the Netherlands per condition for (A) boiled and (B) raw vegetables. In the smell condition, participants (n = 48) sniffed non-pureed vegetables (identification based on smell cues). In the taste condition, participants (n = 49) tasted pureed vegetables while wearing a nose clip (identification based on taste cues). In the flavour condition, participants (n = 48) tasted pureed vegetables without a nose clip (identification based on smell and taste cues). In the flavour-texture condition, participants (n = 49) tasted non-pureed vegetables (identification based on smell, taste and texture cues). Significant differences between conditions within a vegetable are indicated by letters A-C ($p < 0.05$). Same letters indicate no significant difference between frequencies of identification

The five most frequently selected vegetables from the 24-item option list are summarized for all ten vegetables in Table 3. For each vegetable presented, the vegetable most often selected from the 24-item option list was the correct vegetable. Identification frequency correlated weakly with the consumption frequency of the presented vegetable ($r = 0.10$, $p < 0.001$).

Table 3. Frequency of vegetable selection from a 24-item option list for ten vegetables commonly consumed in the Netherlands. Frequencies for the five most often selected vegetables are presented.

Vegetable presented	Frequency of five most often selected vegetables (%)				
Broccoli	Broccoli 41.2	Cauliflower 28.4	Brussels sprout 5.2	French bean 4.6	Carrot 4.1
Cauliflower	Cauliflower 53.1	Broccoli 20.3	Brussels sprout 10.9	Endive 3.1	Carrot 2.6
French bean	French bean 44.0	Broccoli 9.3	Cauliflower 8.3	Peas 7.3	Brussels sprout 4.7
Leek	Leek 43.3	Onion 14.4	Carrot 5.2	Zucchini 5.2	Chicory 4.6
Bell pepper	Bell pepper 65.5	Celery 5.2	Peas 3.1	Tomato 2.6	Zucchini/tomato 2.6
Carrot	Carrot 67.5	Radish 5.7	Celery 5.2	Peas 3.1	Lettuce 2.6
Cucumber	Cucumber 73.2	Tomato 4.1	Carrot 3.1	Eggplant 2.1	Lettuce/eggplant 2.1
Lettuce	Lettuce 36.6	Endive 12.9	Chicory 6.2	Radish 5.7	Leek/Zucchini 4.6
Onion	Onion 70.5	Leek 14.0	Radish 6.2	Celery 3.1	Bell pepper 1.6
Tomato	Tomato 73.7	Cucumber 4.1	Celery 3.1	Radish 3.1	Bell pepper 2.6

Intensity of vegetable smell, taste and flavour cues

Perceived intensities assessed under the four conditions are referred to as intensity hereafter. A significant main effect of test condition on intensity was found [$F(3,187) = 25.574$, $p < 0.001$]. Intensities in the four conditions averaged over all vegetables differed significantly from each other ($p < 0.001$), except for the flavour and flavour-texture conditions. Highest mean intensities were found in the flavour and flavour-texture condition (58.1 and 59.8), followed by the smell (47.6) and taste condition (40.5) (Table B1, Appendix B).

Significant differences in intensities between the taste and flavour conditions were found for all vegetables. Smell and flavour intensities differed significantly from each other for French bean, carrot, lettuce, onion and tomato. No significant differences were found between intensities in the flavour and flavour-texture conditions for any of the vegetables tested. A significant main effect of vegetable on intensity rating was found [$F(8.170,1527.760) = 77.995$, $p < 0.001$]. Onion had a significantly higher intensity compared to the other vegetables, whereas the intensity of lettuce was significantly lower than all other vegetables (Table B1, Appendix B). The frequency of identification correlated positively with perceived intensity of the sensory cue ($r = 0.73$, $p < 0.001$) (Figure 3).

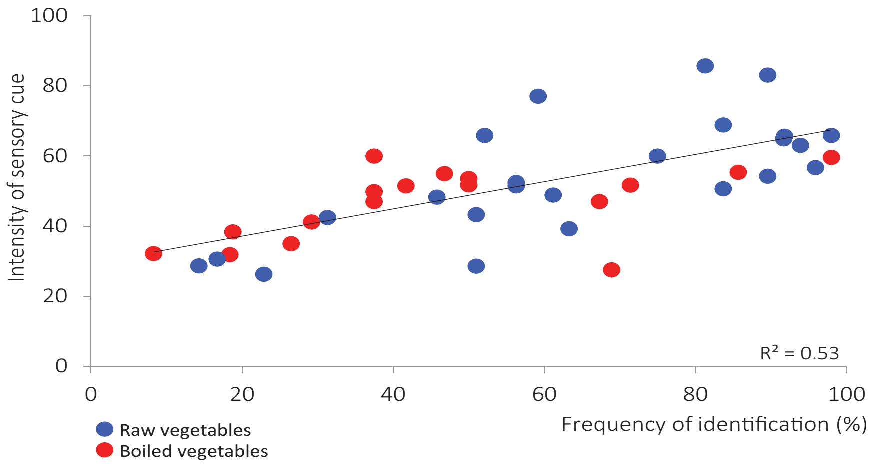


Figure 3. Perceived intensity of sensory cue versus frequency of identification (%) for raw and boiled vegetables commonly consumed in the Netherlands for all four conditions (smell, taste, flavour and flavour-texture).

Discussion

To assess the role of smell, taste, flavour and texture cues in the identification of vegetables blindfolded Dutch adults were asked to identify ten vegetables from a list of 24 vegetables based on different sensory cues. For all vegetables, highest frequencies of identification were found in the flavour-texture condition, *i.e.* when flavour and texture cues were present. This was expected as in this condition participants were provided with all sensory cues except visual cues to identify the vegetables. Identification frequency in the smell, taste and flavour conditions did not significantly differ from each other for broccoli, cauliflower, leek and lettuce, but identification frequency did significantly increase in the flavour-texture condition, indicating that texture cues were needed in addition to flavour cues for the identification of these vegetables. French bean and all raw vegetables except lettuce were significantly less often identified in the smell and taste conditions compared to the flavour and flavour-texture conditions, indicating that these vegetables were more difficult to identify by only their smell or taste cues, while the combination of both sensory cues in the flavour condition significantly improved identification. For four raw vegetables (carrot, cucumber, onion and tomato) frequencies of identification did not differ significantly between the flavour and flavour-texture conditions. As the presence of texture cues in addition to flavour cues did not significantly increase the frequency of identification, flavour cues seem to be sufficient for the identification of these vegetables.

For boiled vegetables (broccoli, cauliflower, French bean and leek), bell pepper and lettuce, frequencies of identification differed significantly between the flavour and flavour-texture conditions. These results indicate that texture cues play a significant role in the identification of these vegetables. Frequencies of identification did not differ significantly between the smell and taste conditions, except for carrot, smell and taste play a minor role in the identification of vegetables. Furthermore, frequency of identification increased with increasing perceived intensity of smell, taste or flavour of the vegetables. Larsson et al.[21] showed that perceived odour intensity was a predictor for odour identification, in this study higher intensities might also have led to higher identification frequencies. However, participants could have also reported higher intensities because they were able to identify the vegetable. Lowest intensity ratings were reported in the taste condition, which is in accordance with previous literature stating that vegetables display low taste intensities [10-14]. By removal of the nose clip, intensity increased (between the taste and flavour conditions), showing the importance of also smell as shown by Mojet et al.[22] with young adults (19-33 years).

Identification frequencies for vegetables in the flavour condition were considerably higher in our study than those reported by Schiffman[15]: broccoli (frequency of identification of 15% averaged over the students and elderly in Schiffman's study versus 37.5% in the present study in the flavour condition), carrot (35% versus 91.7%), cucumber (3.5% versus 89.6%), green/French bean (22% versus 50%) and tomato (60.5% versus 83.3%). An explanation for the differences in identification frequencies between the two studies is the method used to quantify identification. In our study, participants identified the vegetables from a 24-item list, whereas in Schiffman's study participants had to recall the vegetable from memory which is a more difficult task. Furthermore, Schiffman[15] diluted the vegetable purees by adding water, which might have decreased the taste intensity of the vegetables making it more difficult to identify the vegetables. Moreover, elderly participants in the study of Schiffman were between 67 and 93 years old (versus 18-65 years old in the present study) and might have had decreased taste and smell sensitivities [23-25]. In the current study, increased age was also associated with decreased likelihood of vegetable identification (r = -0.15, $p < 0.05$), which is in accordance with literature [15, 23, 26].

Although most raw vegetables were more frequently identified than boiled vegetables, lettuce provided an exception and was not identified often compared to the other vegetables. The low identification frequency of lettuce is probably due to the low smell, taste and flavour intensities. The presence of textural cues in addition to flavour cues improved identification significantly for lettuce compared to the other conditions. Texture also appears to play a major role in the identification of boiled vegetables, as the flavour-texture condition had significantly higher frequencies of identification compared to the other three conditions. This might be explained by the fact that during boiling, volatile flavour molecules are released from the food matrix [27, 28]. As a result of the loss of flavour volatiles, identification of the vegetable might have become more difficult in conditions without texture cues (smell, taste and flavour conditions). However, no clear differences in intensity were found between raw and boiled vegetables. Degradation or Maillard reactions during boiling of the vegetables might have influenced the flavour or aroma profile of the boiled vegetable which might have influenced identification frequency. Another explanation for the low frequencies of identification of boiled vegetables could be that these vegetables were often misidentified for other, similar vegetables. The misidentifications of the boiled vegetables appear to be related to similarities between vegetables of the same species or genus. Broccoli, Brussels sprout and cauliflower are members of the group of cabbages (*Brassica oleracea*) which produce volatile compounds responsible for the typical cabbage flavour, including sulphides, isothiocyanates and cyanides [29]. Moreover, French beans were found to produce the same low-boiling volatiles as cauliflower [30], which can explain why these vegetables were mixed-up by more than 5% of the participants. Leek and onion are both are members of the *Allium* genus and produce organic sulphur compounds upon cutting that are typical for this group of plants [32]. Misidentifications in raw vegetables were less common and more dispersed over the choice options. Lettuce was one of the most difficult vegetables to identify in most conditions and was most commonly misidentified for endive. Lettuce and endive are both members of the same botanical family, the *Asteraceae/Compositae* and the same part of the plants are eaten, namely the leaves [33].

The intensities of the sensory cues of onion were significantly higher than the intensities of the sensory cues of all other vegetables. The intensities of the sensory cues of tomato were significantly higher than the intensities of the sensory cues of all other vegetables except for bell pepper, which is similar to results found by van Stokkom et al.[14].

As participants tasted pureed vegetables in two test conditions, this might have led to differences in flavour profiles compared to the flavour profiles of non-pureed vegetables. However, no significant differences were found between flavour intensity ratings in the flavour (evaluating pureed vegetables) and flavour-texture (evaluating non-pureed vegetables) conditions, which implies pureeing did not have an effect on flavour perception in this study. In addition, van Stokkom et al.(14) found that basic taste intensities did not differ significantly between boiled and mashed vegetables and between raw and cold pureed vegetables. The difference in serving temperature between boiled (50 ± 5°C) and raw vegetables (20°C) might have indicated to the participants how the presented vegetable is generally consumed. This is supported by the fact that boiled vegetables were mostly mistaken for vegetables that are often heated before consumption. Boiled vegetables were not cooled down to room temperature before serving to make the serving temperature more comparable to a real-life consumption situation. The consistency of the pureed samples was not equal across the ten vegetables. Schiffman(15) added water to some of the foods to obtain purees with similar consistencies. We did not do this in the current study, leading to minor texture differences of the pureed vegetables by which might have assisted in identification. However, the addition of water to the samples results in smell, taste and flavour dilution, causing the vegetable samples to be less representative of the real-life consumption situation. In the flavour-texture conditions, especially for the crispier (raw) vegetables, auditory cues were present (34) which might have helped in the identification of these vegetables.

Conclusions

The current study assessed the role of smell, taste, flavour and texture cues in the identification of ten vegetables that are frequently consumed in the Netherlands. Smell and taste cues led to considerably lower identification frequencies compared to flavour and flavour-texture cues. For identification of carrot, cucumber, onion and tomato, flavour cues were important. For all other vegetables, flavour and texture cues were more important for identification. This suggests that texture cues in addition to flavour cues and auditory cues contribute to the identification of vegetables, especially vegetables typically consumed warm, while flavour cues are important for the identification of vegetables typically consumed raw. These results show which sensory cues are important for the identification of vegetables and are of interest to sensory scientists and product developers who investigate sensory factors which potentially contribute to food preference and selection. However, the relationships between food identification and preference go beyond the scope of this study and should be investigated further.

Acknowledgements
This study was carried out with the financial support of Centre of Expertise Food and Centre of Expertise Greenport (Ministry of Economic Affairs), The Netherlands.

References

1. Van Rossum CTM, Fransen HP, Verkaik-Kloosterman J, Buurma-Rethans EJM, Ocke MC. Dutch National Food Consumption Survey 2007-2010: diet of children and adults aged 7 to 69 years. *National Institute for Public Health and the Environment,* Bilthoven, The Netherlands; 2011 (350050006/2011).
2. Health Council of the Netherlands. Dutch Dietary Guidelines 2015. The Hague, The Netherlands; 2015 (2015/24).
3. Bowen J, Klose D, Syrette J, Noakes M. Australian children's vegetable intake: findings of the 2007 Australian children's national nutrition and physical activity survey. 2009 (VG07160).
4. Alexy U, Sichert-Hellert W, Kersting M. Fifteen-year time trends in energy and macronutrient intake in German children and adolescents: results of the DONALD study. *British Journal of Nutrition.* 2002;87(6):595-604.
5. Dennison BA, Rockwell HL, Baker SL. Fruit and vegetable intake in young children. *Journal of the American College of Nutrition.* 1998;17(4):371-8.
6. Brug J, Tak NI, te Velde SJ, Bere E, De Bourdeaudhuij I. Taste preferences, liking and other factors related to fruit and vegetable intakes among schoolchildren: results from observational studies. *British Journal of Nutrition.* 2008;99(1):7-14.
7. Tak NI, te Velde SJ, Brug J. Are positive changes in potential determinants associated with increased fruit and vegetable intakes among primary schoolchildren? Results of two intervention studies in the Netherlands: The Schoolgruiten Project and the Pro Children Study. *International Journal of Behavioral Nutrition and Physical Activity.* 2008;5(1):1.
8. Dinehart M, Hayes J, Bartoshuk L, Lanier S, Duffy V. Bitter taste markers explain variability in vegetable sweetness, bitterness, and intake. *Physiology & Behavior.* 2006;87(2):304-13.
9. Drewnowski A, Gomez-Carneros C. Bitter taste, phytonutrients, and the consumer: a review. *American Journal of Clinical Nutrition.* 2000;72(6):1424-35.
10. Martin C, Visalli M, Lange C, Schlich P, Issanchou S. Creation of a food taste database using an in-home "taste" profile method. *Food Quality and Preference.* 2014;36:70-80.
11. Van Dongen MV, van den Berg MC, Vink N, Kok FJ, de Graaf C. Taste–nutrient relationships in commonly consumed foods. *British Journal of Nutrition.* 2012;108(01):140-7.
12. Lim J, Padmanabhan A. Retronasal olfaction in vegetable liking and disliking. *Chemical Senses.* 2013;38(1):45-55.
13. Poelman AAM, Delahunty CM, de Graaf C. Vegetables and other core food groups: A comparison of key flavour and texture properties. *Food Quality and Preference.* 2017;56, Part A:1-7.
14. Van Stokkom VL, Teo PS, Mars M, de Graaf C, van Kooten O, Stieger M. Taste intensities of ten vegetables commonly consumed in the Netherlands. *Food Research International.* 2016;87:34-41.
15. Schiffman S. Food recognition by the elderly. *Journal of Gerontology.* 1977;32(5):586-92.

16. Hummel T, Kobal G, Gudziol H, Mackay-Sim A. Normative data for the “Sniffin’ Sticks” including tests of odor identification, odor discrimination, and olfactory thresholds: an upgrade based on a group of more than 3,000 subjects. *European Archives Oto-rhino-laryngology*. 2007;264(3):237-43.
17. Hummel T, Sekinger B, Wolf SR, Pauli E, Kobal G. ‘Sniffin’ sticks’: olfactory performance assessed by the combined testing of odor identification, odor discrimination and olfactory threshold. *Chemical Senses.* 1997;22(1):39-52.
18. Sorokowska A, Schriever VA, Gudziol V, Hummel C, Hahner A, Iannilli E, et al. Changes of olfactory abilities in relation to age: odor identification in more than 1400 people aged 4 to 80 years. *European Archives Oto-rhino-laryngology.* 2015;272(8):1937-44.
19. Borgdorff-Rozeboom A. Consumptie van Nederlandse en Duitse consumenten in kaart gebracht. Overizcht van resultaten uit de Groenten- en Fruitmonitor over 2012. *Productschap Tuinbouw, Markt & Innovatie*, Zoetermeer, The Netherlands; 2013.
20. Field A. Discovering statistics using SPSS. 3rd ed. SAGE Publications LtD, London, United Kingdom; 2009.
21. Larsson M, Finkel D, Pedersen NL. Odor identification: influences of age, gender, cognition, and personality. *Journals of Gerontology, Series B. Psychological Sciences and Social Sciences.* 2000;55(5):P304-10.
22. Mojet J, Christ-Hazelhof E, Heidema J. Taste perception with age: pleasantness and its relationships with threshold sensitivity and supra-threshold intensity of five taste qualities. *Food Quality and Preference.* 2005;16:413-23.
23. Doty RL, Shaman P, Applebaum SL, Giberson R, Siksorski L, Rosenberg L. Smell identification ability: changes with age. *Science.* 1984;226(4681):1441-3.
24. Cain WS, Reid F, Stevens JC. Missing Ingredients: Aging and the discrimination of flavor. *Journal of Nutrition for the Elderly.* 1990;9(3):3-15.
25. Stevens JC, Cain WS, Demarque A, Ruthruff AM. On the discrimination of missing ingredients: Aging and salt flavor. *Appetite.* 1991;16(2):129-40.
26. Boyce J, Shone G. Effects of ageing on smell and taste. *Postgraduate Medical Journal.* 2006;82(966):239-41.
27. MacLeod A, MacLeod G. Effects of variations in cooking methods on the flavor volatiles of cabbage. *Journal of Food Science.* 1970;35(6):744-50.
28. Hewitt EJ, Mackay DA, Konigsbacher KS. Natural flavor of processed foods. *US Patent 2924521 A*; 1960.
29. Buttery RG, Guadagni DG, Ling LC, Seifert RM, Lipton W. Additional volatile components of cabbage, broccoli, and cauliflower. *Journal of Agricultural and Food Chemistry.* 1976;24(4):829-32.
30. Self R, Casey J, Swain T. The low-boiling volatiles of cooked foods. *Chemistry & Industry.* 1963;21:863-4.
31. MacLeod A, MacLeod G. Flavor volatiles of some cooked vegetables. *Journal of Food Science.* 1970;35(6):734-8.
32. Block E. Garlic and other Alliums. *Royal Society of Chemistry,* Cambridge, United Kingdrom; 2009.

33. Pennington JAT, Fisher RA. Classification of fruits and vegetables. *Journal of Food Composition and Analysis.* 2009;22:S23-S31.
34. Fillion L, Kilcast D. Consumer perception of crispness and crunchiness in fruit and vegetables. *Food Quality and Preference.* 2002;13:23-9.

Chapter 4

Effect of taste enhancement on consumer acceptance of pureed cucumber and green bell pepper

Vera L. van Stokkom, Cees de Graaf, Olaf van Kooten, Markus Stieger

Based on publication in the Journal of Food Science, 2018. 83(10): p.2578-2585

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 bell pepper purees. Three concentrations of sugar, citric acid, caffeine, mono-sodium glutamate, NaCl and sunflower oil were added to pureed cucumber and green bell pepper. Participants (n = 66, 35.6 ± 17.7 years) rated taste and fattiness intensity. Different participants (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 bell pepper 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 bell pepper 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, flavour or texture modifications are required to enhance acceptance of vegetables. Results can be used by cultivators to select and grow vegetable varieties with enhanced taste and flavour. Especially for cucumber, relatively small sweetness enhancement is sufficient to increase acceptance.

Introduction

Diets often do not contain enough vegetables [1-4]. Taste is an important driver for food choice [5, 6]. One explanation for the limited acceptance of some vegetables is their bitterness [7-9]. However, recent studies have shown that vegetables in general have low taste intensities compared to other foods [10, 11]. 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.

Several studies investigated the effect of taste enhancement on liking of foods and beverages. Taste intensity is often enhanced by addition of tastants [12-14]. Although increasing vegetable consumption is a desirable goal, only few studies focussed on the effect of taste enhancement on acceptance of vegetables. Capaldi and Privitera[15] 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 et al.[16] 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[17] investigated the effect of taste enhancement on liking of vegetable soups. Mono-sodium 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 savoury taste was observed. Bouhlal et al.[18] and Bouhlal et al.[19] 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 [18, 20]. Bouhlal et al.[19] 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 [21-23]. Previous studies showed that offering raw broccoli with a regular and light version of a salad dressing as dip increases intake [24], while offering green beans with butter does not [25].

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 bell pepper 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 [26-28]. 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 bell pepper 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 bell pepper were selected since these vegetables belong to the 20 most commonly consumed vegetables in the Netherlands [4]. These vegetables display very different taste profiles. Cucumber was chosen due to its neutral taste profile whereas green bell pepper was selected due to its bitter taste profile [10, 11]. To our knowledge, the effect of taste enhancement on acceptance has not been studied in cucumber and green bell pepper.

Methods

Participants

Participants 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. Participants with food allergies or intolerances, problems with chewing, swallowing, tasting or smelling were excluded from the study. Pregnant or breast-feeding women were excluded too. Participants were asked not to wear perfume and not to eat or drink (except water) one hour prior to the test session. Participants received financial compensation for participation in the study. In total n = 166 participants were included in the study (138 females; 28 males). A group of n = 66 participants (54 females; 12 males, 35.8 ± 17.7 years) participated in the sensory evaluation of the vegetable purees. A group of n = 100 participants (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 University.

Vegetable preparation

Cucumber (*Cucumis sativus*) and green bell pepper (*Bell pepper 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 bell pepper was characterized by higher bitterness intensity [10, 11]. Second, both vegetables should be commonly consumed in the Netherlands. Cucumber is one of the five and green bell pepper one of the 20 most commonly consumed vegetables in the Netherlands [4]. 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 bell pepper are commonly consumed raw [4]. Fourth, the effect of taste enhancement on acceptance has not been studied yet in cucumber and green bell pepper.

Cucumber (variety Lausanna) and green bell pepper (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 [29]. The 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 h prior to the first test session. During test sessions, vegetable purees were kept at 5˚C. Participants 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, participants came to the test location at Wageningen University, The Netherlands, once for a maximum of 90 min. Participants 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). Participants (n = 66) received the vegetable purees differing in taste modalities and fattiness in random order during the session. For each taste modality and fattiness, participants received three vegetable purees and an unmodified vegetable puree simultaneously in random order to eliminate order effects. Participants 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. Participants were naive and did not receive training for the use of the line scale. Between the evaluations of different taste modalities, a one minute break followed in which participants could cleanse their palate with water or a cracker. Participants were instructed to also regularly sip water between samples. For umami, participants received a solution of MSG in water with a medium intensity (0.3%) to get familiar with umami taste.

Table 1. Composition of cucumber and green bell pepper 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

For the hedonic evaluation of the vegetable purees, participants came twice to the test location, Wageningen University, The Netherlands, for a maximum of 60 min each session. Participants 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). Participants (n = 100) received all 19 vegetable purees (Table 1) of one type of vegetable in random order. Half of the participants received cucumber purees first, the other half received bell pepper purees first. Participants 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 participants could cleanse their palate with water or a cracker. In the second session, participants received 19 samples of the other (second) vegetable following the same experimental procedure.

Statistical data analyses

Statistical data analyses were performed using 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 analyse 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 bell pepper samples and for the analysis of differences in acceptance between cucumber and green bell pepper samples. Mixed model analysis of variance including a random (participant) and fixed factor (sample, 19 levels) was used to analyse differences in acceptance between unmodified vegetables and modified samples followed by Tukey post hoc test.

Table 2. Self-reported participant characteristics and demographics.

Characteristic	**Sensory evaluation group (*n* = 66) Mean ± SD**	**Hedonic evaluation group (*n* = 100) Mean ± SD**
Age (years)	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/day)	152.5 ± 48.2	153.4 ± 53.6

Consumption frequency cucumber and green bell pepper *(n)*							
		Never	< once a year	Yearly	Monthly	Weekly	Daily
Sensory evaluation group	Cucumber	3	1	7	19	30	6
	Green bell pepper	1	0	14	35	16	0
Hedonic evaluation group	Cucumber	4	3	13	28	44	8
	Green bell pepper	2	2	21	48	27	0

Results

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

Sensory evaluation of cucumber and green bell pepper 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 bell pepper, between medium and high sunflower oil concentration for cucumber and between unmodified and low citric acid for green bell pepper.

When comparing the taste intensity between cucumber and green bell pepper purees, it was found that for the unmodified vegetable purees, sweetness and fattiness intensity did not differ significantly between cucumber and green bell pepper. Unmodified green bell pepper 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 bell pepper 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 bell pepper purees. Bitterness intensity at medium tastant concentration was significantly higher in green bell pepper purees compared to cucumber purees ($t(65) = 2.229$, $p < 0.05$). The other taste intensities did not differ significantly between cucumber and green bell pepper purees.

Acceptance of cucumber and green bell pepper 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 bell pepper 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".

Table 3. Mean taste and fattiness intensities of cucumber and green bell pepper purees for unmodified, low, medium and high tastant concentrations (*n* = 66). Letters A-D indicate significant differences ($p < 0.05$) in taste intensity between different concentrations of added tastants for each taste modality.

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 bell pepper					
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}	$F(3,195)=91.30$, $p < 0.01$

Acceptance for sweetness low, sourness low, saltiness low and saltiness high was significantly higher for cucumber purees than for green bell pepper 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 bell pepper purees ($t(99)=-2.79$, $p < 0.01$). For the other samples, there were no significant differences in acceptance between cucumber and green bell pepper purees.

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). Letters A-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 bell pepper purees using dependent t-tests. Level of significance of comparison of the means is shown.

Taste	**Intensity**	**Cucumber** **Acceptance Mean ± SD**	**Green bell pepper** **Acceptance Mean ± SD**	**Significance of difference in acceptance between cucumber and green bell pepper 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

Figure 1 shows mean differences in acceptance between vegetables purees with added tastants and unmodified purees for cucumber and green bell pepper 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 bell pepper [$F(18,1782) = 31.12$, $p < 0.01$]. 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 bell pepper purees, acceptance of medium sweetness (+1.0) and high sweetness (+0.8) was significantly higher than acceptance of unmodified green bell pepper, whereas acceptance of all three bitterness intensities (-0.9, -1.7, -2.7) and high saltiness (-1.0) was significantly lower than acceptance of unmodified green bell pepper puree (Figure 1).

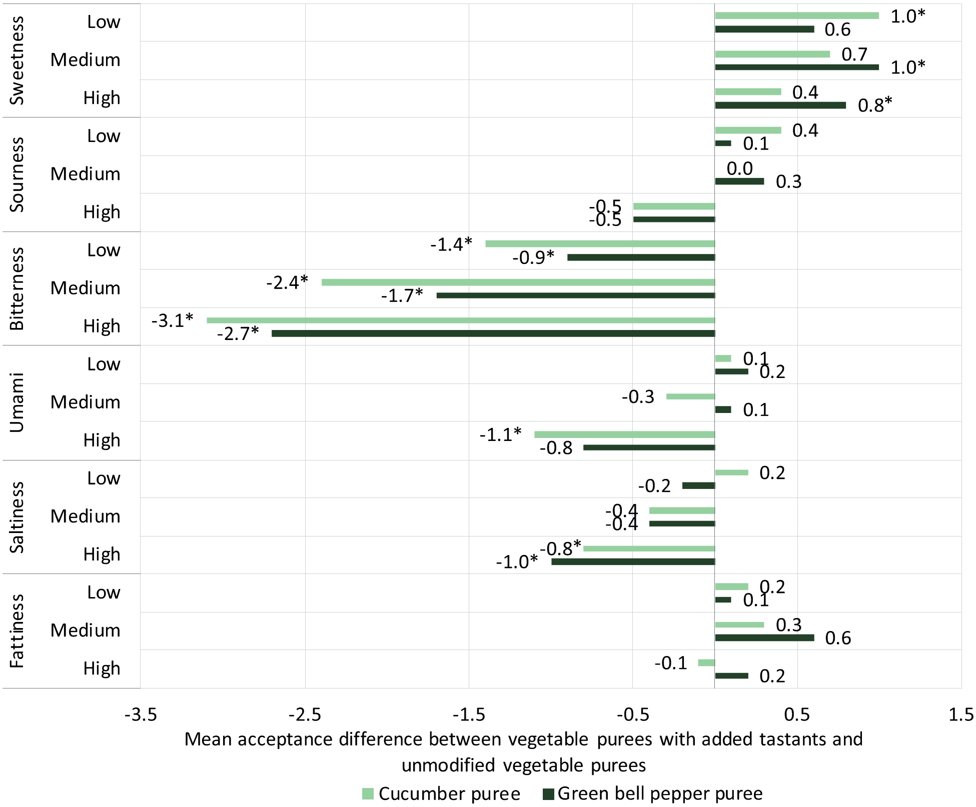


Figure 1. Mean difference in acceptance between purees with added tastants and unmodified purees for cucumber and green bell pepper purees (n = 100) for sweetness, sourness, bitterness, umami, saltiness and fattiness. * indicates significant differences ($p < 0.05$) in acceptance compared to unmodified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

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 bell pepper purees compared to unmodified vegetable purees, which is consistent with existing literature [15, 16]. 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 bell pepper 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 bell pepper puree, a vegetable with a higher bitterness [10, 11].

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[30] showed that low sweetness can increase bitterness. Since unmodified green bell pepper displayed a significant higher bitterness compared to unmodified cucumber, it is possible that bitterness was increased by the presence of sweetness in green bell pepper, but not in cucumber. During the sensory evaluation participants 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 [7, 31] and increasing energy density has been suggested to be an effective strategy to increase food intake; however, results are inconsistent [32-35]. In addition, enhancing fattiness intensity, did not significantly increase acceptance. In the current study participants 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 bell pepper purees. In green bell pepper 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 bell pepper which might have suppressed sourness, therefore discrimination between tastes might have been more difficult. Participants 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 participants might have confused sourness with other taste modalities. The benefit of using naive participants for the sensory evaluation of the vegetable purees is that they are more representative for consumers compared to trained and experienced participants. 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 bell pepper. Low sourness was significantly more accepted in cucumber than in green bell pepper purees. Low sourness might have enhanced bitterness in green bell pepper, as Keast and Breslin[30] 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[30] suggested that high sourness also supresses' bitterness. Mojet et al.[36] 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 only assessed 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 [36]. Bitterness is not well accepted [7, 37]. 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 participants. We used *n* = 166 healthy participants without taste or swallowing problems (self-reported). We speculate that participants included PROP-supertasters, PROP-tasters and PROP non-tasters. The study did not aim to cluster participants 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, 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 [38]. 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, participants 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 participants. 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 bell pepper 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 bell pepper 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 [(17, 39, 40)]. Masic and Yeomans[(17)] 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[(17)] 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[(17)] 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 [(7, 29, 37, 41, 42)]. Enhancing saltiness by salt addition can suppress bitterness [(18, 20, 25, 30)]. On the contrary, Mojet et al.[(36)] 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.[(18)], 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.[(18)] 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.[18] 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 bell pepper purees and therefore less accepted. Fattiness was the only sensory attribute related to the addition of sunflower oil assessed by the participants. 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, participants 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 [43].

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 bell pepper purees. It is possible that more complex modifications of the taste profile or the flavour 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 flavour 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 flavour 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, flavour and texture combinations are needed to increase acceptance for vegetables further.

Taste enhancement method

Cucumber and green bell pepper 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 bell pepper purees had acceptance scores of -0.1 and -0.4, respectively, indicating participants 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 [28, 44]. Zeinstra et al.[28] showed that young adults (18-25 years) like uniformity in vegetables and dislike granular texture and brown colour. Smashed preparations were not well liked, but steamed and boiled were liked (carrots, French beans). Bouhlal et al.[18], Capaldi and Privitera[15] and Sharafi et al.[16] 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.[11] 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 [45, 46]. 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 bell pepper purees differed per tastant, concentration of tastant and vegetable type. Only enhancement of sweetness increased acceptance of cucumber and green bell pepper purees, at different concentrations of added sucrose. For cucumber purees, less sweetness enhancement was needed to increase acceptance compared to green bell pepper purees, probably because cucumber displayed a relatively neutral taste profile whereas green bell pepper 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, flavour or texture modifications are required to enhance acceptance of vegetables. Results can be used by cultivators to grow vegetable varieties with more taste and flavour, 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.

Acknowledgements
This study was carried out with the financial support of Centre of Expertise Food and Centre of Expertise Greenport (Ministry of Economic Affairs), The Netherlands. We like to thank TOP BV, The Netherlands, for their help during the production of the samples.

References

1. Alexy U, Sichert-Hellert W, Kersting M. Fifteen-year time trends in energy and macronutrient intake in German children and adolescents: results of the DONALD study. *British Journal of Nutrition.* 2002;87(6):595-604.
2. Bowen J, Klose D, Syrette J, Noakes M. Australian children's vegetable intake: findings of the 2007 Australian children's national nutrition and physical activity survey. 2009 (VG07160).
3. Dennison BA, Rockwell HL, Baker SL. Fruit and vegetable intake in young children. *Journal of the American College of Nutrition.* 1998;17(4):371-8.
4. Van Rossum CT, De Boer EJ, Ocke MC. Dutch National Food Consumption Survey-Young Children 2005/2006. *Annals of Nutrition and Metabolism.* 2009;55:521-2.
5. Cox DN, Melo L, Zabaras D, Delahunty CM. Acceptance of health-promoting Brassica vegetables: the influence of taste perception, information and attitudes. *Public Health Nutrition.* 2012;15(8):1474-82.
6. Kourouniotis S, Keast RSJ, Riddell LJ, Lacy K, Thorpe MG, Cicerale S. The importance of taste on dietary choice, behaviour and intake in a group of young adults. *Appetite.* 2016;103:1-7.
7. Birch LL. Development of food preferences. *Annual Review of Nutrition.* 1999;19:41-62.
8. Nicklaus S, Boggio V, Chabanet C, Issanchou S. A prospective study of food variety seeking in childhood, adolescence and early adult life. *Appetite.* 2005;44(3):289-97.
9. Zeinstra GG, Koelen MA, Kok FJ, de Graaf C. Cognitive development and children's perceptions of fruit and vegetables; a qualitative study. *International Journal of Behavioral Nutrition and Physical Activity.* 2007;4:30.
10. Poelman AAM, Delahunty CM, de Graaf C. Vegetables and other core food groups: A comparison of key flavour and texture properties. *Food Quality and Preference.* 2017;56, Part A:1-7.
11. Van Stokkom VL, Teo PS, Mars M, de Graaf C, van Kooten O, Stieger M. Taste intensities of ten vegetables commonly consumed in the Netherlands. *Food Research International.* 2016;87:34-41.
12. Liem DG, de Graaf C. Sweet and sour preferences in young children and adults: role of repeated exposure. *Physiology & Behavior.* 2004;83(3):421-9.
13. De Graaf C, Zandstra EH. Sweetness intensity and pleasantness in children, adolescents, and adults. *Physiology & Behavior.* 1999;67(4):513-20.
14. Liem DG, Westerbeek A, Wolterink S, Kok FJ, de Graaf C. Sour taste preferences of children relate to preference for novel and intense stimuli. *Chemical Senses.* 2004;29(8):713-20.
15. Capaldi ED, Privitera GJ. Decreasing dislike for sour and bitter in children and adults. *Appetite.* 2008;50(1):139-45.
16. Sharafi M, Hayes JE, Duffy VB. Masking Vegetable Bitterness to Improve Palatability Depends on Vegetable Type and Taste Phenotype. *Chemosensory Perception.* 2013;6(1):8-19.

17. Masic U, Yeomans MR. Does monosodium glutamate interact with macronutrient composition to influence subsequent appetite? *Physiology & Behavior.* 2013;116:23-9.
18. Bouhlal S, Chabanet C, Issanchou S, Nicklaus S. Salt content impacts food preferences and intake among children. *PLoS One.* 2013;8(1):e53971.
19. Bouhlal S, Issanchou S, Chabanet C, Nicklaus S. 'Just a pinch of salt'. An experimental comparison of the effect of repeated exposure and flavor-flavor learning with salt or spice on vegetable acceptance in toddlers. *Appetite.* 2014;83C:209-17.
20. Mennella JA, Pepino MY, Beauchamp GK. Modification of bitter taste in children. *Developmental Psychobiology.* 2003;43(2):120-7.
21. Besnard P, Passilly-Degrace P, Khan NA. Taste of Fat: A Sixth Taste Modality? *Physiological Reviews.* 2016;96(1):151-76.
22. Liu D, Archer N, Duesing K, Hannan G, Keast R. Mechanism of fat taste perception: Association with diet and obesity. *Progress in Lipid Research.* 2016;63:41-9.
23. Running CA, Craig BA, Mattes RD. Oleogustus: The Unique Taste of Fat. *Chemical Senses.* 2015;40(7):507-16.
24. Fisher JO, Mennella JA, Hughes SO, Liu Y, Mendoza PM, Patrick H. Offering "Dip" Promotes Intake of a Moderately-Liked Raw Vegetable among Preschoolers with Genetic Sensitivity to Bitterness. *Journal of the Academy of Nutrition and Dietetics.* 2012;112(2):235-45.
25. Bouhlal S, Issanchou S, Nicklaus S. The impact of salt, fat and sugar levels on toddler food intake. *British Journal of Nutrition.* 2011;105(4):645-53.
26. Duffy EM, Hayes JE, Feeney EL. Understanding taste and texture perception to enhance vegetable acceptance. *Proceedings of the Nutrition Society.* 2017;76(Oce3):E67-E.
27. Nederkoorn C, Theibetaen J, Tummers M, Roefs A. Taste the feeling or feel the tasting: Tactile exposure to food texture promotes food acceptance. *Appetite.* 2018;120:297-301.
28. Zeinstra GG, Koelen MA, Kok FJ, de Graaf C. The influence of preparation method on children's liking for vegetables. *Food Quality and Preference.* 2010;21(8):906-14.
29. Martin C, Visalli M, Lange C, Schlich P, Issanchou S. Creation of a food taste database using an in-home "taste" profile method. *Food Quality and Preference.* 2014;36:70-80.
30. Keast SJR, Breslin PAS. An overview of binary taste-taste interactions. *Food Quality and Preference.* 2003;14(2):111-24.
31. Ventura AK, Worobey J. Early influences on the development of food preferences. *Current Biology.* 2013;23(9):R401-8.
32. Caton SJ, Ahern SM, Remy E, Nicklaus S, Blundell P, Hetherington MM. Repetition counts: repeated exposure increases intake of a novel vegetable in UK pre-school children compared to flavour-flavour and flavour-nutrient learning. *Britsh Journal of Nutrition.* 2013;109(11):2089-97.
33. Hausner H, Olsen A, Moller P. Mere exposure and flavour-flavour learning increase 2-3 year-old children's acceptance of a novel vegetable. *Appetite.* 2012;58(3):1152-9.
34. Gibson EL, Wardle J. Energy density predicts preferences for fruit and vegetables in 4-year-old children. *Appetite.* 2003;41(1):97-8.

35. De Wild VW, de Graaf C, Jager G. Effectiveness of flavour nutrient learning and mere exposure as mechanisms to increase toddler's intake and preference for green vegetables. *Appetite.* 2013;64:89-96.
36. Mojet J, Heidema J, Christ-Hazelhof E. Effect of concentration on taste-taste interactions in foods for elderly and young subjects. *Chemical Senses.* 2004;29(8):671-81.
37. Drewnowski A. Taste preferences and food intake. *Annual Review of Nutrition.* 1997;17:237-53.
38. Drewnowski A, Gomez-Carneros C. Bitter taste, phytonutrients, and the consumer: a review. *American Journal of Clinical Nutrition.* 2000;72(6):1424-35.
39. Beauchamp GK. Sensory and receptor responses to umami: an overview of pioneering work. *American Journal of Clinical Nutrition*. 2009;90(3):723S-7S.
40. Yamaguchi S, Ninomiya K. Umami and food palatability. *Journal of Nutrition.* 2000;130(4S Suppl):921S-6S.
41. Ahern SM, Caton SJ, Bouhlal S, Hausner H, Olsen A, Nicklaus S, et al. Eating a Rainbow. Introducing vegetables in the first years of life in 3 European countries. *Appetite.* 2013;71:48-56.
42. Leshem M. Biobehavior of the human love of salt. *Neuroscience and Biobehavioral Reviews.* 2009;33(1):1-17.
43. Holley CE, Farrow C, Haycraft E. A Systematic Review of Methods for Increasing Vegetable Consumption in Early Childhood. *Current Nutrition Reports.* 2017;6(2):157-70.
44. Poelman AAM, Delahunty CM. The effect of preparation method and typicality of colour on children's acceptance for vegetables. *Food Quality and Preference.* 2011;22:355-64.
45. Le Calvé B, Saint-Léger C, Babas R, Gelin J-L, Parker A, Erni P, et al. Fat Perception: How Sensitive are We? *Journal of Texture Studies.* 2015;46(3):200-11.
46. Mela DJ. Sensory assessment of fat content in fluid dairy products. *Appetite.* 1988;10(1):37-44.

Chapter 5

Sweetness but not sourness enhancement increases acceptance of cucumber and green bell pepper purees in children

Vera L. van Stokkom, Astrid A.M. Poelman, Cees de Graaf, Olaf van Kooten, Markus Stieger

Based on publication in Appetite, 2018. 131: p. 100-107

Abstract

For children it is important to consume enough vegetables to establish healthy dietary patterns. Taste acceptance is an important factor contributing to food choice and consumption. Sweetness and sourness enhancement can increase acceptance of specific foods in children. The aim of this study was to determine the effect of sweetness and sourness enhancement on acceptance of cucumber and green bell pepper purees in 5-6-year-old children. Three concentrations of sucrose (2, 5 and 10%) and citric acid (0.05, 0.08 and 0.15%) were added to cucumber and green bell pepper purees. Children (n = 70, 5.7 ± 0.5 years) assessed acceptance of the vegetable purees using a 5-point hedonic facial scale. Sweetness enhancement significantly increased acceptance of cucumber purees (5 and 10% sucrose) and green bell pepper purees (2 and 10% sucrose) compared to unmodified purees. Sourness enhancement (0.05, 0.08 and 0.15% citric acid) did not significantly influence acceptance of cucumber and green bell pepper purees compared to unmodified purees. Children differed in acceptance of vegetable purees with added sucrose and citric acid. Sweetness likers (cucumber 77.1%, green bell pepper 58.6%) accepted sucrose concentrations better than sweetness non-likers in both vegetables. Sourness likers (cucumber 50.0%, green bell pepper 44.3%) accepted medium and high concentrations of citric acid better than sourness non-likers in cucumber and all citric acid concentrations in green bell pepper. We conclude that enhancement of sweetness increases acceptance of cucumber and green bell pepper purees in most children whereas enhancement of sourness is better accepted by only a few children. This study highlights the challenge to get children to better accept vegetables, since only sweetness enhancement improved acceptance while addition of sucrose is undesirable. For a small subset of children enhancing sourness might be an alternative strategy to increase acceptance of vegetables.

Introduction

Consumption of vegetables by children is below recommended intake in multiple countries even though vegetables are an important part of a healthy diet [1-5]. Children form a key target group to increase vegetable consumption as vegetable consumption at a young age contributes to vegetable consumption later in life [6]. Taste acceptance is an important factor contributing to food consumption, especially in children [7, 8]. Recent studies showed that vegetables in general have low taste intensities compared to other foods [9, 10]. The low taste intensities of vegetables might contribute to low acceptance. Therefore, taste enhancement might be an effective approach to increase vegetable acceptance.

Several studies investigated the effect of taste enhancement of different taste modalities on food acceptance in children. Liem and de Graaf[11] showed that enhancing sweetness but not sourness increased preference of orangeade and yoghurt in children [11]. However, some children have a preference for extreme sourness intensities of foods [12]. Enhancing sweetness of grapefruit juice, a more bitter food, by adding sucrose reduced initial dislike of grapefruit juice by children. An increased liking was even sustained when later on sucrose was removed [13]. In summary, children's acceptance of specific beverages and foods increased when taste intensities were enhanced and depends on taste modality and type of food.

Limited research has been conducted to investigate the effect of taste enhancement on children's acceptance of vegetables. Bouhlal et al.[14] demonstrated that enhancing saltiness of green beans by adding sodium chloride increases children's acceptance of green beans. In adults, the effect of taste enhancement of different taste modalities on vegetable acceptance has been investigated more extensively. Sweetness enhancement increased acceptance of broccoli and cauliflower in adults [13]. A recent study by van Stokkom et al.[15] demonstrated that enhancing sweetness by adding sucrose to cucumber and green bell pepper purees increases acceptance of these vegetable purees in adults. A relatively low sweetness enhancement (2% sucrose) was sufficient to increase acceptance of cucumber purees, while for green bell pepper purees a higher sweetness enhancement was needed (5% sucrose). Sharafi et al.[16] 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 in adults. Aspartame was the most effective bitterness suppressor and increased liking for all vegetables in adults.

Taste perception and discriminatory abilities for taste often differ within children and between children and adults [17, 18], which might contribute to differences in acceptance. Children can prefer higher intensities of sweetness than adults in a variety of foods [19]. De Graaf and Zandstra[17] demonstrated that children prefer higher sucrose concentrations in water and in lemonade than adults. Mennella et al.[7] also showed that children prefer higher concentrations of sucrose in water than adults. In another study, children preferred higher sucrose concentrations in pudding compared to their mothers [20]. Children might also prefer higher sourness than adults. Liem and Mennella[21] showed that 35% of children preferred high levels of sourness in gelatine gels while for adults this was not the case. Vegetables such as cucumber and green bell pepper do not have an inherit sour taste or might not have a flavour that is congruent with sourness. However, sour seasonings such as vinaigrettes or dressings are commonly used for the preparation of many vegetables [22]. Therefore, enhancing sourness of vegetables such as cucumber and green bell pepper might increase acceptance in children.

To the best of our knowledge, the effect of sweetness and sourness enhancement on children's acceptance of cucumber and green bell pepper has not been studied yet. The aim of this study was to investigate the effect of sweetness and sourness enhancement on acceptance of cucumber and green bell pepper purees in 5-6-year-old children. We hypothesize that both sweetness and sourness enhancement increase acceptance for cucumber and green bell pepper purees in children, but that sweetness enhancement has a stronger effect in most children than sourness enhancement. Additionally, we hypothesize that the higher the sucrose concentration, the larger the influence on acceptance. Knowledge about the effect of taste enhancements on acceptance of vegetables by children might help devise strategies to increase children's vegetable consumption.

Methods

Participants

A dedicated recruitment agency for consumer trials located in the Sydney metropolitan area (Australia) was used for the recruitment. Children aged 5 and 6 years were selected. Children were included if they were generally in good health and had consumed the target vegetables (cucumber and bell pepper) at least once before participating in the study. Children were excluded when they had a strong dislike for either target vegetable, had any known food allergies or dietary intolerances or had any problems with chewing or swallowing (parental reported). In total, $n = 72$ children participated in the study. Two children refused most samples and were therefore excluded from data analysis. One child refused all bell pepper purees. For the remaining children refusals were rare. N = 70 children were included in the data analysis for cucumber purees and $n = 69$ children for bell pepper purees. The CSIRO Human Research Committee granted ethical approval for the study registered under number #25/2016. Participants received financial compensation for participation.

Vegetable purees

The study included cucumber (*Cucumis sativus,* variety Telegraph) and green bell bell pepper, hereafter referred to as green bell pepper (*Bell pepper annuum*). Selection of vegetables was based on three criteria: first, one vegetable should display a relatively neutral taste profile whereas the other vegetable should display a slight bitter taste. In previous studies cucumber displayed a neutral taste profile while green bell pepper was characterized by higher bitterness intensity compared to other vegetables [9, 10]. Secondly, both vegetables should be commonly consumed in Australia [5]. Thirdly, both vegetables should be consumable cold and without further preparation.

Vegetable purees were prepared at CSIRO in Sydney, North Ryde, Australia. Vegetables were collected in bulk to eliminate between batch variation. Vegetables were rinsed, cut in pieces and pureed with a mixer (NutriBullet, LLC. Los Angeles, United States). Three concentrations of sucrose (2, 5 and 10% w/w) and three concentrations of citric acid (0.05, 0.08 and 0.15% w/w) were added to the vegetable purees and are referred to as low, medium and high tastant concentrations. Tastant concentrations were based on reference solutions used in the modified Spectrum Method. In the modified Spectrum Method, three reference solutions with fixed intensities for each tastant are used to evaluate the intensity of the basic tastes (sweetness, sourness, bitterness, umami and saltiness) on an absolute scale (Martin et al., 2014). Using these concentrations ensured that purees had low, medium and high intensities. Tastants were mixed into the vegetable purees with a hand mixer until complete dissolution. Purees were poured into plastic food freezer bags. Samples were frozen immediately after production and stored at -20°C. On each test day, one bag per sample was defrosted at 4°C. One hour prior to each session, the defrosted samples were removed from the refrigerator and kept at room temperature so that vegetable purees reached room temperature before the start of the session.

Cucumber and green bell pepper purees used in this study were the same as vegetable purees used previously [15]. In the previous study, adult consumers (n = 66, 35.8 ± 17.7 years) rated the intensity of sweetness and sourness of vegetable purees using a 100 mm line scale. Sweetness and sourness intensities of vegetable purees assessed by adults increased significantly ($p < 0.01$) with increasing tastant concentration (sucrose and citric acid). Sweetness intensity increased from unmodified (14 for cucumber; 14 for green bell pepper) to low (35; 41), medium (71; 69) and high (84; 86) sucrose concentrations. Sourness intensity increased from unmodified (15 for cucumber; 28 for green bell pepper) to low (40; 31), medium (55; 43) and high (76; 70) citric acid concentrations. All taste intensities significantly differed between vegetable purees with the exception of unmodified and low citric acid concentration for green bell pepper.

Procedure

The acceptance test had a within subject design. Session typically took less than 30 min, only very few sessions lasted up to 45 min. Sessions were performed at the research facilities of CSIRO in Sydney, North Ryde, Australia. Each session included no more than four children. Sessions started with oral instructions after which the parent signed the informed consent form and children gave their assent by colouring in a happy smiley face. If children did not want to participate, they had the option colouring in a sad smiley face. One child coloured in a sad smiley face and therefore did not participate. Children were placed in test rooms with no more than two children per test room. Research assistants helped each child one-on-one and recorded the results. Parents were seated nearby, but not in direct view of the child and were instructed not to communicate with the child during the test.

Serving order of vegetable type was balanced and alternated across sessions, so in one session all children started with cucumber and the next session with green bell pepper. For each vegetable type, children tasted a small portion of each of the seven samples, one by one, using a randomized design across participants. Vegetable samples (~15 g per sample) were offered at room temperature in plastic containers (30 ml) covered with a lid until consumption. During tasting, children were instructed to sip a small amount of water between samples to cleanse their palate. Children received a tray containing seven samples of the first vegetable (unmodified; low, medium and high sucrose; low, medium and high citric acid). When children completed the assessment of the first vegetable type, there was a break of at least one minute. The procedure was then repeated for the second vegetable. Acceptance was assessed using a 5-point hedonic facial scale and by preference ranking. First, children categorised each sample by placing the sample below the appropriate image of a 5-point hedonic facial scale. The five categories were visualized with smiley faces on an A3 page. Children's understanding of the scale was established during the oral instruction by asking children to explain the different categories in their own words. Additionally, the research assistant repeated that the faces represent 'really yucky', 'yucky', 'okay', 'yummy' and 'really yummy'. Next, the same seven samples were ranked for preference from most (rank number 1) to least liked (rank number 7). Samples were re-tasted whenever relevant. Previous studies with children used similar methods [17, 23-26].

Parental questionnaire

During the session, parents completed a questionnaire to collect background information including demographics (gender and age of parent and child, parental educational level). Data was collected about the consumption frequency of vegetables (excluding potatoes) in general (servings per day for parent and child) and about the child's consumption frequency of the target vegetables (less than once a month; 1-3 times a month; once a week or more). Parents were also asked how they typically prepare cucumber and green bell pepper and if they typically use any seasonings during the preparation. Parents assessed their child's food neophobia by the six-item version of the Child Food Neophobia Scale (CFNS) [27, 28].

Statistical data analyses

Statistical data analyses were performed using IBM SPSS Statistics version 24. A *p* value of 0.05 was used as criterion for statistical significance. Descriptive data were generated for demographic and vegetable variables. Acceptance categorised by the 5-point hedonic facial scale and ranked preference were analysed separately. Acceptance categories were coded from -2 ('really yucky') to 2 ('really yummy') with 0 corresponding to 'okay'. Ranked preference was coded from 1 (most preferred) to 7 (least preferred). Refusals were coded as missing values. There was one refusal during preference ranking of cucumber purees and categorised acceptance of green bell pepper purees. There were three refusals during preference ranking of green bell pepper purees. Means and standard deviation of categorised acceptance, ranked preference and mean acceptance differences between samples and the unmodified sample were calculated.

Differences in acceptance categories between cucumber and green bell pepper vegetable purees were analysed using dependent t-test. General Linear Model analysis including participant as random and sample as fixed factor was used to analyse differences in acceptance between unmodified vegetable purees and modified vegetable purees followed by LSD post-hoc testing. Spearman's Rho correlation coefficients were calculated to test for correlations between age, gender, CFNS and acceptance of cucumber and green bell pepper purees. No significant correlations between these variables were found and therefore these variables were not included in results and discussions. Ranked preference was analysed with Friedman's test. When significant differences were found between samples, Wilcoxon signed-rank test was used with 20 comparisons per vegetable type corrected for number of comparisons resulting in an adjusted *p* value of 0.003 [29].

To assess individual differences in acceptance, children were divided based on their acceptance of sucrose and citric acid additions. Children were classified as 'sweetness likers' when they rated acceptance of samples containing medium and high concentrations of sucrose with either 1 or 2. All remaining children were assigned to the sweetness non-likers group. The same criteria for medium and high concentrations of citric acid addition were applied to classify children into sourness likers and sourness non-likers. Differences in acceptance within subgroups were analysed using the same GLM analyses as conducted for the overall group. Differences in acceptance between likers and non-likers were analysed using an independent t-test. Chi-square tests and independent t-tests were used to determine differences in age, gender and CFN score between 'likers' and 'non-likers'.

Results

Characteristics of children and parents

Table 1 shows parent and child characteristics. The mean age of children was 5.7 ± 0.5 years and 54.3% were girls. Both parental and child vegetable consumption (2.71 and 2.12 serves/d) were below recommended intakes (> 5 and 4.5 serves/d) [30]. It should be noted that the Australian guidelines include potatoes while we excluded potatoes as this is common in WHO guidelines as well as guidelines of most other western countries. Cucumber was consumed more often than bell pepper. Cucumber was most often consumed raw with skin (81.4%), green bell pepper was most often consumed stir-fried (78.5%).

Acceptance of cucumber and green bell pepper purees by children

Table 2 summarizes the mean acceptance scores assessed by children (5-6 years) for cucumber and green bell pepper purees of categorised acceptance and preference ranking. For categorised acceptance, mean acceptance scores ranged from -0.15 to 0.74 for cucumber purees and from -0.62 to 0.14 for green bell pepper purees. As a consequence of the taste intensity modifications, acceptance varied from ‘yucky’ to ‘yummy’. Acceptance of 11 out of 14 vegetable purees (79% of samples) ranged between -0.5 and 0.5 corresponding to ‘okay’. Significant differences between acceptance of cucumber purees ($F(6,427)= 4.30$, $p < 0.01$) and between acceptance of green bell pepper purees ($F(6,408)= 4.06$, $p < 0.01$) were found.

For cucumber purees, acceptance of purees with medium (5%) and high (10%) sucrose concentrations was significantly higher than acceptance of unmodified cucumber puree (mean difference +0.53 and +0.49). Acceptance of cucumber puree with low sucrose concentration (2%) was not significantly different from unmodified puree (mean difference +0.15). Acceptance of cucumber purees with low (0.05%), medium (0.08%) and high (0.15%) citric acid concentrations did not significantly differ from unmodified cucumber puree (mean difference -0.03, -0.21 and -0.37). All cucumber purees with citric acid had a significantly lower acceptance than cucumber puree with medium (5%) and high (10%) concentrations of added sucrose (Table 2 and Figure 1).

For green bell pepper, acceptance of purees with low (2%) and high (10%) concentrations of added sucrose was significantly higher compared to unmodified green bell pepper puree (mean difference +0.50 and +0.55). Acceptance of green bell pepper puree with medium concentration of sucrose (5%, mean difference +0.35) did not significantly differ from unmodified green bell pepper puree, but acceptance tended to increase ($p = 0.09$) in a similar direction as the other added sucrose concentrations. Low (0.05%), medium (0.08%) and high (0.15%) concentrations of citric acid (mean difference +0.02, -0.21 and +0.02) did not differ significantly from unmodified green bell pepper puree. Green bell pepper purees with low (2%) and high (10%) concentrations of sucrose were significantly better accepted than all green bell pepper purees with citric acid. Green bell pepper puree with medium concentration of sucrose (5%) was significantly better accepted than puree with medium concentration of citric acid (0.08%) (Table 2 and Figure 1).

Table 1. Characteristics of children and parents participating in the study which were self-reported by parent.

Parent characteristics (*n* = 70)	**Mean ± SD or frequency (%)**	
Age (years)	37.8 ± 6.2	
Gender (% female)	87.1	
Education level		
Some high school	1.4%	
Completed high school	2.9%	
Tech, trade or TAFE qualification	25.7 %	
University	48.6 %	
Post graduate studies	21.4%	
Use seasoning while preparing vegetables		
Cucumber (% yes)	11.4 %	
Bell pepper (% yes)	44.3 %	
Vegetable consumption (serves / day)	2.71 ± 1.0	
Child characteristics (*n* = 70)	**Mean ± SD or frequency (%)**	
Age (years)	5.7 ± 0.5	
Gender (% girls)	54.3	
Child food neophobia (CFN) score (range 6-42)	20.0 ± 7.7 (range 6-37)	
Vegetable consumption (serves / day)	2.12 ± 1.1	
Cucumber consumption frequency		
< once a month 4.3%	1-3 times a month 5.7%	Once a week or more 90.0%
Bell pepper consumption frequency		
< once a month 17.1%	1-3 times a month 40.0%	Once a week or more 42.9%
Cucumber preparation method (multiple options possible)		
Raw with skin 81.4%	Raw without skin 35.6%	Other 2.8%
Green bell pepper preparation method (multiple options possible)		
Raw 60%	Stir fry 78.5%	Other 25.8%

Unmodified cucumber puree was significantly better accepted than unmodified green bell pepper puree. Medium (5%) and high (10%) sucrose concentrations and low and medium citric acid concentrations were better accepted in cucumber purees than in green bell pepper purees. Acceptance did not differ significantly between cucumber purees and green bell pepper purees for low sucrose (2%) and high citric acid concentration (0.15%) (Table 2 and Figure 1).

For ranked preference, Friedman's test indicated that there were significant differences in acceptance between cucumber (χ^2 (6) = 35.6, $p < 0.01$) and green bell pepper purees (χ^2 (6) = 19.2, $p < 0.05$). Rank of preference for cucumber with added sucrose and added citric acid did not significantly differ compared to unmodified cucumber puree. Cucumber puree with high concentration of citric acid (0.15%) was significantly higher ranked than cucumber puree with low (2%), medium (5%) and high (10%) concentration of sucrose (Z =-3.10, p = 0.02; Z = -4.04, $p < 0.001$ and Z= -4.46, $p < 0.01$). Rank of preference of green bell pepper purees with added sucrose and added citric acid did not differ significantly compared to unmodified green bell pepper puree. Rank of preference of green bell pepper purees with medium concentration of citric acid (0.08%) was significantly higher than rank of preference of green bell pepper purees with low (2%), medium (5%) and high (10%) concentrations of sucrose (Z = -3.15, $p < 0.01$; Z = -2.83, $p < 0.01$; Z= -2.86, $p < 0.01$) (Table 2).

Table 2. Mean categorised acceptance assessed by children (5-6 years) for cucumber (n = 70) and green bell pepper purees (n = 69) using a 5-point hedonic facial scale ranging from 'really yucky' (-2) to 'really yummy' (+2) and mean preference ranks assessed by children for cucumber (n = 69) and green bell pepper purees (n = 67) ranging from most preferred (1) to least preferred (7). Letters A-C indicate significant differences in acceptance between vegetable purees belonging to the same type of vegetable.

	Cucumber puree		**Green bell pepper puree**		
Tastants and oncentrations	**Categorised acceptance (n =70) Mean ± SD**	**Preference ranking (n = 69) Mean ± SD**	**Categorised acceptance (n = 69) mean ± SD**	**Preference ranking (n = 67) mean ± SD**	**Significance of difference in acceptance between cucumber and green bell pepper purees**
Unmodified	0.21 ± 1.45^{BC}	4.19 ± 1.94^{AB}	-0.41 ± 1.55^{BC}	4.27 ± 2.12^{AB}	t(68) = 2.96, $p < 0.01$
Sucrose					
Low	0.36 ± 1.47^{AB}	3.86 ± 1.78^{A}	0.09 ± 1.53^{A}	3.46 ± 1.91^{A}	t(68) = 1.08, p = 0.29
Medium	0.74 ± 1.38^{A}	3.30 ± 1.90^{A}	-0.06 ± 1.51^{AB}	3.61 ±b 1.89^{A}	t(68) = 3.58, $p < 0.01$
High	0.70 ± 1.48^{A}	3.11 ± 2.04^{A}	0.14 ± 1.59^{A}	3.43 ± 2.13^{A}	t(68) = 2.43, $p < 0.05$
Citric acid					
Low	0.23 ± 1.49^{BC}	4.17 ± 1.96^{AB}	-0.39 ± 1.34^{BC}	4.19 ± 1.77^{AB}	t(68) = 2.80, $p < 0.01$
Medium	0.18 ± 1.37^{BC}	4.30 ± 1.95^{AB}	-0.62 ± 1.44^{C}	4.63 ± 1.75^{B}	t(68) = 3.87, $p < 0.01$
High	-0.15 ± 1.55^{C}	4.94 ± 1.96^{B}	-0.39 ± 1.56^{BC}	4.04 ± 2.16^{AB}	t(68) = 1.01, p = 0.32

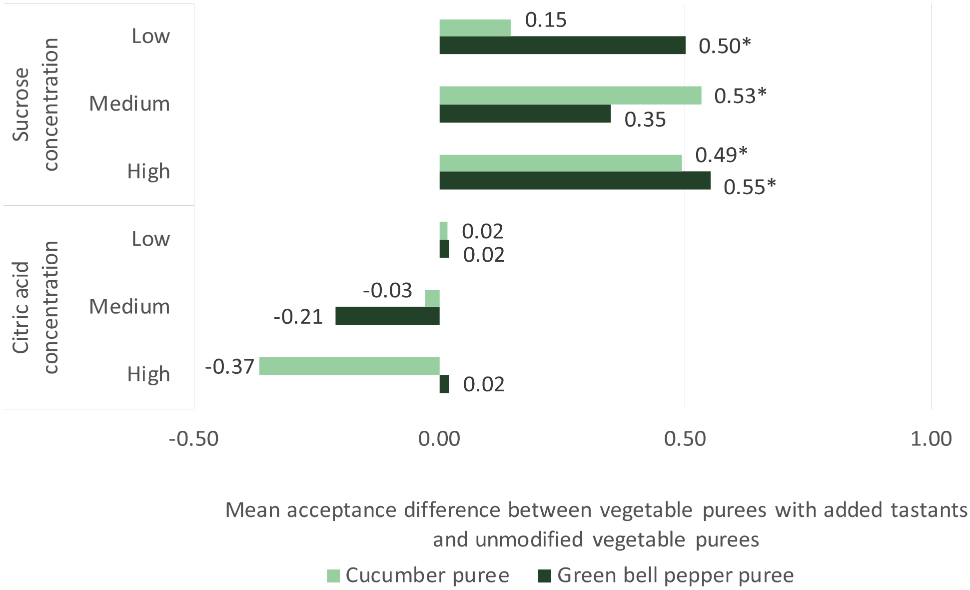


Figure 1. Mean categorised acceptance difference between cucumber and green bell pepper purees with added sucrose and citric acid and corresponding unmodified vegetable purees. Acceptance was measured on a 5-point hedonic facial scale ranging from 'really yucky' (-2) to 'really yummy' (+2). * indicates significant differences ($p < 0.05$) in acceptance compared to unmodified vegetable puree of the same type.

Sweetness and sourness likers versus non-likers

Table 3 shows categorised acceptance for sweetness likers versus sweetness non-likers and sourness likers versus non-likers in children (5-6 years). For cucumber, 54 children (77.1%) were classified as sweetness likers, and 35 children (50.0%) as sourness likers. For sweetness likers, medium (5%) and high (10%) sucrose concentrations increased acceptance significantly compared to unmodified cucumber puree. For sweetness non-likers, sucrose addition did not significantly increase nor decrease acceptance. Sweetness likers accepted unmodified cucumber puree and low (2%), medium (5%) and high (10%) sucrose concentrations significantly better than sweetness non-likers. For sourness likers, citric acid addition did not significantly increase nor decrease acceptance of cucumber. For sourness non-likers, high citric acid concentration (0.15%) significantly decreased acceptance compared to unmodified cucumber puree. Medium (0.08%) and high (0.15%) citric acid concentrations were significantly better accepted by sourness likers than sourness non-likers.

For cucumber, sweetness likers and sweetness non-likers and sourness likers and non-likers were not significantly different in age (t(68) =0.070, p = 0.06; t(68) = 0.236, p =0.55), gender (χ(1)=0.564, p = 0.45; χ(1) = 0.230, p = 0.63) and CFN score (t(68) = 0.547, p = 0.53; t(68)=1.693, p = 0.41).

Table 3. Mean categorised acceptance assessed by children (5-6 years) using a 5-point hedonic facial scale ranging from 'really yucky' (-2) to 'really yummy' (+2) for sweetness likers versus sweetness non-likers (cucumber purees: n = 54; n = 16, green bell pepper purees: n = 41, n = 28) and for sourness likers versus non-likers (cucumber purees: n = 35, n = 35; green bell pepper purees n = 31, n = 38). Letters A-B indicate significant differences in acceptance between vegetable purees belonging to the same type of vegetable for likers and non-likers.

	Cucumber puree Categorised acceptance (mean ± SD)		
Tastants and concentrations	**Sweetness likers (n = 54)**	**Sweetness non-likers (n = 16)**	**Significance of difference in acceptance between likers and non-likers**
Unmodified	0.44 ± 1.34^{B}	-0.44 ± 1.59^{A}	t(68) = 0.796, $p < 0.05$
Sucrose			
Low	0.56 ± 1.44^{B}	-0.31 ± 1.40^{A}	t(68)= 0.068, $p < 0.05$
Medium	1.17 ± 1.19^{A}	-0.69 ± 0.95^{A}	t(68)= 0.095, $p < 0.01$
High	1.31 ± 1.04^{A}	-1.25 ± 0.86^{A}	t(68) = 0.043, $p < 0.01$
	Sourness likers (n = 35)	**Sourness non-likers (n = 35)**	
Unmodified	0.63 ± 1.37^{A}	-0.14 ± 1.42^{A}	t(68) = 0.280, $p = 0.08$
Citric acid			
Low	0.69 ± 1.35^{A}	-0.23 ± 1.50^{A}	t(68)=0.724, $p = 0.10$
Medium	1.23 ± 0.97^{A}	-0.80 ± 0.80^{AB}	t(68)=0.127, $p < 0.01$
High	0.89 ± 1.47^{A}	-1.20 ± 0.72^{B}	t(68)= 3.238, $p < 0.01$
	Green bell pepper puree Categorised acceptance (mean ± SD)		
Tastants and concentrations	**Sweetness likers (n = 41)**	**Sweetness non-likers (n = 28)**	**Significance of difference in acceptance between likers and non-likers**
Unmodified	-0.15 ± 1.65^{B}	-0.79 ± 1.32^{A}	t(67) = 4.174, $p = 0.09$
Sucrose			
Low	0.66 ± 1.41^{A}	-0.75 ± 1.32^{A}	t(67) = 0.695, $p < 0.01$
Medium	0.73 ± 1.38^{A}	-1.21 ± 0.79^{AB}	t(67) = 8.638, $p < 0.01$
High	1.22 ± 1.01^{A}	-1.43 ± 0.74^{B}	t(67) = 2.501, $p < 0.01$
	Sourness likers (n = 31)	**Sourness non-likers (n = 38)**	
Unmodified	0.52 ± 1.39^{AB}	-1.16 ± 1.24^{B}	t(67) = 1.880, $p < 0.01$
Citric acid			
Low	-0.03 ± 1.40^{B}	-0.68 ± 1.23^{A}	t(67) = 0.257, $p < 0.05$
Medium	0.52 ± 1.29^{AB}	-1.55 ± 0.69^{B}	t(67) = 11.819, $p < 0.01$
High	0.84 ± 1.34^{A}	-1.39 ± 0.86^{B}	t(67) = 6.623, $p < 0.01$

For green bell pepper, 41 children (58.6%) were classified as sweetness likers and 31 children (44.3%) as sourness likers. For sweetness likers, acceptance increased by addition of low (2%), medium (5%) and high (10%) sucrose concentrations compared to unmodified green bell pepper puree. For sweetness non-likers, a high concentration of sucrose (10%) significantly decreased acceptance compared to unmodified green bell pepper puree. Sweetness likers accepted low (2%), medium (5%) and high (10%) sucrose concentrations significantly better than sweetness non-likers. Addition of citric acid did not affect acceptance for sourness likers compared to unmodified green bell pepper puree. Low citric acid concentration (0.05%) improved acceptance for sourness non-likers compared to unmodified green bell pepper puree and medium (0.08%) and high (0.15%) citric acid concentrations. Sourness likers accepted unmodified green bell pepper puree and low (0.05%), medium (0.08%) and high (0.15%) citric acid concentrations better than sourness non-likers.

For green bell pepper, sweetness likers and sweetness non-likers were not significantly different in age ($t(67)=0.434$, $p = 0.14$), gender ($\chi(1)=0.606$, $p = 0.44$) and CFN score ($t(67)=1.158$, $p =0.40$). Sourness likers and non-likers were not significantly different in gender ($\chi(1) = 2.029$, $p = 0.15$), CFN score ($t(67)=0.188$, $p = 0.21$), but sourness likers were older than sourness non-likers ($t(67)=2.223$, $p = 0.04$).

Discussion

The aim of this study was to investigate the effect of sweetness and sourness enhancement on acceptance of cucumber and green bell pepper purees in 5-6-year-old children. The main finding of this study is that sweetness enhancement by sucrose addition increased acceptance by children of an initially not well accepted vegetable puree, green bell pepper puree, and a neutrally accepted vegetable puree, cucumber puree, but sourness enhancement by addition of citric acid addition did not.

Influence of sucrose and citric acid addition on acceptance of vegetable purees by children

Unmodified cucumber puree, which has a more neutral taste profile, was better accepted by children (5-6 years) than unmodified green bell pepper puree, which has a more bitter taste profile [9, 10]. This difference in acceptance is probably caused by the bitterness of the green bell pepper puree. Sucrose addition increased acceptance in both vegetables. Humans have an innate preference for sweetness [31, 32]. Therefore, is was not surprising that children accepted cucumber and green bell pepper purees with added sucrose better than the corresponding unmodified purees. However, the concentration that was needed to increase acceptance differed between cucumber and green bell pepper purees. Medium and high concentrations of added sucrose increased acceptance in cucumber purees, while in green bell pepper purees, low and high concentrations of added sucrose increased acceptance compared to unmodified vegetable purees. This difference between cucumber and green bell pepper could be a result of differences in taste-flavour interactions between added sucrose and the flavour of the vegetables. Cucumber is fairly neutral tasting and therefore taste-flavour interactions might occur to a lower extent, while green bell pepper is less neutral tasting and more bitter. In cucumber, sucrose addition probably increased acceptance due to higher sweetness intensity. In green bell pepper, sucrose addition might also have increased acceptance due to bitterness suppression by sweetness [(33)]. Moreover, differences between the complexity of taste, flavour and texture of cucumber and green bell pepper might have led to differences in perception and discrimination between concentrations of added tastants [(34)]. We acknowledge that descriptive sensory profiling would be needed to quantify possible taste-taste and taste-flavour interactions. This was outside the scope of the current study. We recommend future studies to apply quantitative descriptive analysis to be able to investigate the effect of added tastants on taste-taste and taste-flavour interactions.

It is unknown whether an increase in acceptance leads to an increase in intake, nor whether the increase in acceptance is continued when sucrose is removed later on. The latter has been shown by Capaldi and Privitera[(13)] in grapefruit juice where increased acceptance after addition of sucrose persisted when sucrose was removed from the grapefruit juice later on.

In a study by Liem et al.[(12)] 58% of the participating children preferred one of the two most sour gelatine gels (0.08 and 0.25 M or 1.5 and 4.8%), which is in contrast with the widely accepted idea that humans are pre-dispositioned to dislike sourness [(31, 32)]. Our results showed that citric acid addition did not change acceptance significantly compared to unmodified vegetable purees. However, the lowest concentration used by Liem et al.[(12)] (0.02 M or 0.38%) was higher than the highest concentration used in our study (0.15% w/w). Maybe the citric acid concentrations used in the current study were too low to increase acceptance for some children. It is also possible that sourness is not a taste associated and congruent with cucumber and green bell pepper and therefore does not lead to clear rejection or acceptance. However, Martin et al.[(22)] classified 47% of the vegetables as more intense in sourness, bitterness, umami and saltiness compared to other food classes. These vegetables were consumed cold with vinaigrette, indicating that sourness enhancement is commonly used for the preparation of vegetables. In our study, participants who indicated using seasonings for the preparation of cucumber and green bell pepper mentioned that they typically add vinegar, lemon and yoghurt (next to salt and pepper) to vegetables (data not shown), which are sour. This indicates that the use of sour seasonings is not uncommon for the preparation of these vegetables.

Consumers often apply some form of preparation and seasoning before consumption of vegetables, as was also reported by parents in this study. These preparations lead to more complex taste alterations of vegetables than the enhancement of a single taste modality (sweetness or sourness) by addition of a single tastant. Adding a single tastant to a vegetable might not be congruent with expectations. Possibly more complex taste, flavour and texture combinations are needed to increase acceptance of vegetables further.

Comparison of influence of taste enhancement on acceptance of vegetable purees in sweetness and sourness likers and non-likers

Of the participating children, a majority was classified as sweetness likers (cucumber 77.1%, green bell pepper 58.6%). Acceptance of vegetable purees with added concentrations of sucrose was significantly higher for sweetness likers than for sweetness non-likers in both vegetables. Although most children accepted sucrose addition in vegetables, this did not apply to all children.

For cucumber, 50.0% of the participating children were classified as sourness likers, while for green bell pepper 44.3% were sourness likers. For children who were classified as sourness likers, adding citric acid did not increase acceptance compared to unmodified purees. Sourness likers did accept most citric acid additions better than sourness non-likers. Classification of the sourness likers group was based on positive acceptance scores for medium and high concentrations of added citric acid. However, results indicate that this group could better be called "sour indifferent". Thus, sour addition had no positive effect on acceptance for a subset of children who liked sourness. However, it needs to be taken into account that the number of children in the segmentation analysis was small and may have been underpowered. Further research with a larger samples size would be recommended. In green bell pepper, sourness non-likers accepted low citric acid concentration significantly better than the unmodified puree, which was unexpected and we cannot offer a suitable explanation.

Comparison of influence of taste enhancement on acceptance of vegetable purees in children and adults

Van Stokkom et al. [(15)] assessed the effect of taste enhancement on acceptance of vegetables by adults (18-65 years) using the same vegetable purees (cucumber and green bell pepper), preparation methods and tastant concentrations as in the current study with children (5-6 years). In adults, mean acceptance of unmodified green bell pepper puree measured using a 9-point scale (-0.4 ± 1.8) was slightly lower than acceptance of unmodified cucumber (-0.1 ± 1.5). In the current study with children, using a 5-point category scale, there was a larger difference in acceptance of unmodified cucumber and green bell pepper purees (-0.4 ± 1.6 vs. 0.2 ± 1.5). This suggests that green bell pepper was less accepted by children than adults.

Sucrose addition increased acceptance of vegetable purees significantly both in adults and children. However, there are some differences between adults and children. In adults, a low concentration of added sucrose increased acceptance of cucumber purees, whereas medium and high concentrations did not. In children, medium and high concentrations of added sucrose were needed to achieve significant increase of acceptance of cucumber purees. This means that for children higher concentrations of added sucrose were needed to increase acceptance of cucumber purees compared to adults which is in agreement with previous studies demonstrating that children prefer higher sucrose concentrations in non-bitter food products (water, lemonade, pudding) compared to adults [(7, 17, 20)]. For green bell pepper purees, medium and high concentrations of added sucrose increased acceptance of green bell pepper purees significantly in adults, whereas low concentration of added sucrose did not. While in the current study, children accepted green bell pepper purees with low and high concentrations of added sucrose significantly better than unmodified purees. This means that for children lower concentrations of added sucrose already led to an increase in acceptance of green bell pepper puree compared to adults. As children might have heightened bitterness sensitivity compared to adults [(35)], bitterness might have been suppressed at lower sucrose concentrations than in adults, leading to an increase in acceptance by addition of a low sucrose concentration in children but not in adults. The sensitivity for other taste modalities might also differ between children and adults. Vennerød et al.[(36)] recently showed that between 4-6 years, sensitivity for sweetness decreases while sensitivity for sourness increases.

In adults, citric acid addition did not influence acceptance of cucumber and green bell pepper purees [(15)]. Liem and Mennella[(21)] showed that a larger proportion of children prefer high sourness intensities of gelatine gels than adults. However, citric acid addition also did not increase acceptance compared to unmodified vegetable purees in the current study with children, also not for children classified as sourness likers. Enhancing sourness might be effective in increasing acceptance of gelatine gels in children but not in vegetables. Gelatine gels might be associated with candy, sweets or drops, so foods in which sourness is typical and common. While using sour seasonings such as vinaigrettes and dressings for the preparation of vegetables is common, citric acid addition did not increase acceptance of cucumber and green bell pepper puree in adults and children.

Perception and discrimination of taste often differs between adults and children [(17, 18, 37)]. In van Stokkom et al. [(15)] adults were able to discriminate between most concentrations of added tastants in cucumber and green bell pepper purees. We did not quantify in the current study how children perceived the taste intensity of the different vegetable purees and how well children were able to discriminate between the three concentrations of both tastants as taste intensity of the vegetable purees was not quantified with children. Differences in perception and discrimination capability between adults and children might depend on the complexity of the stimulus. The latter has been suggested by James et al.[34] where children could discriminate between different concentrations of sucrose in water similar as adults, but not between different concentrations of sucrose in orange drinks.

Vegetable purees and use of sucrose

In the current study, we used vegetable purees to be able to control the concentration of added tastants. Presenting vegetables as a puree resulted in a different texture than in which the vegetables are commonly consumed. Although children had to have consumed cucumber and bell pepper at least once to be included in this study, puree is not a common way to consume these vegetables. Preparation method and familiarity are important factors contributing to food preferences [25, 26, 38-42]. It is not known to what extent pureeing affected acceptance scores. However, all vegetables studied were pureed and compared to one another. We used raw vegetables to eliminate possible effects of preparation methods on taste. More importantly, by pureeing the vegetables, we ensured that each bite contained the same concentration of added tastant for all samples.

Children that have a strong dislike for vegetables are less likely to take part in a vegetable tasting study. Therefore, it is not surprising that children who participated in the study consumed more vegetables than the national average amongst 4-8 years olds which is 1.2 serves [5]. It might be more difficult to increase acceptance in a population that already consumes and accepts vegetables. Hence, the effect of added tastants on acceptance might be larger for children that have a stronger dislike for vegetables. Future studies could attempt to include children with a stronger dislike for vegetables. For exploring differences in food consumption between children who do and who do not like sweetness or sourness, we recommend future studies to collect food consumption data.

Although acceptance of an initially not well accepted vegetable, green bell pepper, increased by addition of sucrose, we stress that we do not wish to promote the use of sucrose in the preparation of vegetables. Current consumption patterns already exceed the recommended intakes of sugars. Only 29% of Australian children (4-8 yrs) do not exceed dietary guidelines for sugar consumption [5]. Sweetness enhancement of vegetables by addition of sucrose should be avoided. Offering disliked vegetables in combination with other vegetables or foods with naturally sweet taste profiles might be a healthy means to enhance sweetness and increase acceptance of disliked vegetables.

Conclusions

Sweetness enhancement by addition of sucrose can increase acceptance of vegetable purees in 5-6-year-old children, even for a vegetable that was initially not well accepted (green bell pepper). The effect of tastant addition on acceptance of vegetable purees by children differed between concentrations of added tastants and vegetable type. For cucumber purees, at least 5% of added sucrose was necessary to increase acceptance by children while for green bell pepper purees 2% of added sucrose was sufficient to increase acceptance. Sourness enhancement by addition of citric acid did not have a significant effect on acceptance in both vegetable purees in children. A majority of children have a higher acceptance of sucrose addition in vegetables (cucumber 77.1%, green bell pepper 58.6%) and a smaller proportion of children accept citric acid addition better in vegetables (cucumber 50.0%, green bell pepper 44.3%). This study highlights the challenge to get children to better accept vegetables. Although sucrose addition increased acceptance, acceptance was still not very high. It is possibly that more complex tastes, flavours and textures are needed to increase acceptance further. Adding sucrose to vegetables to increase acceptance should be avoided as from a health perspective extra sugar consumption should be discouraged. However, for a smaller subset of children enhancing sourness of vegetables might be an alternative strategy to increase acceptance.

Acknowledgements
This study was carried out with the financial support of the Centre of Expertise Food and Centre of Expertise Greenport (Ministry of Economic Affairs), The Netherlands. Jessica Heffernan is acknowledged for her technical assistance in the study.

References

1. Alexy U, Sichert-Hellert W, Kersting M. Fifteen-year time trends in energy and macronutrient intake in German children and adolescents: results of the DONALD study. *British Journal of Nutrition*. 2002;87(6):595-604.
2. Bowen J, Klose D, Syrette J, Noakes M. Australian children's vegetable intake: findings of the 2007 Australian children's national nutrition and physical activity survey. 2009 (VG07160).
3. Dennison BA, Rockwell HL, Baker SL. Fruit and vegetable intake in young children. *Journal of the American College of Nutrition.* 1998;17(4):371-8.
4. Van Rossum CT, De Boer EJ, Ocke MC. Dutch National Food Consumption Survey-Young Children 2005/2006. *Annals of Nutrition and Metabolism.* 2009;55:521-2.
5. Commonwealth Scientific Industrial Research Organisation. 2007 Australian National children's nutrition and physical activity survey: Main findings. Canberra, Australia; 2008.
6. Nicklaus S. Development of food variety in children. *Appetite.* 2009;52(1):253-5.
7. Mennella JA, Finkbeiner S, Lipchock SV, Hwang LD, Reed DR. Preferences for salty and sweet tastes are elevated and related to each other during childhood. *PLoS One.* 2014;9(3):e92201.
8. Brug J, Tak NI, te Velde SJ, Bere E, de Bourdeaudhuij I. Taste preferences, liking and other factors related to fruit and vegetable intakes among schoolchildren: results from observational studies. *British Journal of Nutrition.* 2008;99 Suppl 1:S7-S14.
9. Poelman AAM, Delahunty CM, de Graaf C. Vegetables and other core food groups: A comparison of key flavour and texture properties. *Food Quality and Preference.* 2017;56, Part A:1-7.
10. Van Stokkom VL, Teo PS, Mars M, de Graaf C, van Kooten O, Stieger M. Taste intensities of ten vegetables commonly consumed in the Netherlands. *Food Research International.* 2016;87:34-41.
11. Liem DG, de Graaf C. Sweet and sour preferences in young children and adults: role of repeated exposure. *Physiology & Behavior.* 2004;83(3):421-9.
12. Liem DG, Westerbeek A, Wolterink S, Kok FJ, de Graaf C. Sour taste preferences of children relate to preference for novel and intense stimuli. *Chemical Senses.* 2004;29(8):713-20.
13. Capaldi ED, Privitera GJ. Decreasing dislike for sour and bitter in children and adults. *Appetite.* 2008;50(1):139-45.
14. Bouhlal S, Chabanet C, Issanchou S, Nicklaus S. Salt content impacts food preferences and intake among children. *PLoS One.* 2013;8(1):e53971.
15. Van Stokkom VL, de Graaf C, van Kooten O, Stieger M. Effect of taste enhancement on consumer acceptance of pureed cucumber and green capsicum. *Journal of Food Science.* 2018; 83(10):2578-2585.
16. Sharafi M, Hayes JE, Duffy VB. Masking Vegetable Bitterness to Improve Palatability Depends on Vegetable Type and Taste Phenotype. *Chemosensory Perception.* 2013;6(1):8-19.

17. De Graaf C, Zandstra EH. Sweetness intensity and pleasantness in children, adolescents, and adults. *Physiology & Behavior.* 1999;67(4):513-20.
18. James CE, Laing DG, Oram N. A comparison of the ability of 8-9-year-old children and adults to detect taste stimuli. *Physiology & Behavior.* 1997;62(1):193-7.
19. Hoffman AC, Salgado RV, Dresler C, Faller RW, Bartlett C. Flavour preferences in youth versus adults: a review. *Tobacco Control.* 2016;25(Suppl 2):ii32-ii9.
20. Mennella JA, Finkbeiner S, Reed DR. The proof is in the pudding: children prefer lower fat but higher sugar than do mothers. *International Journal of Obesity.* 2012;36(10):1285-91.
21. Liem DG, Mennella JA. Heightened sour preferences during childhood. *Chemical Senses.* 2003;28(2):173-80.
22. Martin C, Visalli M, Lange C, Schlich P, Issanchou S. Creation of a food taste database using an in-home "taste" profile method. *Food Quality and Preference.* 2014;36:70-80.
23. Guthrie CA, Rapoport L, Wardle J. Young children's food preferences: a comparison of three modalities of food stimuli. *Appetite.* 2000;35(1):73-7.
24. Havermans RC, Jansen A. Increasing children's liking of vegetables through flavour-flavour learning. *Appetite.* 2007;48(2):259-62.
25. Poelman AAM, Delahunty CM, de Graaf C. Cooking time but not cooking method affects children's acceptance of Brassica vegetables. *Food Quality and Preference.* 2013;28(2):441-8.
26. Poelman AAM, Delahunty CM. The effect of preparation method and typicality of colour on children's acceptance for vegetables. *Food Quality and Preference.* 2011;22:355-64.
27. Cooke L, Carnell S, Wardle J. Food neophobia and mealtime food consumption in 4-5 year old children. *International Journal of Behavioral Nutrition and Physical Activity.* 2006;3:14.
28. Pliner P. Development of measures of food neophobia in children. *Appetite.* 1994;23(2):147-63.
29. Field A. Discovering statistics using SPSS. 3rd ed. London: SAGE Publications LtD; 2009.
30. National Health and Medical Research Council. Australian Dietary Guidelines. Canberra, Australia; 2013.
31. Birch LL. Development of food preferences. *Annual Review of Nutrition.* 1999;19:41-62.
32. Drewnowski A. Taste preferences and food intake. *Annual Review of Nutrition.* 1997;17:237-53.
33. Keast SJR, Breslin PAS. An overview of binary taste-taste interactions. *Food Quality and Preference.* 2003;14(2):111-24.
34. James CE, Laing DG, Oram N, Hutchinson I. Perception of sweetness in simple and complex taste stimuli by adults and children. *Chemical Senses.* 1999;24(3):281-7.
35. Mennella JA, Reiter AR, Daniels LM. Vegetable and Fruit Acceptance during Infancy: Impact of Ontogeny, Genetics, and Early Experiences. *Advances in Nutrition.* 2016;7(1):211s-9s.
36. Vennerød FFF, Nicklaus S, Lien N, Almli VL. The development of basic taste sensitivity and preferences in children. *Appetite.* 2018;127:130-7.

37. Oram N, Laing DG, Freeman MH, Hutchinson I. Analysis of taste mixtures by adults and children. *Developmental Psychobiology.* 2001;38(1):67-77.
38. Cooke L, Wardle J. Age and gender differences in children's food preferences. *British Journal of Nutrition.* 2005;93(5):741-6.
39. Bongoni R, Stieger M, Dekker M, Steenbekkers B, Verkerk R. Sensory and health properties of steamed and boiled carrots (Daucus carota ssp sativus). *International Journal of Food Sciences and Nutrition.* 2014;65(7):809-15.
40. Bongoni R, Verkerk R, Steenbekkers B, Dekker M, Stieger M. Evaluation of Different Cooking Conditions on Broccoli (Brassica oleracea var. italica) to Improve the Nutritional Value and Consumer Acceptance. *Plant Foods for Human Nutrition.* 2014;69(3):228-34.
41. Zeinstra GG, Koelen MA, Kok FJ, de Graaf C. The influence of preparation method on children's liking for vegetables. *Food Quality and Preference*. 2010;21(8):906-14.
42. Poelman AAM, Delahunty CM, de Graaf C. Vegetable preparation practices for 5-6 years old Australian children as reported by their parents; relationships with liking and consumption. *Food Quality and Preference*. 2015;42:20-6.

Chapter 6

Combining vegetables with other vegetables influences sensory properties and can increase acceptance

Vera L. van Stokkom, Cees de Graaf, Shuna Wang, Olaf van Kooten, Markus Stieger

Based on publication in Food Quality and Preference, 2019. 72: p. 147-158

Abstract

Enhancing sweetness of vegetables by addition of sucrose can increase acceptance but is not necessarily desirable. An alternative strategy could be to combine vegetables with other vegetables. By offering combinations of vegetables it might be possible to suppress bitterness, enhance sweetness and provide texture variety leading to increased acceptance. The aim of this study was to determine the influence of combining vegetables with other vegetables on sensory properties and acceptance. Carrot (sweet), cucumber (neutral), green bell pepper (bitter) and red bell pepper (sour) were assessed individually and in combination with the other three vegetables in two mixing ratios (1:2 and 2:1). Additionally, four combinations of three vegetables (mixing ratio 1:1:1) were assessed. A trained panel (n = 24) evaluated taste, flavour and texture and a consumer panel (n = 83) evaluated acceptance of all vegetables and combinations. Combining vegetables influenced sensory properties. Combining green bell pepper with carrot (1:2 and 2:1), increased sweetness and decreased bitterness. Combining cucumber, carrot or red bell pepper with green bell pepper (1:2) increased bitterness. Cucumber was the most accepted vegetable followed by carrot, red bell pepper and green bell pepper. Acceptance of vegetable combinations can change compared to individual vegetables depending on vegetable type and mixing ratio. Three of 16 vegetable combinations had higher acceptance compared to the least accepted vegetable in the combination and similar acceptance as the other, more accepted vegetable in the combination. These findings suggest that strategies aimed at increasing vegetable consumption can be devised using combinations of vegetables.

Introduction

Taste, especially bitterness, can contribute to low acceptance and low consumption of vegetables. Vegetables contain phytochemicals which can be beneficial for health, however some can be bitter [1]. As humans generally do not like bitter taste [2, 3], the food industry started to decrease bitterness of some vegetables by cultivation [1, 4], which might be accompanied by a decrease of phytochemical content. It has been suggested that there should be more focus on increasing phytochemical content of vegetables as this could be beneficial for health [1, 5]. However, a higher phytochemical content can lead to higher bitterness [6] and this might decrease consumer acceptance of vegetables [7-9].

While it is a challenge to develop healthy and highly palatable vegetables, considerable efforts have been made in recent years. There have been numerous studies evaluating the effect of taste modifications on acceptance of vegetables in adults and children. Enhancing taste of foods such as water, lemonade and gelatine gels by addition of sucrose or citric acid can increase acceptance [10-12]. Sucrose addition can reduce initial dislike of bitter grapefruit juice [13]. In vegetables, taste modifications can also increase acceptance. Bouhlal et al.[14] showed that adding sodium chloride to green beans can increase children's green beans intake. Van Stokkom et al. [15, 16] showed that addition of sucrose to vegetables increased sweetness and consequently increased acceptance of a neutral tasting vegetable (cucumber) and a slightly bitter tasting vegetable (green bell pepper) in adults and children. However, even though sucrose addition can increase acceptance of vegetables, adding sucrose to vegetables is not desirable as the intake of sugars should be reduced [17]. Sharafi et al.[18] showed that addition of sweeteners to vegetables can also suppress bitterness and increase acceptance. However, taste modifications by addition of sweeteners might also be not desirable as sweetness might be dissociated from energy and therefore alters taste response and possibly appetite [19].

An alternative strategy to modify taste properties of vegetables to enhance acceptance could be to combine different vegetables with each other. By offering combinations of vegetables it might be possible to suppress bitterness and enhance sweetness leading to higher acceptance of the vegetable combination compared to the individual vegetables. We hypothesize that instead of adding sucrose to bitter vegetables, using a sweet vegetable in vegetable combinations, such as carrot [20] might lead to higher sweetness, lower bitterness and higher acceptance of the vegetable combination compared to an individual bitter tasting vegetable. In addition to taste, texture influences acceptance of foods and vegetables [21]. Zeinstra et al.[22] showed that children prefer crunchiness in vegetables, so combining a crunchy vegetable with a not crunchy vegetable might increase acceptance. De Moura[23] suggested that even disliked vegetable might become acceptable when they are part of a tasty mixture. Thus, we hypothesize that acceptance of vegetable combinations is higher than acceptance of disliked vegetables and possibly of liked vegetables. The aim of this study was to determine the influence of combining vegetables with other vegetables on sensory properties and acceptance.

Methods

Vegetables

Carrot (*Daucus carrotota)*, cucumber (*Cucumberumis sativus*), green bell pepper and red bell pepper (*Capsicum annuum)* were used. Vegetable selection was based on the following criteria: vegetables should be able to be consumed raw, vegetables should be commonly consumed in the Netherlands [(24)] and vegetables should have different taste profiles. Van Stokkom et al.[(20)] and Poelman et al.[(25)] determined taste profiles of vegetables using the modified Spectrum Method. They demonstrated that carrot had a sweet taste profile (high sweetness and low intensities for other taste modalities), cucumber a fairly neutral taste profile (low intensities for all taste modalities), green bell pepper a bitter taste profile (high bitterness and low intensities for other taste modalities), and red bell pepper a slightly sour and sweet taste profile (moderate sweetness and sourness and low intensities for other taste modalities). Carrot (variety Evora, Spain) was obtained from a local retailer for the sensory evaluation, and from Bakker Barendrecht, Ridderkerk, The Netherlands for the hedonic evaluation. For cucumber, different varieties were used for the sensory and hedonic evaluation due to seasonal variation in availability. In consultation with the cultivator, another similar variety from the same cross-breeding program was selected. Cucumber (variety Proloog, The Netherlands for sensory evaluation, Variety Lausanna for hedonic evaluation), green bell pepper and red bell pepper (variety Keessie, The Netherlands) were obtained from Personal Vision, Bleiswijk, The Netherlands.

Vegetable preparation

Vegetables were stored for max. 48 hours at 15°C before preparation. Carrot was pealed, the other vegetables were not. After rinsing the vegetables with water, they were cut into cubes of 5x5x5 mm (brunoise) and used within 4 hours. After vegetables were cut, they were stored at 7°C. One hour prior to consumption vegetable cubes were removed from the refrigerator and kept at room temperature. Carrot, cucumber, green bell pepper and red bell pepper were assessed individually and in combinations with each other. Each vegetable was combined with any of the other three vegetables in two mixing ratios (1:2 and 2:1). All samples provided to participants were composed of six vegetable cubes. The mixing ratio was based on number of cubes used. For example, the sample carrot-cucumber (2:1) contained four carrot cubes and two cucumber cubes. Additionally, all vegetables were offered in combinations of three vegetables in a mixing ratio of 1:1:1 corresponding to two cubes per vegetable. This resulted in 20 vegetables samples (Table 1).

Table 1. Overview of individual vegetables and vegetable combinations. All samples provided to participants were composed of six vegetable cubes (5x5x5 mm each cube). The mixing ratio corresponds to number of cubes per vegetable.

No.	Ratio	Composition		
		Individual vegetables	**Variety**	
1	NA	Carrot	Evora (Spain)	
2	NA	Cucumber	Proloog/Lausanna (The Netherlands)	
3	NA	Green bell pepper	Keessie (The Netherlands)	
4	NA	Red bell pepper	Keessie (The Netherlands)	
		Combinations of two vegetables		
5	2:1	Carrot	Cucumber	
6	1:2	Carrot	Cucumber	
7	2:1	Carrot	Green bell pepper	
8	1:2	Carrot	Green bell pepper	
9	2:1	Carrot	Red bell pepper	
10	1:2	Carrot	Red bell pepper	
11	2:1	Cucumber	Green bell pepper	
12	1:2	Cucumber	Green bell pepper	
13	2:1	Cucumber	Red bell pepper	
14	1:2	Cucumber	Red bell pepper	
15	2:1	Green bell pepper	Red bell pepper	
16	1:2	Green bell pepper	Red bell pepper	
		Combinations of three vegetables		
17	1:1:1	Carrot	Cucumber	Green bell pepper
18	1:1:1	Carrot	Cucumber	Red bell pepper
19	1:1:1	Carrot	Green bell pepper	Red bell pepper
20	1:1:1	Cucumber	Green bell pepper	Red bell pepper

Sensory evaluation

Sensory test rooms of Wageningen University & Research, Business Unit Greenhouse Horticulture, Bleiswijk, The Netherlands, were used for sensory evaluation. Quantitative Descriptive Analysis (QDA) was carried out by a trained panel of 24 participants (58.5 ± 10.2 years, 19 female, 6 male) experienced in the sensory evaluation of fruits and vegetables such as melon, tomatoes, bell pepper and beans. On average, panel members take part in 1-2 sessions per week of descriptive sensory profiling of fruits and vegetables. In addition to the descriptive analysis sessions, panel members follow about 15 sessions per year for product and attribute training. For the sensory evaluation of this study, panel members came to the test location twice. On each test day, ten samples (randomly divided over the two test days) were evaluated during one session of 45 min. Each panel member received the samples in a random order. Samples were offered in plastic cups of 25 ml. Each sample contained six vegetable cubes (5x5x5mm each cube). Panel members were instructed to always put all six vegetable cubes on a spoon and assess sensory properties. A second sample was available for tasting, if needed. Twelve sensory attributes describing taste, flavour and texture of vegetables were assessed: firmness, crunchiness, juiciness, chewiness, sweetness, sourness, bitterness, umami, saltiness, flavour, astringent and filming. A 100-mm line scale anchored at the ends of the line with 'weak' and 'strong' was used. Attributes were selected based on experience of the panel leaders. Panel members were familiar with all attributes that were included from previous trainings and descriptive evaluations. Between each sample was a break of 20 s during which panel members neutralized their taste with water. After five samples, a break of 5 min followed. The following day, the panel members returned for the second session. Sessions took place between 10.00 am and 06.00 pm.

Hedonic evaluation

For the hedonic evaluation, naïve consumers were recruited at the University of Applied Sciences, Delft, The Netherlands. Participants were included when they were at least 18 years, not pregnant or breastfeeding and in good general health (self-reported). Participants were excluded when they had any allergies for vegetables. Participants had to come to the test location twice on separate days. Sessions took place between 12.00 am and 5.00 pm. Participants were asked not to eat or drink (except water) at least 30 min prior to the test. For each participant all 20 samples were randomly divided over two sessions of 20 min. Within both sessions, the order of samples was randomized. All samples were coded with three-digit randomized numbers. Participants were seated in individual booths. During the first session participants received general instructions and completed a questionnaire to obtain general participant information (e.g. age, gender, educational level) and to assess vegetable consumption frequency. In total, n = 83 participants (26.5 ± 11.8 years, 45 female, 38 male) participated in the study. None of the participants participating in the hedonic evaluation participated in the sensory evaluation. Most participants (72%) had at least an intermediate education level (high school). All target vegetables were consumed at least monthly by most participants (80%). Vegetable samples consisted of six cubes (5x5x5 mm each cube) and were offered simultaneously on a tray in non-transparent plastic containers covered with a lid. Participants were instructed to remove the lid of the sample they had to assess, and to taste all six cubes simultaneously using the spoon provided with each sample. Participants rated acceptance of the vegetables using a 9-point hedonic scale ranging from 'extremely like' to 'extremely dislike'. After each sample, a 20 s break followed during which participants were instructed to neutralize their palate with water.

Statistical data analyses

Statistical data analyses were performed using IBM SPSS Statistics version 24. A significance level of $p < 0.05$ was used. Sensory and hedonic data were analysed individually and together. For the sensory data, means and standard deviations for each attribute for each sample were calculated. To determine significant differences between samples, MANOVA was used. Four separate analyses of variance were conducted, for samples containing carrot, samples containing cucumber, samples containing green bell pepper and samples containing red bell pepper. This means that 10 samples were included per analysis, one individual vegetable and nine combinations containing that vegetable. Panel members were included in the model as random effect and sample as fixed effect. Tukey post-hoc test was used to further investigate significant differences between samples. Principle component analysis (PCA) was performed on the covariance matrix of the mean attribute scores using varimax rotation. Products were grouped based on cluster analysis. For the hedonic data, four analyses of variance were conducted, one per individual vegetable and combinations containing that vegetables. This resulted in 10 samples per analysis of variance. Participants were included in the model as random effect and sample as fixed effect. Tukey post-hoc test was used to investigate significant differences in acceptance.

To link the sensory to the hedonic evaluation data, external preference mapping was used. Individual acceptance scores were related to sensory evaluation data by external preference mapping. The external preference map was created using a quadratic model with EyeOpenR® 4.9.6.

Results

Sensory evaluation

The mean intensity scores of all sensory attributes of all individual vegetable and the combinations containing that vegetable are presented in Appendix C. Compared to carrot as individual vegetable, sweetness was significantly lower in the combinations carrot-cucumber (1:2), carrot-green bell pepper (1:2), carrot-cucumber-green bell pepper (1:1:1) and carrot-green bell pepper-red bell pepper (1:1:1). Sourness was significantly higher in the combinations carrot-green bell pepper (1:2), carrot-red bell pepper (1:2) and carrot-green bell pepper-red bell pepper (1:1:1). Bitterness was significantly higher in the combinations carrot-green bell pepper (1:2) and carrot-red bell pepper (1:2). Juiciness was significantly higher in the combinations carrot-cucumber-red bell pepper (1:1:1) and carrot-green bell pepper-red bell pepper (1:1:1) (Table C1, Appendix C).

Compared to cucumber as individual vegetable, firmness and crunchiness were significantly higher in the combination cucumber-carrot (1:2). Bitterness was significantly higher in the combinations cucumber-green bell pepper (1:2). Flavour was significantly higher in the combinations cucumber-green bell pepper (1:2), cucumber-red bell pepper (1:2) and cucumber-carrot-red bell pepper (1:1:1) (Table C2, Appendix C).

Compared to green bell pepper as individual vegetable, firmness was significantly lower in the combination green bell pepper-cucumber (1:2). Crunchiness was significantly lower in the combinations green bell pepper-red bell pepper (1:2) and green bell pepper-cucumber-red bell pepper (1:1:1). Juiciness was significantly lower in the combination green bell pepper-carrot (2:1) and sweetness was significantly higher in the combinations green bell pepper-carrot (1:2 and 2:1), green bell pepper-red bell pepper (1:2), green bell pepper-carrot-cucumber (1:1:1) and green-bell pepper-carrot-red bell pepper (1:1:1). Bitterness was significantly lower in the combinations green bell pepper-carrot (2:1 and 1:2), green bell pepper-cucumber (1:2), green bell pepper-carrot-cucumber (1:1:1) and green bell pepper-carrot-red bell pepper (1:1:1) (Table C3, Appendix C).

Compared to red bell pepper as individual vegetable, crunchiness was significantly higher in the combination red bell pepper-carrot (1:2). Juiciness was significantly lower in the combinations red bell pepper-carrot (2:1 and 1:2), red bell pepper-green bell pepper (1:2) and red bell pepper-carrot-green bell pepper (1:1:1). Bitterness was significantly higher in the combination red bell pepper-green bell pepper (1:2) (Table C4, Appendix C).

Principle component analysis of QDA data

The biplot representation of the PCA and visualization of three vegetable clusters are shown in Figure 1. The first component accounted for 57.2% of the variance and the second component for 19.1%, in total explaining 76.3% of the variance between samples. Vegetables were grouped into three clusters. Cluster 1 can be described as bitter and not sweet containing green bell pepper, cucumber-green bell pepper (1:2) and green bell pepper-red bell pepper (2:1) (15% of all samples). Cluster 2 can be described as sour, juicy, not firm and not crispy containing most samples with cucumber and red bell pepper (40% of all samples). Cluster 3 can be described as sweet, not bitter, not sour, firm, crunchy and not juicy and contained all samples with carrot (45% of all samples) except for carrot-green bell pepper-red bell pepper (1:1:1) which was the only sample with carrot belonging to cluster 2.

Hedonic evaluation

Tables C1-C4, Appendix C summarize the mean acceptance of all vegetable samples. Cucumber and carrot were the most accepted vegetables, acceptance for red bell pepper was lower and acceptance for green pepper was the lowest. The mean differences in acceptance between individual vegetables and all combinations containing the vegetable are presented in Figure 2.

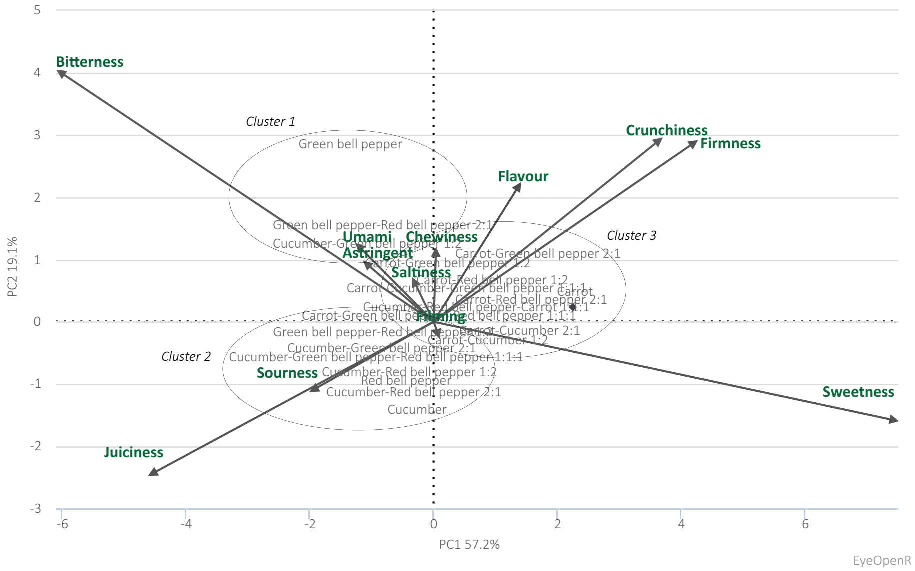
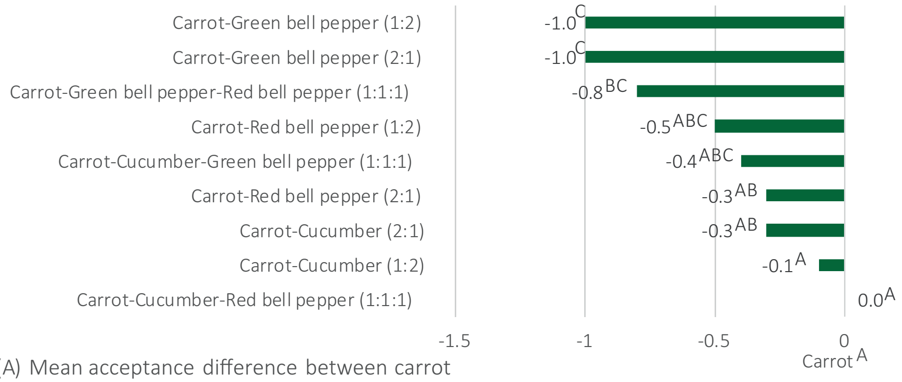


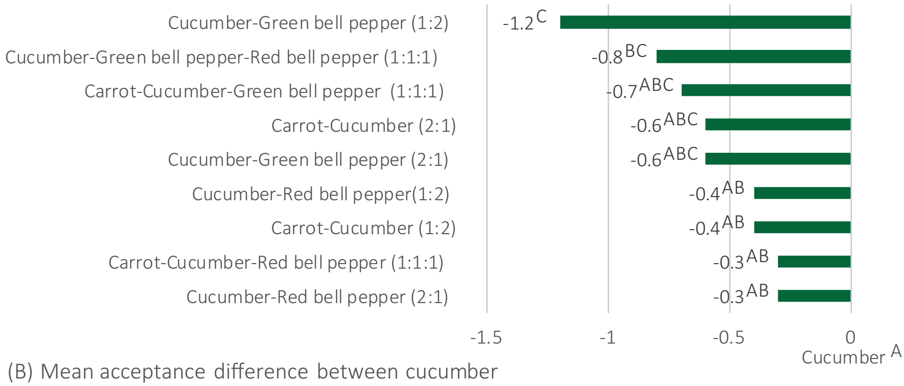
Figure 1. Biplot representation of the PCA covariance matrix of sensory attributes obtained by Quantitative Descriptive Analysis (*n* = 24 trained participants) of individual vegetables and all vegetable combinations together with visualization of three main clusters.

When carrot was combined with green bell pepper (1:2 and 2:1), acceptance of the vegetable combination was significantly lower compared to carrot and not significantly different compared to green bell pepper. Acceptance of the combination carrot-green bell pepper-red bell pepper (1:1:1) was significantly lower compared to carrot, but not significantly different compared to green bell pepper and red bell pepper. Acceptance of the combination cucumber-green bell pepper (1:2) was significantly lower than acceptance of cucumber and not significantly different from acceptance of green bell pepper. Acceptance of the combination cucumber-green bell pepper-red bell pepper (1:1:1) was significantly lower compared to cucumber, significantly higher compared to green bell pepper and not significantly different to red bell pepper.

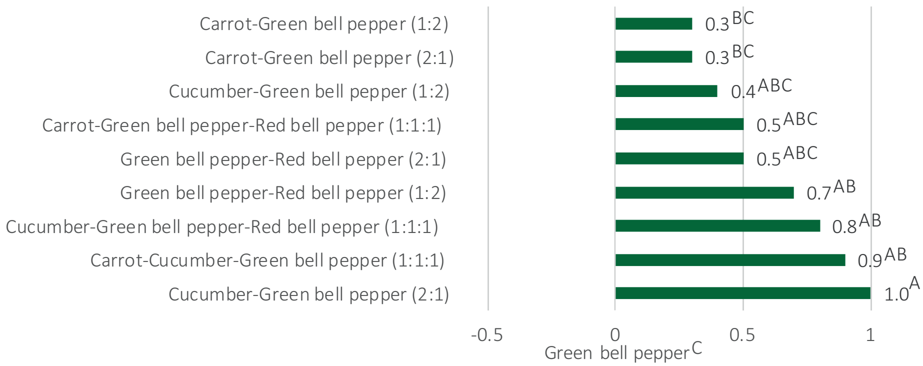
For three of 16 vegetable combinations, acceptance of the combination was higher than acceptance of the individual, least accepted vegetable in the combination and not significantly different from acceptance of the individual, more accepted vegetables in the combination. For the combination cucumber-green bell pepper (2:1), acceptance of the combination was not significantly different from acceptance of cucumber and significantly higher compared to green bell pepper. For the combination green bell pepper-red bell pepper (1:2), acceptance of the combination was significantly higher compared to acceptance of green bell pepper and did not significantly differ compared to acceptance of red bell pepper.



(A) Mean acceptance difference between carrot and combinations containing carrot



(B) Mean acceptance difference between cucumber and combinations containing cucumber



(C) Mean acceptance difference between green bell pepper and combinations containing green bell pepper

Figure 2 continues

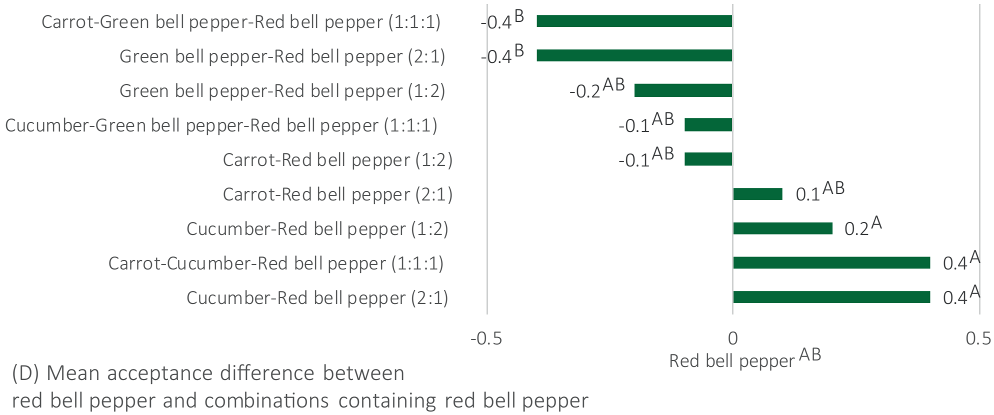


Figure 2. Mean difference in acceptance between carrot (A), cucumber (B), green bell pepper (C), red bell pepper (D) and combinations (mixing ratio) containing those vegetables (9 combinations per vegetable, n = 83 naïve consumers). Letters A-C indicate significant differences in acceptance between samples ($p < 0.05$).

For the combination green bell pepper-carrot-cucumber (1:1:1), acceptance of the combination was significantly higher compared to acceptance of green bell pepper and did not significantly differ from acceptance of carrot and cucumber.

External preference map of vegetables and combinations thereof

External preference mapping was used to link consumer acceptance with sensory properties of all vegetables and their combinations assessed by a trained panel (Figure 3). Red colour indicates high acceptance, yellow indicates neutral acceptance and blue indicates low acceptance. The sweetness-bitterness axis is the main driver for acceptance. The other sensory axis ranges from juiciness/sourness towards crunchiness/firmness. This sensory axis does not play a major role in acceptance of vegetable and tends to run parallel to the contour lines of acceptance in the external preference map. Samples containing carrot and cucumber are mostly in the red area indicating high acceptance. Green bell pepper is in the blue area indicating low acceptance, while carrot-green bell pepper (1:2 and 2:1) are in the area of neutral acceptance.

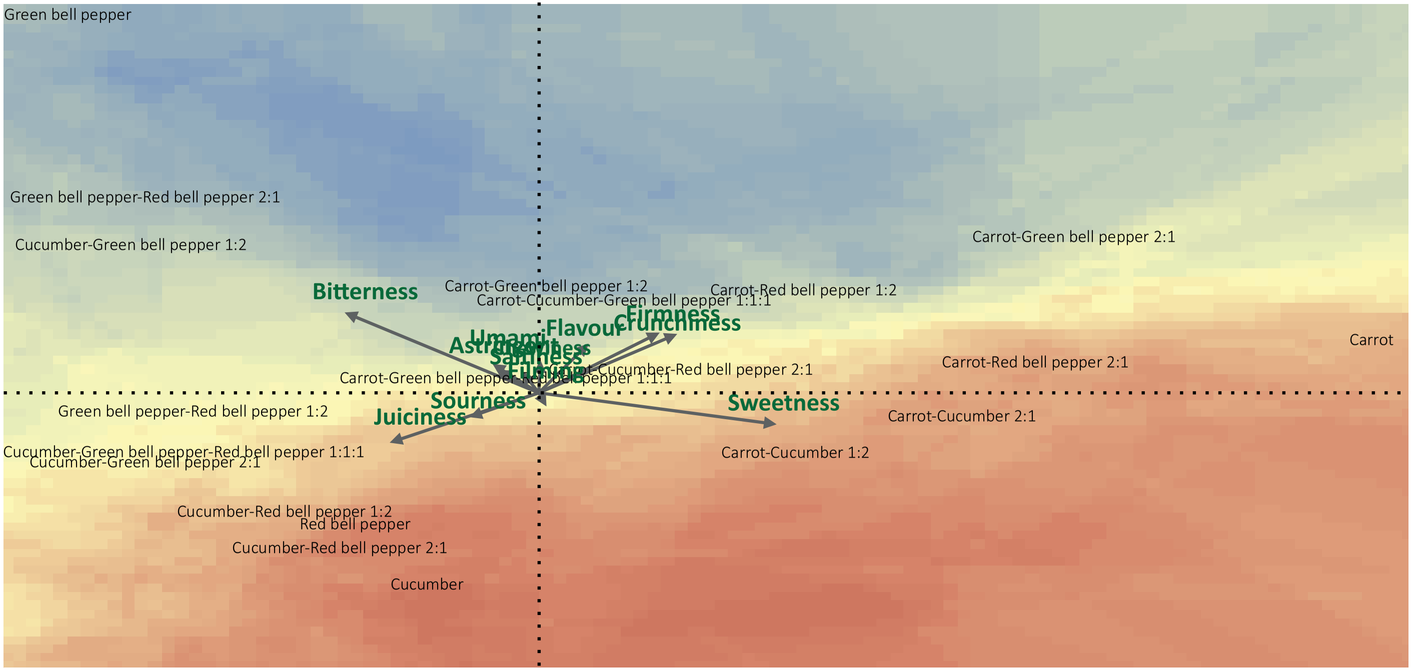


Figure 3. External preference map linking acceptance (*n* = 83 naïve consumers) to sensory properties (*n* = 24 trained participants, Quantitative Descriptive Analysis) of individual vegetables and vegetable combinations. Red colour indicates high acceptance, yellow indicates neutral acceptance and blue indicates low acceptance.

Discussion

Sweetness and bitterness as main drivers of vegetable acceptance
For three of 16 vegetable combinations, acceptance of the vegetable combination (cucumber-green bell pepper, 2:1; green bell pepper-red bell pepper, 1:2 and carrot-cucumber-green bell pepper, 1:1:1) was significantly higher than acceptance of the individual least accepted vegetable (green bell pepper) while acceptance did not change compared to the individual, more accepted vegetable(s) in the combination (carrot, cucumber and red bell pepper). Compared to green bell pepper, the combination green bell pepper-red bell pepper (1:2) was higher in sweetness and crunchiness and the combination green bell pepper-carrot-cucumber (1:1:1) was higher in sweetness and lower in bitterness. The combination cucumber-green bell pepper (2:1) was not significantly different in sweetness compared to both individual vegetables, but bitterness was significantly lower in the combination cucumber-green bell pepper (2:1). This demonstrates that by combining vegetables with each other sensory properties can be altered in the direction of enhanced sweetness and reduced bitterness. By those means combinations of vegetables can be obtained of which acceptance of the combination is higher than the acceptance of the least accepted individual vegetable and similar to acceptance of the other vegetables used in the combination.

The study shows that sweetness is mainly associated with high acceptance and bitterness with low acceptance. Because combining green bell pepper with carrot significantly increased sweetness and decreased bitterness (both mixing ratios), it is surprising that these combinations were not significantly more liked than green bell pepper. Dinehart et al.[9] concluded that in addition to bitterness, sweetness influences the acceptance of vegetables. However, in this study bitterness in the combination cucumber-green bell pepper (2:1) was lower, while sweetness was not significantly higher compared to green bell pepper. This was more accepted than higher sweetness of the combination carrot-green bell pepper (1:2, 2:1). Beauchamp[26] suggested that it is not only the sweet taste that is responsible for food selection or rejection, but the ratio between sweetness and bitterness. While the combination green bell pepper-carrot (1:2) was not better accepted, it might be that the balance between sweet and bitter was more appreciated in the combination with cucumber. Another potential explanation is that the combination carrot-green bell pepper was significantly lower in juiciness compared to green bell pepper as individual vegetable (only 2:1 ratio), however in the external preference map juiciness was not clearly associated with acceptance.

While the combination cucumber-green bell pepper (2:1) was better accepted than green bell pepper and equally accepted as cucumber, the ratio containing a majority of green bell pepper, (cucumber-green bell pepper 1:2) was less accepted than cucumber as individual vegetable. Additionally, combinations with carrot or cucumber and a majority of green bell pepper (1:2 ratio) were the least accepted combinations. In general, more green bell pepper in a combination, leads to higher bitterness. As green bell pepper is a more bitter vegetable, this was not surprising, but the findings indicate the importance of offering the vegetables in a balanced mixing ratio. Compared to red bell pepper as individual vegetable, acceptance of none of the combinations was significantly different. While some combinations of vegetables are better accepted than the least accepted vegetable while maintaining acceptance of the other vegetables used in the combination, it should be kept in mind when selecting vegetable combinations or developing vegetable products that adding too much of a bitter vegetable to the combination, acceptance of the combination might be lower than acceptance of otherwise well liked vegetables.

Influence of other taste and texture attributes on acceptance of vegetable combinations

Sourness was significantly higher for the combination carrot-red bell pepper (1:2) compared to carrot. Carrot was the least sour and red bell pepper the most sour vegetable, so this was not surprising. Whether sourness is a desired taste in vegetables or not remains unclear. In our study, sourness was not associated with acceptance. Previous studies showed that increasing sourness of vegetables does not increase but can decrease acceptance [15, 16]. In our study, combinations containing a vegetable with a slightly sour vegetable (red bell pepper), did not have high sourness intensities (range sourness 6.3-19.5) and did therefore not influence acceptance. This also applies for umami and saltiness: since intensities were low, they did not influence acceptance (range umami 9.8-20.3, range saltiness 5.1-10.3). Low intensities for umami and saltiness were not surprising as van Stokkom et al. (2016) showed that in general, vegetables have low taste intensities compared to other foods. Moreover, vegetables more known for having an umami taste, such as tomatoes [20], were not included in this study.

Werthmann et al.[27] showed that texture and not taste was important for children's liking or disliking of yoghurt. In a study by Nederkoorn et al.[21] sensing the texture of a food increased children's acceptance of foods with a similar texture. Texture also seems to play a role in vegetable acceptance as Zeinstra et al.[22] showed that vegetable liking was moderately associated with crunchiness. Therefore, several texture and mouthfeel attributes were included in the QDA profiling: firmness, crunchiness, juiciness, chewiness, astringent and filming. Carrot is a crunchy vegetable, more so than pepper and cucumber [28]. Combinations with carrot were often higher in firmness, crunchiness or both. Duffy et al.[7] found that raw carrots are most preferred, also indicating that for some vegetables crunchiness is a desired attribute as raw vegetables are more crunchy in general than boiled vegetables [29]. However, Poelman and Delahunty[30] showed that differences in texture as a result of different preparation methods were not associated with vegetable acceptance. In our study, none of the texture or mouthfeel attributes were strongly associated with acceptance, taste clearly had a stronger influence on acceptance. The only indication that texture might play a role was that juiciness of green bell pepper-carrot was significantly lower compared to green bell pepper as individual vegetable. As we only used raw vegetables in our study, differences in texture, such as crunchiness between carrot, cucumber, red- and green bell pepper were probably smaller than in other studies as in those studies different preparation methods were included which influence texture stronger [7, 22].

Future implications and limitations

Drewnowski and Gomez-Carneros[1] and Sun-Waterhouse and Wadhwa[5] suggested that vegetable consumption should be increased without decreasing the phytochemical content as phytochemicals have important health benefits. However, this is difficult as phytochemical content is associated with bitterness [6] and bitterness is associated with decreased acceptance of vegetables [7-9]. Taste enhancement, by addition of tastants can increase acceptance but might not be desirable from a health perspective. This study shows that sensory properties of vegetable combinations, including sweetness and bitterness, can be altered to increase acceptance of vegetable combinations compared to individual vegetables. Moreover, acceptance of vegetable combinations was higher compared to acceptance of an individual bitter vegetable. Thus, vegetable combinations can be more palatable compared to individual vegetables without adding sucrose, sweeteners or dips. Additionally, combining raw vegetables is easy to implement by both consumers and food industry. Results of this study can be used to develop combinations of raw vegetables with good consumer acceptance. To some extent, combinations of raw vegetables are already commercially available in supermarkets. For example, in the Netherlands raw bell peppers, cherry tomatoes and cucumber are commercially sold in combination. This indicates that offering combinations of raw vegetables in supermarkets is feasible which might contribute to increasing vegetable intake in the future.

It might be that the increase in acceptance of vegetable combinations is caused by offering a variety of vegetables compared to offering a single vegetable only. Mennella et al.[31] and Parizel et al.[32] showed that offering a variety of vegetables (green beans, zucchinis and spinach) in a meal can increase vegetable acceptance compared to offering only one vegetable. Additionally, Meengs et al.[33] and Bucher et al.[34] showed that offering a variety of vegetables can increase choice and intake, although this was not found by Parizel et al.[32]. In our study the hedonic evaluation shows that in general the combinations with three vegetables were not more accepted than the combination with two vegetables or even the individual vegetables indicating that the changes in acceptance observed in this study cannot be explained by a variety effect only.

As this study shows that sensory properties of vegetable combinations depend on the vegetables used in the combinations, we recommend similar studies including other bitter and sweet vegetables. The vegetables included in this study are all consumable raw. It would be interesting to investigate how acceptance is influenced in cooked, warm vegetables, so for example using Brussel sprouts or broccoli in combination with carrot or another sweet vegetable. Also, vegetables used in this study are commonly consumed. Future studies could explore how offering vegetable combinations can be used to increase acceptance of less commonly consumed vegetables. It would also be interesting to investigate the effect of adding herbs and spices to vegetable combinations on acceptance. Carney et al.[35] investigated the effect of three different herbs and spice blends on consumption of carrots and found that there is potential for improving vegetable intake in children who are sensitive to bitter taste.

From this study, it is not known how offering raw vegetable combinations influences food choice and intake. However, previous studies showed that offering a variety of vegetables can increase choice and intake [33, 34].

Conclusions

Combinations of vegetables can be more accepted than individual, not well accepted vegetables that are part of the combination, depending on type of vegetable and mixing ratio. Mainly sweetness and bitterness were associated with vegetable acceptance and texture attributes such as crunchiness, firmness and juiciness did not strongly influence acceptance. For three of 16 vegetable combinations acceptance was higher of the combination than acceptance of the least accepted vegetable while acceptance of these combinations remained unchanged compared to the other, more accepted vegetables. We conclude that combining vegetables with other vegetables influences sensory properties and that combinations can be more accepted than individual vegetables. This suggests that this approach can be followed for the development of fresh vegetable products and to devise strategies to increase vegetable consumption.

Acknowledgements
This study was carried out with the financial support of the Centre of Expertise Food (Ministry of Economic Affairs), The Netherlands.

References

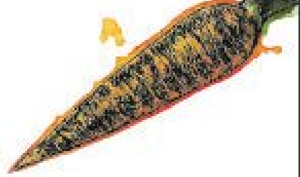
1. Drewnowski A, Gomez-Carneros C. Bitter taste, phytonutrients, and the consumer: a review. *American Journal of Clinical Nutrition.* 2000;72(6):1424-35.
2. Birch LL. Development of food preferences. *Annual Review of Nutrition.* 1999;19:41-62.
3. Beauchamp GK, Mennella JA. Flavor perception in human infants: development and functional significance. *Digestion.* 2011;83 Suppl 1:1-6.
4. Van Doorn HE. Development of vegetables with improved consumer quality: A case study in Brussels sprouts (Doctoral dissertation). *Wageningen University*, The Netherlands; 1999.
5. Sun-Waterhouse D, Wadhwa SS. Industry-Relevant Approaches for Minimising the Bitterness of Bioactive Compounds in Functional Foods: A Review. *Food and Bioprocess Technology.* 2013;6(3):607-27.
6. Breslin PA. An evolutionary perspective on food and human taste. *Current Biology.* 2013;23(9):R409-18.
7. Duffy EM, Hayes JE, Feeney EL. Understanding taste and texture perception to enhance vegetable acceptance. *Proceedings of the Nutrition Society.* 2017;76(Oce3):E67-E.
8. Donadini G, Fumi MD, Porretta S. Influence of preparation method on the hedonic response of preschoolers to raw, boiled or oven-baked vegetables. *LWT - Food Science and Technology.* 2012;49(2):282-92.
9. Dinehart ME, Hayes JE, Bartoshuk LM, Lanier SL, Duffy VB. Bitter taste markers explain variability in vegetable sweetness, bitterness, and intake. *Physiology & Behavior.* 2006;87(2):304-13.
10. Liem DG, Westerbeek A, Wolterink S, Kok FJ, de Graaf C. Sour taste preferences of children relate to preference for novel and intense stimuli. *Chemical Senses.* 2004;29(8):713-20.
11. De Graaf C, Zandstra EH. Sweetness intensity and pleasantness in children, adolescents, and adults. *Physiology & Behavior.* 1999;67(4):513-20.
12. Liem DG, Mennella JA. Heightened sour preferences during childhood. *Chemical Senses.* 2003;28(2):173-80.
13. Capaldi ED, Privitera GJ. Decreasing dislike for sour and bitter in children and adults. *Appetite.* 2008;50(1):139-45.
14. Bouhlal S, Chabanet C, Issanchou S, Nicklaus S. Salt content impacts food preferences and intake among children. *PLoS One.* 2013;8(1):e53971.
15. Van Stokkom VL, de Graaf C, van Kooten O, Stieger M. Effect of taste enhancement on consumer acceptance of pureed cucumber and green capsicum. Journal of Food Science. 2018;83(10):2578-2585.
16. Van Stokkom VL, Poelman AAA, de Graaf C, van Kooten O, Stieger M. Sweetness but not sourness enhancement increases acceptance of cucumber and green capsicum in children. *Appetite.* 2018;131:100-107.
17. World Health Organization. Guideline: sugars intake for adults and children. Geneva, Switserland; 2015.

18. Sharafi M, Hayes JE, Duffy VB. Masking Vegetable Bitterness to Improve Palatability Depends on Vegetable Type and Taste Phenotype. *Chemosensory Perception.* 2013;6(1):8-19.
19. Drewnowski A, Mennella JA, Johnson SL, Bellisle F. Sweetness and food preference. *Journal of Nutrition.* 2012;142(6):1142S-8S.
20. Van Stokkom VL, Teo PS, Mars M, de Graaf C, van Kooten O, Stieger M. Taste intensities of ten vegetables commonly consumed in the Netherlands. *Food Research International.* 2016;87:34-41.
21. Nederkoorn C, Theibetaen J, Tummers M, Roefs A. Taste the feeling or feel the tasting: Tactile exposure to food texture promotes food acceptance. *Appetite.* 2018;120:297-301.
22. Zeinstra GG, Koelen MA, Kok FJ, de Graaf C. The influence of preparation method on children's liking for vegetables. *Food Quality and Preference.* 2010;21(8):906-14.
23. De Moura SL. Determinants of food rejection amongst school children. *Appetite.* 2007;49(3):716-9.
24. Van Rossum CTM, Fransen HP, Verkaik-Kloosterman J, Buurma-Rethans EJM, Ocke MC. Dutch National Food Consumption Survey 2007-2010: diet of children and adults aged 7 to 69 years. *National Institute for Public Health and the Environment*, Bilthoven, The Netherlands; 2011 (350050006/2011).
25. Poelman AAM, Delahunty CM, de Graaf C. Vegetables and other core food groups: A comparison of key flavour and texture properties. *Food Quality and Preference.* 2017;56, Part A:1-7.
26. Beauchamp GK. Why do we like sweet taste: A bitter tale? *Physiology & Behavior.* 2016;164 (Pt B):432-7.
27. Werthmann J, Jansen A, Havermans R, Nederkoorn C, Kremers S, Roefs A. Bits and pieces. Food texture influences food acceptance in young children. *Appetite.* 2015;84:181-7.
28. Fillion L, Kilcast D. Consumer perception of crispness and crunchiness in fruit and vegetables. *Food Quality and Preference.* 2002;13:23-9.
29. Miglio C, Chiavaro E, Visconti A, Fogliano V, Pellegrini N. Effects of different cooking methods on nutritional and physicochemical characteristics of selected vegetables. *Journal of Agricultural and Food Chemistry.* 2008;56(1):139-47.
30. Poelman AAM, Delahunty CM. The effect of preparation method and typicality of colour on children's acceptance for vegetables. *Food Quality and Preference.* 2011;22:355-64.
31. Mennella JA, Nicklaus S, Jagolino AL, Yourshaw LM. Variety is the spice of life: strategies for promoting fruit and vegetable acceptance during infancy. *Physiology & Behavior.* 2008;94(1):29-38.
32. Parizel O, Labouré H, Marsset-Baglieri A, Fromentin G, Sulmont-Rossé C. Providing choice and/or variety during a meal: Impact on vegetable liking and intake. *Appetite.* 2017;108:391-8.
33. Meengs JS, Roe LS, Rolls BJ. Vegetable variety: an effective strategy to increase vegetable intake in adults. *Journal of the Academy for Nutrition and Dietetics.* 2012;112(8):1211-5.

34. Bucher T, Siegrist M, van der Horst K. Vegetable variety: an effective strategy to increase vegetable choice in children. *Public Health Nutrition.* 2014;17(6):1232-6.
35. Carney EM, Stein WM, Reigh NA, Gater FM, Bakke AJ, Hayes JE, et al. Increasing flavor variety with herbs and spices improves relative vegetable intake in children who are propylthiouracil (PROP) tasters relative to nontasters. *Physiology & Behavior.* 2018;188:48-57.

Chapter 7

General discussion



The aim of this thesis was to investigate the role of taste in the acceptance of vegetables. In this chapter, main findings of the thesis are summarized, and methodological considerations are discussed. Next, results of this thesis are placed in a broader context and practical implications and suggestions for future research are discussed.

Main findings

The main findings of this thesis are summarized in Table 1. Taste and fattiness intensity of ten vegetables commonly consumed in the Netherlands, determined with the modified Spectrum method on an "absolute" scale, was generally low. On average, sweetness was the most intensive taste, followed by sourness, bitterness, fattiness, umami and saltiness. Most vegetables displayed similar taste and fattiness intensities. The influence of preparation method on taste perception differed between vegetables. For most vegetables, boiling and mashing increased sweetness and fattiness and decreased sourness and bitterness. In vegetable juices sweetness, bitterness and umami increased compared to raw vegetables (Chapter 2). The importance of sensory cues in the identification of vegetables differed between vegetables. Identification based on taste or smell cues alone was often insufficient to correctly identify vegetables, probably because of low intensities. Flavour was often sufficient for the identification of vegetables commonly consumed raw, such as carrot and cucumber, while texture was important for vegetables usually consumed warm after boiling, such as broccoli and cauliflower (Chapter 3).

Taste modifications by addition of different concentrations of tastants to cucumber and green bell pepper influenced vegetable acceptance in adults. Only sweetness enhancement by sucrose addition increased acceptance in cucumber and green bell pepper. Addition of caffeine (bitterness enhancement) and addition of a high concentration of NaCl (saltiness enhancement) decreased acceptance in both cucumber and green bell pepper. In cucumber, addition of a high concentration of MSG (umami enhancement) also decreased acceptance of vegetable purees by adults (Chapter 4). In children (5-6-years-old), sucrose addition (sweetness enhancement) increased acceptance of cucumber and green bell pepper purees (Chapter 5). Thus, sweetness enhancement in vegetables by sucrose addition can increase vegetable acceptance in children and adults. However, the sucrose concentration at which acceptance increased differed between children and adults. In cucumber, addition of medium and high concentrations of sucrose (5 and 10%) increased children's acceptance while for adults, acceptance only increased when a low concentration of sucrose (2%) was added. In green bell pepper, addition of a low concentration of sucrose (2%) already increased children's acceptance while for adults, addition of medium and high concentrations (5 and 10%) were needed.

Table 1. Overview of the main findings of this thesis.

Chapter	Aim of study	Main findings
2	Describe taste and fattiness intensity for ten vegetables prepared by different methods.	• Vegetables displayed low taste intensities on an "absolute" taste intensity scale. • Most vegetables displayed similar taste and fattiness intensities. • Preparation methods influenced taste and fattiness intensities: compared to raw vegetables, boiling and mashing increased sweetness and fattiness and decreased sourness and bitterness. Sweetness, bitterness and umami were higher in vegetable juices.
3	Assess role of smell, taste, flavour and texture cues in identification of vegetables.	• Identification frequency of vegetables strongly depended on sensory cues present. • Most vegetables were correctly identified based on flavour and texture cues (88%) and flavour cues (63%), whereas vegetable identification based on smell cues (39%) and taste cues (38%) was limited. • Taste cues were often insufficient to correctly identify most vegetables, possibly because of low taste intensities.
4	Investigate effect of taste and fattiness enhancement of vegetables on acceptance by adults.	• Sweetness enhancement increased acceptance of cucumber and green bell pepper purees by adults. • Sourness, bitterness, umami, saltiness and fattiness enhancement did not increase acceptance of cucumber and green bell pepper purees by adults.
5	Determine effect of sweetness and sourness enhancement of vegetables on acceptance by 5-6-year-old children.	• Sweetness enhancement increased acceptance of cucumber and green bell pepper purees by children. • Sourness enhancement did not increase acceptance of cucumber and green bell pepper purees by children. • Children differed in acceptance of sweetness and sourness enhancement. In cucumber and green bell pepper, most children preferred higher sweetness (77% and 59%) and a smaller proportion preferred higher sourness (50% and 44%).
6	Determine influence of combining vegetables with other vegetables on sensory properties and acceptance.	• The change in sensory properties of vegetable combinations compared to individual vegetables depends on vegetable type and mixing ratio. • Three of 16 vegetable combinations had higher acceptance than the least accepted vegetable in the combination, while acceptance did not change compared to more accepted vegetable(s) in the combination. • Acceptance was positively associated with sweetness and negatively with bitterness.

Only a subset of children who were classified as sourness likers, accepted sourness enhancement of vegetables better than children who were classified as sourness non-likers. For adults and the majority of children, citric acid addition (sourness enhancement) did not influence acceptance of cucumber and green bell pepper puree. Combining vegetables with other vegetables led to changes in sensory properties. Acceptance of some combinations of vegetables (three of 16) was higher compared to acceptance of the individual, least liked vegetable in the combination while acceptance compared to the other individual, more liked vegetable(s) in the combination was unchanged. This demonstrates that acceptance of vegetable combinations can be higher than acceptance of an individual, not well accepted vegetable. Sweetness was positively and bitterness negatively associated with acceptance, but texture was not associated with acceptance (Chapter 6).

While sweetness enhancement was able to increase acceptance (Chapters 4 and 5) and vegetable combinations can be more accepted than individual, not well accepted vegetables (Chapter 6), results demonstrate the difficulty of increasing vegetable acceptance beyond 'okay'.

Methodological considerations

Vegetable selection

In this thesis, commonly consumed vegetables were selected based on consumption frequency in the Netherlands [(1)]. Ten vegetables were selected: broccoli, carrot, cauliflower, cucumber, French beans, iceberg lettuce, leek, onion, red bell pepper and tomato. These vegetables, or a selection of these vegetables were used in all chapters. Additionally, green bell pepper was selected for Chapters 4, 5 and 6.

It is likely that commonly consumed vegetables are commonly consumed because they are generally well accepted. As bitterness is not well accepted, perhaps commonly consumed vegetables are frequently consumed, because they have low bitterness intensities. One could argue that typical bitter vegetables like Brussels sprouts [(2)] and eggplant [(3)] were not included. However, bitterness in Brussels sprouts results from glucosinolates and their breakdown products [(4)], which are also present in other brassica vegetables, such as broccoli and cauliflower. Moreover, Martin et al.[(5)] classified broccoli, cauliflower and green beans as mainly bitter and these vegetables were included in Chapters 2 and 3. Additionally, Poelman et al.[(3)] classified green bell pepper as bitter which was included in Chapters 4, 5 and 6. Thus, several bitter vegetables were included. By using commonly consumed vegetables, it might have been difficult to increase acceptance as it is likely that acceptance of commonly consumed vegetables is relatively high. Using less commonly consumed vegetables might have led to different acceptance ratings in Chapters 4, 5 and 6. However, using uncommon vegetables might have also influenced acceptance due to unfamiliarity [(6)].

In Chapters 4 and 5, the effect of taste enhancement on vegetable acceptance was only investigated in green bell pepper and cucumber purees. Previous studies showed that sweetness enhancement can increase acceptance of broccoli, cauliflower, asparagus, Brussels sprouts and kale [7, 8] and in Chapters 4 and 5, sweetness enhancement increased acceptance of cucumber and green bell pepper. It is likely that sweetness enhancement will also increase acceptance of other vegetables. The addition of other tastants did not increase acceptance of cucumber and green bell pepper purees. Bitterness enhancement at any concentration decreased acceptance by adults, while enhancing umami, saltiness and fattiness influenced acceptance differently between vegetables and concentrations. Previous studies showed somewhat contradictory results for enhancement of umami, saltiness and fattiness [8-12]. This indicates that the effect of taste modifications on acceptance other than sweetness and bitterness enhancement probably depends on the type of vegetable. Therefore, in contrast to sweetness and bitterness, the effect of umami, saltiness and sourness enhancement on acceptance of vegetables cannot be generalized over vegetables.

Vegetable preparation

In all chapters of this thesis, some form of preparation was applied to vegetables. Protocols for all preparation methods were established to ensure that each sample was prepared in the same way. Protocols were followed for storing, rinsing, cutting and any further preparation of the vegetables. Except for the tastants mentioned in Chapters 4 and 5, vegetables were prepared unseasoned, so without the use of condiments, salt, spices or oil as this could have influenced taste intensities. In general, common preparation methods were chosen. However, in Chapters 4 and 5 raw vegetables were offered as purees. Purees were used to ensure that tastants were divided over the samples equally and to allow for precise control of concentration of added tastants. In both Australia and the Netherlands, cucumber and green bell pepper are usually not consumed pureed. Acceptance might have been lower for all purees compared to if whole vegetables were used. However, the same preparation method was used for all samples and therefore acceptance of the samples was comparable.

In Chapters 4, 5 and 6 raw vegetables were used to reduce the possible influence of preparation method on taste. However, by only using raw vegetables, it is unknown what the effect of taste enhancement or combining vegetables with other vegetables on acceptance would be for other preparation methods. As preparation methods and tasting temperature can also influence taste perception [13, 14], it is likely that using for example warm boiled vegetables would have led to different results. Additionally, using raw vegetables in Chapter 6, possibly led to only minor textural differences between the vegetables used in the combinations. This might have led to an underestimation of the contribution of texture to acceptance.

The effect of taste enhancement and sensory properties of vegetable combinations should be further investigated including different preparation methods.

Participants

Participants were recruited in Wageningen (Chapters 3 and 4), Delft (Chapters 3 and 6) and Sydney (Chapter 5) using various sources such as social media and flyers. Participation was limited to participants living or working in the area of the studies. Results might not be generalizable to the general population. Participants were relatively high educated and younger adults were overrepresented as most studies took place at a university and therefore many students were among the participants. Additionally, participants might consume more vegetables than the average population.

In both the Netherlands and Australia, the average consumption of vegetables is below recommended intakes [1, 15-18]. Vegetable consumption of Dutch participants was also below recommended intake and ranged from 132 to 162 g/d, which is slightly higher than the average consumption in the Netherlands (≈130 g/d) [16]. Australian participants reported a higher vegetable consumption than the Dutch participants, 2.71 serves/d by parents and 2.12 serves/d by children. One serve is 75 g, so this equals to 203 g/d for adults and 159 g/d for children. In Australia, the recommended intake of vegetables is higher as potatoes and other starchy root vegetables are also included (adults 5 to 6 serves/d; children aged 4-8 years, 4.5 serves/d) [19]. Australian participants were asked not to include potatoes in self-reported and parental reported vegetable consumption. Compared to guidelines from the World Health Organization [20], reported vegetable consumption of the Australian participants meets dietary guidelines.

There are two reasons why reported vegetable consumption was somewhat high in the studies of this thesis, especially for Australian participants in Chapter 5. The first is selection bias. Participants of food studies are generally more interested in food and might like and consume more vegetables than the average population. The second is over-reporting of vegetable consumption. Socio-demographic data and data about vegetable consumption was self-reported and in Chapter 5, all child characteristics were parental reported. Self-reported data is sensitive to bias and misreporting vegetable consumption might have occurred [21].

To reduce selection bias, more efforts must go in the recruitment of participants for inclusion of a diverse sample of participants. To avoid any misreporting, other methods, like a 3-day dietary recall might increase reliability [22, 23]. However, these methods would have been too elaborate as vegetable consumption of the participants was merely used for descriptive purposes.

In all chapters, adult participants (18-65 years) were included except for Chapter 5. In Chapter 5, 5-6-year-old children participated. Children are an important target group for increasing vegetable consumption as children who consume a variety of vegetables seem to have healthier diets later in life (24). Parents often struggle to get children to eat more vegetables as food neophobia and refusal of vegetables is common (25, 26). While food neophobia might be higher in slightly younger children, 5-6-year-old children had the cognitive abilities to participate in the sensory test (27). The participating children had an average child food neophobia score of 20 on a scale ranging from 6-42, indicating that children were neither neophillic nor neophobic (6, 28). Children of parents with an interested in food are more prone to participate in these types of studies and might have had more exposure to vegetables. This explains the relatively low child food neophobia score in the participating children. Therefore, children who participated were probably not representative for typical 5-6-year-old children and results cannot be generalized.

PROP-status was of participants not measured in the studies of this thesis since PROP-status was not associated with dietary patterns or vegetable consumption in previous studies (29-31). PROP-tasters, supertasters and non-tasters were probably among the participants. PROP-status has been associated with perception of bitterness in vegetables (32). In Sharafi et al.(8), PROP-status influenced acceptance of vegetables with added aspartame. Therefore, vegetable acceptance might have differed between PROP-tasters and non-tasters. Additional studies are needed to determine the association between PROP-status and vegetable acceptance and consumption, however that was out of the scope of this thesis.

Study design

In Chapters 4, 5 and 6 a within-subject design was used to test acceptance of vegetable purees and vegetable combinations. By using a within-subject design, there was no inter-individual variability and less participants were needed. To reduce any order effect, the order of samples was randomized. In Chapter 3, a between-subject design was used to eliminate learning between the four conditions as participation in more than one of the four different conditions would have influenced the ability to identify vegetables correctly in the subsequent conditions.

In Chapters 4, 5 and 6, acceptance was used as an outcome measure. In Chapters 4 and 6, acceptance was measured on a 9-point hedonic scale. The 9-point hedonic scale is appropriate to use to compare acceptance between products within individuals. For comparisons between groups, for example PROP-tasters versus non-tasters, the General Labelled Magnitude Scale might be more appropriate because using the 9-point scale might lead to differences in interpretation between individuals and groups that taste differently (33, 34). Since there were no comparisons between groups in Chapters 4 and 6 and all participants rated all products, the 9-point hedonic scale was appropriate.

In Chapter 5, a 5-point hedonic facial scale and preference ranking was used. Smiley faces were used to make it easier for children to understand and children's understanding of the facial scale was established before the start of the test. Another appropriate option would have been the 7-point hedonic facial scale [27], which might have reduced the risk of a type II error. However, previous studies also used the 5-point scale, indicating that this scale is appropriate to use with children of this age group [35-39].

In Chapter 4, participants only rated the taste intensity of the enhanced taste modality to asses if the three concentrations were significantly different between unmodified, low, medium and high concentrations. It is likely that addition of tastants to vegetables did not only modify the intensity of enhanced taste modality. By not including a measurement for all taste intensities of the samples, it is unknown how the addition of tastants influenced taste intensities other than the added taste modality. Perhaps, not only sweetness enhancement led to higher acceptance of cucumber and green bell pepper by addition of sucrose but suppression of bitterness contributed and enhancement of bitterness might have decreased sweetness and therefore decreased acceptance [40]. It would be valuable to understand taste-interactions between the vegetable taste and added tastants as this provides further insight in the role of taste in the acceptance of vegetables. Future studies investigating the effect of added tastants, or any other modifications should include sensory evaluation of all tastes.

While sweetness enhancement increased acceptance and some vegetable combinations were more accepted compared to individual vegetables (Chapters 4, 5 and 6), it is unclear if these modifications also influence food choice and food intake. Additionally, in Chapters 4, 5 and 6 participants only tasted each sample once. Therefore, it is unknown if the increase in acceptance persists after multiple exposures. It has been shown that more exposures can lead to an increase in acceptance and food intake of vegetables [10, 41], however possibly repeated exposure maybe not have this effect in more familiar foods, such as the vegetables that were included in this study [42].

The environment in which a food in consumed influences acceptance. All sessions took place in a research environment. The advantage of this is that the environment can be controlled to a large extend. Cardello and Meiselman[43] stress the importance of context while testing. Future studies should consider investigating the effect of taste modifications and offering vegetable combinations on acceptance, choice and consumption in a real-life setting.

Discussion and interpretation of results

Innate preferences and sensory properties of vegetables
Poelman et al.(3) used the modified Spectrum method to compare taste intensities of vegetables to other foods on a 100 mm line scale. The modified Spectrum method uses an "absolute scale" to provide taste intensities that are not product specific making it possible to compare different types of foods (5). Poelman et al.(3) showed that while some vegetables might be bitter compared to other foods, taste intensities were generally low. Thus, relative to what humans are able to perceive, vegetables have low taste intensities. Additionally, Martin et al.(5) showed that only few vegetables can be classified as 'mainly bitter' on the modified Spectrum scale. Findings presented in Chapter 2 support that bitterness intensity in vegetables is low, in fact sweetness was the most intense taste in vegetables commonly consumed in the Netherlands. Perhaps vegetables are commonly consumed because of their sweetness and uncommon vegetables are not frequently consumed because of their bitterness, as discussed in the methodological considerations in this chapter. In Chapter 2, bitterness intensity of the three vegetables classified as mainly bitter by Martin et al.(5) (broccoli, cauliflower and green beans) was low after boiling (<5, measured on a 100-mm line scale). Of those vegetables, raw broccoli juice had the highest bitterness intensity (12.8), which is still not very high. These findings are supported by results in Chapter 3, where it became clear that taste plays only a minor role in the identification of vegetables compared to flavour and texture. However, previous studies (6, 44, 45) and results from Chapters 4, 5 and 6 show that bitterness is associated with vegetable rejection and sweetness with vegetable acceptance. This indicates that even low bitterness intensities can lead to low vegetable acceptance. Bitterness acceptance or rejection possibly differs between foods (46). While bitterness is accepted in some food products, like coffee and chocolate, in vegetables this is generally not the case. Taste-nutrient associations seems to be stronger for minimally and moderately processed foods (47). As vegetables are often consumed minimally processed, nutrient sensing by taste might be more important in the acceptance of vegetables compared to highly processed foods, where more complex taste and textures might lead to less taste-nutrient sensing (47-49). This could explain why low bitterness leads to low acceptance in vegetables, while in other foods it does not and can even be appreciated.

Low bitterness intensities might also lead to low acceptance due to the eating rate of vegetables. Eating rate determines the taste-exposure time in the mouth (50). Because vegetables are often consumed raw or minimally processed, eating rate is low and taste-exposure time long (51-53). Therefore, exposure time to bitterness during the consumption of vegetables might be relatively long compared to other bitter, high processed foods. Moreover, eating rate is also associated with intake (50) and if vegetables have a low eating rate, this possibly leads to a low intake.

The difficulty of increasing vegetable acceptance

Based on results of Chapter 2 and 3 it was hypothesised that low taste intensity might be involved in low acceptability of vegetables. However, results of Chapters 4 do not support this as enhancing sourness, bitterness, umami, saltiness and fattiness did not increase acceptance of vegetables. In fact, any enhancement of bitterness and high concentrations of umami or saltiness decreased vegetable acceptance. For bitterness, results were not surprising and the effect of bitterness enhancement on acceptance will probably be similar in other vegetables. However, adding sour dressings, salt, dips or sauces to vegetables is common practice and it was expected that sourness, saltiness and fattiness would increase acceptance, but this was not the case. Only enhancing sweetness increased acceptance of vegetables. Although it is likely that sweetness enhancement can increase acceptance of a wide variety of types of vegetables as this has also been shown in previous studies [7, 8], sweetness enhancement only led to small changes in acceptance.

In Chapters 4 and 5, acceptance of vegetables with or without taste modifications was generally low and around 'okay'. Moreover, it seems that decreasing acceptance by taste modifications leads to larger differences. For example, in Chapter 4 acceptance of cucumber and green bell pepper increased one point measured on a 9-point hedonic scale by addition of sucrose while enhancing bitterness by addition of caffeine decreased acceptance compared to unmodified vegetable purees up to -3.1 for cucumber and -2.7 for green bell pepper. In Chapter 6, the most accepted and least accepted vegetables were neither extremely liked nor extremely disliked (cucumber, 6.7; green bell pepper, 5.1) and acceptance of all vegetable combinations was in between. This limited effect of modifications on acceptance has also been shown previous studies [7-10].

Results demonstrate that it is difficult to increase vegetable acceptance by addition of tastants other than sucrose and that even sweetness enhancement does not lead to high acceptance of vegetables. In Chapters 4 and 5 taste enhancement was achieved by addition of a single tastant. It is possible that more complex tastes are needed to increase vegetable acceptance as these might be more in line with seasonings that consumers use at home, for example vinaigrette, dressings or dips.

Preparation method, phytochemicals and bioavailability

In Chapter 2, the effect of preparation method on taste and fattiness intensity differed between vegetables. Boiling and mashing increased sweetness of broccoli, carrot, cauliflower and leek and decreased bitterness in broccoli and onion. In a study by Donadini et al.[6] boiling also increased sweetness in carrot, tomatoes, zucchini, spinach and chicory. Therefore, based on taste, boiling might be the preferred preparation method for multiple vegetables. Previous studies did show that boiling, not too long and not too short is the preferred preparation method for carrot, broccoli and cauliflower [39, 54-56], however, other studies showed that preferred preparation method differs between vegetables [6, 44, 57].

Next to taste, preparation methods influence vegetable texture [58]. While some studies found an association between texture and acceptance [6, 56, 59], in Chapter 6, texture of vegetable combinations was not associated with acceptance. All vegetables in the combinations were raw, possibly texture differences were too small to influence acceptance.

Preparation methods influence nutritional quality, this should be considered in strategies aimed at increasing vegetable consumption. The influence of preparation methods on nutritional quality differs between vegetables and between preparation methods [58, 60-64]. From all preparations, steaming might be better than boiling as this leads to only minor loss of phytochemicals and in particular glucosinolates, while glucosinolates are lost by boiling due to leaching in the cooking water [54, 55, 58, 60, 64, 65]. Boiling and steaming can also positively influence bioavailability of certain nutrients in some vegetables [54, 60, 61, 64, 66, 67]. Additionally, phytochemical bioavailability might be influenced by other meal components [67].

Since the effect of preparation methods on vegetable taste, nutritional quality and consumer acceptance differs between vegetables and between preparation methods, different preparation methods could be preferred and advised for different vegetables.

Practical implications and future research

Variety selection and cultivation

The most promising strategy to enhance nutritional quality of the diet might be variety selection [68]. There are large differences in phytochemical content between vegetable varieties [69, 70]. By cultivating vegetable varieties with better nutritional quality, the intake of these nutrients increases even when vegetable consumption does not [69].

However, cultivating varieties with better nutritional quality might lead to less favourable taste profiles [46, 71], as some phytochemicals can taste bitter [2]. Increased bitterness as a result of higher nutritional quality might decrease acceptance. Schonhof et al.[71] suggested to solve this problem by breeding varieties with increased sugar content. However, increasing sugar content of vegetables might not be appropriate. Not all health promoting glucosinolates are bitter tasting [58, 71, 72], so a better strategy could be cultivating or developing varieties containing non-bitter health promoting glucosinolates, thereby decreasing bitterness but not total glucosinolate content. Cultivating vegetable varieties with higher phytochemical content might lower yield [73]. Cross-breeding could be used to obtain optimal quality (extrinsic and intrinsic) [62]. Phytochemical content can also be increased to some extent by modifying agricultural practices [74].

Product development

Improving the nutritional quality of vegetables does not necessarily increase vegetable acceptance or consumption and additional approaches that can increase acceptance and consumption are needed. Acceptance of several vegetable combinations was higher compared to an individual, not well accepted vegetable (Chapter 6). Offering combinations of vegetables is easy to implement, especially for vegetables consumed raw. Moreover, by offering vegetables in combinations, the intake of a variety of vegetables can be increased. In a study by Meengs et al.[75], it was shown that offering vegetables in a combination increased consumption with an average of 48 g. A similar effect was seen in children [76]. These results indicate that simply offering multiple vegetables instead of an individual vegetable can increase acceptance and consumption. However, in Chapter 6 the acceptance of vegetable combinations was still not very high. Perhaps more complex modifications are needed to achieve even higher acceptance, for example by addition of spices and herbs. In vegetables dishes, few spices are used in the preparation compared to meat dishes. The most used spices are onion, pepper, garlic, chilli pepper and lemon or lime, however there are many more spices and herbs that can be used [77]. Carney et al.[78] seasoned carrots with three different blends, cinnamon-nutmeg-ginger-salt, cardamom-cumin-allspice-salt and garlic-pepper-oregano-salt and found that spices improved acceptance for PROP-tasters. It would be interesting to further investigate acceptance of different vegetable-spice combinations.

In Chapter 6, texture was not associated with acceptance while in previous studies, texture was associated with acceptance [6, 56, 59]. Possibly, texture differences between vegetables in Chapter 6 were too small to influence acceptance because all vegetables were raw. In addition to more complex tastes, future studies could investigate if offering different preparation methods of vegetables and different textures in combinations can increase acceptance further.

Most vegetables are still consumed at home during dinner, a little during lunch but virtually not as a snack [16, 79]. If consumers eat vegetables at other extra consumption moments, vegetable consumption could be increased. Vegetable products appropriate for these other consumption moments, like breakfast or as a snack, could be developed and tested. It has been suggested that vegetable juice is a promising convenient vegetable product suitable for multiple consumption moments [80]. Because of the liquid form, eating rate is fast and therefore there might be less bitterness exposure. Consuming vegetables as a juice influences taste, sometimes increasing bitterness compared to raw or boiled vegetables (Chapter 2). Fruit is often added to vegetable juices, probably to improve the palatability. Perhaps instead of fruit, vegetable juices could contain combinations of vegetables. In the Netherlands, vegetables that are easily consumed raw, like cherry tomatoes and small carrots and cucumbers are more often positioned as a snack in supermarkets and canteens since recent years. Consuming raw vegetables as snacks is also recommended by the World Health Organization[20]. It should be investigated how consuming products like these contribute to total vegetable consumption and how the current assortment can be extended.

Another development is the use of vegetable waste products, like vegetable pomace for enrichment of food products [81-84]. However, with any new type of processing, the influence on the nutritional quality of vegetables should be investigated. Liu[85] suggested that the interaction between phytochemicals leads to health benefits rather than just one or two compounds and that consumption of whole vegetables should be preferred. Processing might influence the effect that consumption of a vegetable product has on health. For example, dietary supplements with breakdown products of glucosinolates might even promote tumour growth, these supplements should therefore be used with caution [63]. Additionally, bioavailability of phytochemicals is heavily influenced by meal context [67], future studies could further investigate the bioavailability of when vegetables are consumed in combination with other foods in a meal. Currently, dietary guidelines refer to vegetables as a single group [20]. However, phytochemical content differs between vegetables [85] and associations with health might also differ between vegetables. For the formulation of more specific guidelines, future studies could further investigate the association between vegetable consumption and health separately for different groups of vegetables and different types of vegetable products.

Taste perception, sensitivity and preferences differ between individuals [86, 87]. For example, in Chapter 5 children differed in their acceptance of sucrose and citric acid acceptance. Future studies should consider these individual differences in taste preferences. Consumers could be segmented based on taste preferences as one size might not fit all. Some consumers might prefer a vegetable combination or variety with a more sour taste while other consumers might prefer a vegetable combination or variety with a sweeter taste. By segmenting consumers based on taste preferences, products can be developed that match taste preferences of specific consumer groups. This might increase vegetable acceptance and consumption.

Even when there are different varieties and convenient vegetable products with high acceptance available for purchase in the supermarket, this does not mean that consumers will choose these products. Food choice remains a complex process and many factors are involved. Social marketing shows promise to improve the image of vegetables and to increase vegetable consumption [(88-90)]. Future studies could investigate the effect of using social marketing techniques on vegetable choice and consumption further.

Conclusions

Of all taste modalities, only sweetness enhancement increased acceptance. Additionally, combinations of vegetables can be more accepted than an individual bitter vegetable. However, only small increases in acceptance of vegetables were achieved and in general, acceptance of vegetables did not go beyond 'okay'. The results of this thesis clearly demonstrate the difficulty of increasing acceptance of vegetables by taste modifications. There is not a simple solution to increase vegetable acceptance. Combining vegetables with other vegetables and spices and herbs to achieve more complex tastes and textures, might increase acceptance and this approach could be further explored. Vegetable products could be developed for other consumption moments than dinner, taking individual differences in taste preferences, the effect of preparation on phytochemical content, convenience and other factors of food choice into consideration. Additionally, cultivators could select or attempt to breed vegetable varieties with high phytochemical content to improve the nutritional quality of the diet.

References

1. Van Rossum CTM, Fransen HP, Verkaik-Kloosterman J, Buurma-Rethans EJM, Ocke MC. Dutch National Food Consumption Survey 2007-2010: diet of children and adults aged 7 to 69 years Bilthoven: National Institute for Public Health and the Environment; 2011 (350050006/2011).
2. Drewnowski A, Gomez-Carneros C. Bitter taste, phytonutrients, and the consumer: a review. *American Journal of Clinical Nutrition*. 2000;72(6):1424-35.
3. Poelman AAM, Delahunty CM, de Graaf C. Vegetables and other core food groups: A comparison of key flavour and texture properties. *Food Quality and Preference*. 2017;56, Part A:1-7.
4. Van Doorn HE. Development of vegetables with improved consumer quality: A case study in Brussels sprouts (Doctoral dissertation): Wageningen University; 1999.
5. Martin C, Visalli M, Lange C, Schlich P, Issanchou S. Creation of a food taste database using an in-home “taste” profile method. *Food Quality and Preference*. 2014;36:70-80.
6. Donadini G, Fumi MD, Porretta S. Influence of preparation method on the hedonic response of preschoolers to raw, boiled or oven-baked vegetables. *LWT - Food Science and Technology*. 2012;49(2):282-92.
7. Capaldi ED, Privitera GJ. Decreasing dislike for sour and bitter in children and adults. *Appetite*. 2008;50(1):139-45.
8. Sharafi M, Hayes JE, Duffy VB. Masking Vegetable Bitterness to Improve Palatability Depends on Vegetable Type and Taste Phenotype. *Chemosensory Perception*. 2013;6(1):8-19.
9. Bouhlal S, Chabanet C, Issanchou S, Nicklaus S. Salt content impacts food preferences and intake among children. *PLoS One*. 2013;8(1):e53971.
10. Bouhlal S, Issanchou S, Chabanet C, Nicklaus S. ‘Just a pinch of salt’. An experimental comparison of the effect of repeated exposure and flavor-flavor learning with salt or spice on vegetable acceptance in toddlers. *Appetite*. 2014;83C:209-17.
11. Bouhlal S, Issanchou S, Nicklaus S. The impact of salt, fat and sugar levels on toddler food intake. *British Journal of Nutrition*. 2011;105(4):645-53.
12. Fisher JO, Mennella JA, Hughes SO, Liu Y, Mendoza PM, Patrick H. Offering “Dip” Promotes Intake of a Moderately-Liked Raw Vegetable among Preschoolers with Genetic Sensitivity to Bitterness. *Journal of the Academy of Nutrition and Dietetics*. 2012;112(2):235-45.
13. Schiffman SS, Sattely-Miller EA, Graham BG, Bennett JL, Booth BJ, Desai N, et al. Effect of temperature, pH, and ions on sweet taste. *Physiology & Behavior*. 2000;68(4):469-81.
14. Talavera K, Ninomiya Y, Winkel C, Voets T, Nilius B. Influence of temperature on taste perception. *Cellular and Molecular Life Sciences*. 2007;64(4):377-81.
15. Commonwealth Scientific Industrial Research Organisation. 2007 Australian National children’s nutrition and physical activity survey: Main findings. Canberra, Australia; 2008.

16. Van Rossum CTM, Buurma-Rethans EJM, Vennemann FBC, Beukers M, Brants HAM, de Boer EJ, et al. The diet of the Dutch. Results of the first two years of the Dutch National Food Consumption Survey 2012-2016. National Institute for Public Health and the Environment, Bilthoven, The Netherlands; 2016 (2016-0082).
17. Australian Bureau of Statistics. Australian Health Survey: Nutrition First Results - Food and Nutrients, 2011-12. 2014 (4364.0.55.007).
18. Health Council of the Netherlands. Dutch Dietary Guidelines 2015. The Hague, The Netherlands; 2015 (2015/24).
19. National Health and Medical Research Council. Australian Dietary Guidelines. Canberra, Australia; 2013.
20. World Health Organization. Healthy Diet. Factsheet N394; 2015.
21. Livingstone MB, Robson PJ, Wallace JM. Issues in dietary intake assessment of children and adolescents. *Br J Nutr*. 2004;92 Suppl 2:S213-22.
22. Bingham SA, Gill C, Welch A, Day K, Cassidy A, Khaw KT, et al. Comparison of dietary assessment methods in nutritional epidemiology: weighed records v. 24 h recalls, food-frequency questionnaires and estimated-diet records. *British Journal of Nutrition*. 1994;72(4):619-43.
23. Burrows TL, Martin RJ, Collins CE. A Systematic Review of the Validity of Dietary Assessment Methods in Children when Compared with the Method of Doubly Labeled Water. *Journal of the American Dietetic Association*. 2010;110(10):1501-10.
24. Cooke L. The importance of exposure for healthy eating in childhood: a review. *Journal of Human Nutrition and Dietetics*. 2007;20(4):294-301.
25. Birch LL. Development of food preferences. *Annual Review of Nutrition*. 1999;19:41-62.
26. Dovey TM, Staples PA, Gibson EL, Halford JC. Food neophobia and 'picky/fussy' eating in children: a review. *Appetite*. 2008;50(2-3):181-93.
27. Guinard JX. Sensory and consumer testing with children. *Trends in Food Science & Technology*. 2000;11(8):273-83.
28. Henriques AS, King SC, Meiselman HL. Consumer segmentation based on food neophobia and its application to product development. *Food Quality and Preference*. 2009;20(2):83-91.
29. Drewnowski A, Henderson SA, Cockroft JE. Genetic Sensitivity to 6-n-Propylthiouracil Has No Influence on Dietary Patterns, Body Mass Indexes, or Plasma Lipid Profiles of Women. *Journal of the American Dietetic Association*. 2007;107(8):1340-8.
30. Lumeng JC, Cardinal TM, Sitto JR, Kannan S. Ability to Taste 6-n-Propylthiouracil and BMI in Low-income Preschool-aged Children. *Obesity*. 2008;16(7):1522-8.
31. Yackinous CA, Guinard J-X. Relation between PROP (6-n-propylthiouracil) taster status, taste anatomy and dietary intake measures for young men and women. *Appetite*. 2002;38(3):201-9.
32. Kaminski LC, Henderson SA, Drewnowski A. Young women's food preferences and taste responsiveness to 6-n-propylthiouracil (PROP). *Physiology & Behavior*. 2000;68(5):691-7.

33. Kalva JJ, Sims CA, Puentes LA, Snyder DJ, Bartoshuk LM. Comparison of the Hedonic General Labeled Magnitude Scale with the Hedonic 9-Point Scale. *Journal of Food Science*. 2014;79(2):S238-S45.
34. Bartoshuk LM, Duffy VB, Fast K, Green BG, Prutkin J, Snyder DJ. Labeled scales (e.g., category, Likert, VAS) and invalid across-group comparisons: what we have learned from genetic variation in taste. *Food Quality and Preference*. 2003;14(2):125-38.
35. De Graaf C, Zandstra EH. Sweetness intensity and pleasantness in children, adolescents, and adults. *Physiology & Behavior*. 1999;67(4):513-20.
36. Guthrie CA, Rapoport L, Wardle J. Young children's food preferences: a comparison of three modalities of food stimuli. *Appetite*. 2000;35(1):73-7.
37. Havermans RC, Jansen A. Increasing children's liking of vegetables through flavour-flavour learning. *Appetite*. 2007;48(2):259-62.
38. Poelman AAM, Delahunty CM. The effect of preparation method and typicality of colour on children's acceptance for vegetables. *Food Quality and Preference*. 2011;22:355-64.
39. Poelman AAM, Delahunty CM, de Graaf C. Cooking time but not cooking method affects children's acceptance of Brassica vegetables. *Food Quality and Preference*. 2013;28(2):441-8.
40. Keast SJR, Breslin PAS. An overview of binary taste-taste interactions. *Food Quality and Preference*. 2003;14(2):111-24.
41. Liem DG, de Graaf C. Sweet and sour preferences in young children and adults: role of repeated exposure. *Physiology & Behavior*. 2004;83(3):421-9.
42. Zeinstra GG, Vrijhof M, Kremer S. Is repeated exposure the holy grail for increasing children's vegetable intake? Lessons learned from a Dutch childcare intervention using various vegetable preparations. *Appetite*. 2018;121:316-25.
43. Cardello AV, Meiselman HL. Chapter 1 - Contextual Influences on Consumer Responses to Food Products A2 - In: Methods in Consumer Research, Volume 2: Woodhead Publishing; 2018. p. 3-54.
44. Duffy EM, Hayes JE, Feeney EL. Understanding taste and texture perception to enhance vegetable acceptance. *Proceedings of the Nutrition Society*. 2017;76(Oce3):E67-E.
45. Dinehart ME, Hayes JE, Bartoshuk LM, Lanier SL, Duffy VB. Bitter taste markers explain variability in vegetable sweetness, bitterness, and intake. *Physiology & Behavior*. 2006;87(2):304-13.
46. Breslin PAS. An Evolutionary Perspective on Food and Human Taste. *Current Biology*. 2013;23(9):R409-R18.
47. Van Dongen MV, van den Berg MC, Vink N, Kok FJ, de Graaf C. Taste-nutrient relationships in commonly consumed foods. *British Journal of Nutrition*. 2012;108(1):140-7.
48. Lease H, Hendrie GA, Poelman AAM, delahunty C, Cox DN. A Sensory-Diet database: A tool to characterise the sensory qualities of diets. *Food Quality and Preference*. 2016;49:20-32.
49. Van Langeveld AWB, Gibbons S, Koelliker Y, Civille GV, de Vries JHM, de Graaf C, et al. The relationship between taste and nutrient content in commercially available foods from the United States. *Food Quality and Preference*. 2017;57:1-7.

50. De Graaf C. Texture and satiation: The role of oro-sensory exposure time. *Physiology & Behavior*. 2012;107(4):496-501.
51. Werthmann J, Jansen A, Havermans R, Nederkoorn C, Kremers S, Roefs A. Bits and pieces. Food texture influences food acceptance in young children. *Appetite*. 2015;84:181-7.
52. Aguayo-Mendoza MG, Ketel EC, van der Linden E, Forde CG, Piqueras-Fiszman B, Stieger M. Oral processing behavior of drinkable, spoonable and chewable foods is primarily determined by rheological and mechanical food properties. *Food Quality and Preference*. 2018.
53. Viskaal-van Dongen M, Kok FJ, de Graaf C. Eating rate of commonly consumed foods promotes food and energy intake. *Appetite*. 2011;56(1):25-31.
54. Bongoni R, Stieger M, Dekker M, Steenbekkers B, Verkerk R. Sensory and health properties of steamed and boiled carrots (Daucus carota ssp sativus). *International Journal of Food Sciences and Nutrition*. 2014;65(7):809-15.
55. Bongoni R, Verkerk R, Steenbekkers B, Dekker M, Stieger M. Evaluation of Different Cooking Conditions on Broccoli (Brassica oleracea var. italica) to Improve the Nutritional Value and Consumer Acceptance. *Plant Foods for Human Nutrition*. 2014;69(3):228-34.
56. Zeinstra GG, Koelen MA, Kok FJ, de Graaf C. The influence of preparation method on children's liking for vegetables. *Food Quality and Preference*. 2010;21(8):906-14.
57. Poelman AAM, Delahunty CM, de Graaf C. Vegetable preparation practices for 5-6 years old Australian children as reported by their parents; relationships with liking and consumption. *Food Quality and Preference*. 2015;42:20-6.
58. Miglio C, Chiavaro E, Visconti A, Fogliano V, Pellegrini N. Effects of different cooking methods on nutritional and physicochemical characteristics of selected vegetables. *Journal of Agricultural and Food Chemistry*. 2008;56(1):139-47.
59. Roininen K, Fillion L, Kilcast D, Lähteenmäki L. Exploring difficult textural properties of fruit and vegetables for the elderly in Finland and the United Kingdom. *Food Quality and Preference*. 2004;15(6):517-30.
60. Pellegrini N, Chiavaro E, Gardana C, Mazzeo T, Contino D, Gallo M, et al. Effect of Different Cooking Methods on Color, Phytochemical Concentration, and Antioxidant Capacity of Raw and Frozen Brassica Vegetables. *Journal of Agricultural and Food Chemistry*. 2010;58(7):4310-21.
61. Pellegrini N, Miglio C, Del Rio D, Salvatore S, Serafini M, Brighenti F. Effect of domestic cooking methods on the total antioxidant capacity of vegetables. *International Journal of Food Sciences and Nutrition*. 2009;60 Suppl 2:12-22.
62. Mithen RF, Dekker M, Verkerk R, Rabot S, Johnson IT. The nutritional significance, biosynthesis and bioavailability of glucosinolates in human foods. *Journal of the Science of Food and Agriculture*. 2000;80(7):967-84.
63. Higdon JV, Delage B, Williams DE, Dashwood RH. Cruciferous vegetables and human cancer risk: epidemiologic evidence and mechanistic basis. *Pharmacology Research*. 2007;55(3):224-36.
64. Palermo M, Pellegrini N, Fogliano V. The effect of cooking on the phytochemical content of vegetables. *Journal of the Science of Food and Agriculture*. 2014;94(6):1057-70.

65. Song L, Thornalley PJ. Effect of storage, processing and cooking on glucosinolate content of Brassica vegetables. *Food and Chemical Toxicology*. 2007;45(2):216-24.
66. Bernhardt S, Schlich E. Impact of different cooking methods on food quality: Retention of lipophilic vitamins in fresh and frozen vegetables. *Journal of Food Engineering*. 2006;77(2):327-33.
67. Martin C. The interface between plant metabolic engineering and human health. *Current Opinion in Biotechnology*. 2013;24(2):344-53.
68. Kalt W. Effects of Production and Processing Factors on Major Fruit and Vegetable Antioxidants. *Journal of Food Science*. 2005;70(1):R11-R9.
69. Verkerk R, Tebbenhoff S, Dekker M, editors. Variation and distribution of glucosinolates in 42 cultivars of Brassica Oleracea vegetable crops. International Society for Horticultural Science (ISHS), Leuven, Belgium; 2010.
70. Nilsson J, Olsson K, Engqvist G, Ekvall J, Olsson M, Nyman M, et al. Variation in the content of glucosinolates, hydroxycinnamic acids, carotenoids, total antioxidant capacity and low-molecular-weight carbohydrates in Brassica vegetables. *Journal of the Science of Food and Agriculture*. 2006;86(4):528-38.
71. Schonhof I, Krumbein A, Bruckner B. Genotypic effects on glucosinolates and sensory properties of broccoli and cauliflower. *Nahrung-Food*. 2004;48(1):25-33.
72. Padilla G, Cartea ME, Velasco P, de Haro A, Ordas A. Variation of glucosinolates in vegetable crops of Brassica rapa. *Phytochemistry*. 2007;68(4):536-45.
73. Rouphael Y, Cardarelli M, Bassal A, Leonardi C, Giuffrida F, Colla G. Vegetable quality as affected by genetic, agronomic and environmental factors. *Journal of Food Agriculture & Environment*. 2012;10(3-4):680-8.
74. Hayes JD, Kelleher MO, Eggleston IM. The cancer chemopreventive actions of phytochemicals derived from glucosinolates. *European Journal of Nutrition*. 2008;47 Suppl 2:73-88.
75. Meengs JS, Roe LS, Rolls BJ. Vegetable variety: an effective strategy to increase vegetable intake in adults. *Journal of the Academy for Nutrition and Dietetics*. 2012;112(8):1211-5.
76. Bucher T, Siegrist M, van der Horst K. Vegetable variety: an effective strategy to increase vegetable choice in children. *Public Health Nutrition*. 2014;17(6):1232-6.
77. Sherman PW, Hash GA. Why vegetable recipes are not very spicy. *Evolution and Human Behavior*. 2001;22(3):147-63.
78. Carney EM, Stein WM, Reigh NA, Gater FM, Bakke AJ, Hayes JE, et al. Increasing flavor variety with herbs and spices improves relative vegetable intake in children who are propylthiouracil (PROP) tasters relative to nontasters. *Physiology & Behavior*. 2018;188:48-57.
79. Bowen J, Klose D, Syrette J, Noakes M. Australian children's vegetable intake: findings of the 2007 Australian children's national nutrition and physical activity survey.2009 (VG07160).
80. Wootton-Beard PC. Improving public health?: The role of antioxidant-rich fruit and vegetable beverages. *Food Research International*. 2011;44:3135-48.

81. Kumar N, Sarkar BC, Sharma HK. Development and Characterization of Extruded Product Using Carrot Pomace and Rice Flour. *International Journal of Food Engineering*. 2010;6(3).
82. Kumar V, Kushwaha R, Goyal A, Tanwar B, Kaur J. Process optimization for the preparation of antioxidant rich ginger candy using beetroot pomace extract. *Food Chemistry*. 2018;245:168-77.
83. Laufenberg G, Kunz B, Nystroem M. Transformation of vegetable waste into value added products:: (A) the upgrading concept; (B) practical implementations. *Bioresource Technology*. 2003;87(2):167-98.
84. Gull A, Prasad K, Kumar P. Effect of millet flours and carrot pomace on cooking qualities, color and texture of developed pasta. *LWT - Food Science and Technology*. 2015;63(1):470-4.
85. Liu RH. Health-promoting components of fruits and vegetables in the diet. *Advances in Nutrition*. 2013;4(3):384S-92S.
86. Garcia-Bailo B, Toguri C, Eny KM, El-Sohemy A. Genetic variation in taste and its influence on food selection. *OMICS*. 2009;13(1):69-80.
87. Liu D, Archer N, Duesing K, Hannan G, Keast R. Mechanism of fat taste perception: Association with diet and obesity. *Progress in Lipid Research*. 2016;63:41-9.
88. Grier S, Bryant CA. Social marketing in public health. *Annual Review of Public Health*. 2005;26:319-39.
89. Pollard CM, Miller MR, Daly AM, Crouchley KE, O'Donoghue KJ, Lang AJ, et al. Increasing fruit and vegetable consumption: success of the Western Australian Go for 2&5 campaign. *Public Health Nutrition*. 2008;11(3):314-20.
90. Gordon R, McDermott L, Stead M, Angus K. The effectiveness of social marketing interventions for health improvement: What's the evidence? *Public Health*. 2006;120(12):1133-9.

Summary

Vegetables are an essential part of a healthy diet, however vegetable consumption is below recommendations in many countries. Sensory attributes, such as smell, taste and texture are important for acceptance of vegetables. This thesis further investigated the role of sensory properties, and in particular taste, in the acceptance of vegetables.

In Chapter 2, a trained panel ($n = 9$) assessed sweetness, sourness, bitterness, umami, saltiness and fattiness intensity of ten vegetables (broccoli, carrot, cauliflower, cucumber, French beans, leek, lettuce, onion, red bell pepper, tomato) using the modified Spectrum method. The modified Spectrum method uses an “absolute scale” to provide taste intensities that are not product specific making it possible to compare different types of foods. Vegetables were assessed raw, boiled, mashed and as a juice. In general, vegetables prepared by different methods displayed low intensities for all tastes and fattiness. Preparation methods influenced taste and fattiness intensities. Boiling and mashing increased sweetness and fattiness and decreased sourness and bitterness in most vegetables. In vegetable juices, sweetness, bitterness and umami increased compared to raw vegetables. Most vegetables displayed similar taste and fattiness intensities. Possibly, low taste and fattiness intensities lead to low consumer acceptance of vegetables.

In Chapter 3, the importance of different sensory cues in the identification of vegetables was investigated. Participants ($n = 194$ consumers) were randomly placed in one of four conditions. In the smell condition, participants had to identify non-pureed vegetables based on orthonasal smell. In the taste condition, participants tasted pureed vegetables while wearing a nose clip. In the flavour condition, participants tasted pureed vegetable without a nose clip, so orthonasal, retronasal smell and taste cues were present. In the flavour-texture condition, participants tasted non-pureed vegetables, so taste, smell and texture cues were present. All participants were blindfolded during smelling or tasting and were asked to identify the vegetable from a 24-option list. Identification frequency was 88% in the flavour-texture condition, 63% in the flavour condition, 39% in the smell condition and 38% in the taste condition. For vegetables that are often consumed raw, flavour was sufficient for identification. For other vegetables, providing texture cues in addition to flavour significantly increases identification frequency. Thus, for correctly identifying vegetables, the presence of only taste or only smell cues is often insufficient.

Based on the results from Chapters 2 and 3 it was hypothesized that low taste intensities lead to low consumer acceptance of vegetables. Therefore, the effect of taste enhancement on acceptance of vegetables was investigated in Chapters 4 and 5. Three concentrations of sucrose (2, 5 and 10%) and citric acid (0.05, 0.08 and 0.15%) were added to a neutral tasting vegetable (cucumber) and to a bitter tasting vegetable (green bell pepper). Sucrose addition increased acceptance in adults (*n*

S

= 100) and 5-6-year-old children (*n* = 70), there were small differences in optimal concentrations between vegetables and adults and children. Enhancing sourness by adding citric acid did not influence acceptance significantly. However, there was a subset of children who accepted sourness enhancement better than other children (cucumber 50%; green bell pepper 44%). In Chapter 4, three concentrations of caffeine (0.05, 0.08, 0.15%), mono-sodium glutamate (0.12, 0.30, 0.70%), NaCl (0.20, 0.35, 0.50%) and sunflower oil (10, 20, 30%) were also added to cucumber and vegetable purees to assess bitterness, umami, saltiness and fattiness enhancement on acceptance of vegetable purees by adults. Enhancement of bitterness, umami, saltiness and fattiness did not increase acceptance compared to unmodified cucumber and green bell pepper in adults, but sweetness enhancement by addition of sucrose can increase acceptance of vegetables by both adults and children.

Adding sucrose to vegetables might not be desirable from a health perspective, therefore it was investigated in Chapter 6 whether acceptance of combinations of vegetables, for example a naturally bitter vegetable combined with a naturally sweet vegetable, was different than acceptance of individual vegetables. Participants (*n* = 83 consumers) rated acceptance of carrot, cucumber, green bell pepper and red bell pepper as individual vegetables and in different combinations. Results showed that three of the 16 combinations were better accepted than an individual not well accepted vegetable, while acceptance of the better accepted vegetables in the combinations did not change. Mainly sweetness was associated with increased acceptance. Combining vegetables with other vegetables is easy to implement by both consumers as the food industry and therefore a feasible strategy for increasing vegetable acceptance.

In Chapter 7, the main findings and their practical implications were discussed. The results in this thesis highlight the difficulty of increasing vegetable acceptance. Vegetable taste and fattiness intensities of commonly consumed vegetables were low and enhancing vegetable taste or combining vegetables with other vegetables generally led only to small increases in acceptance. Possibly, more complex tastes, flavours and textures are needed to increase vegetable acceptance further. A strategy to increase nutritional quality of the diet is cultivating vegetables with higher phytochemical content. To increase acceptance and consumption, convenient vegetable products could be developed for other consumption moments than dinner.

Appendices

Appendix A

Supplementary table

Chapter 2. Taste intensities of ten vegetables commonly consumed in the Netherlands

Table A1. F-values per taste modality for ten vegetables

Vegetable	Sweetness	Sourness	Bitterness	Umami	Saltiness	Fattiness
Cauliflower	$F(4,104)=98.902$, $p<0.01$	$F(4,104)=15.077$, $p<0.01$	$F(4104)=16.670$, $p<0.01$	$F(4,104)=24.575)$, $p<0.01$	$F(4,104)=11.830$, $p<0.01$	$F(4,104)=20.009$, $p<0.01)$
Broccoli	$F(4,104)=84.910$, $p<0.01$	$F(4,104)=15.811$, $p<0.01$	$F(4,104)=37.051$, $p<0.01$	$F(4,104)=19.876$, $p<0.01$	$F(4,104)=16.576$, $p<0.01)$	$F(4,104)=19.953$, $p<0.01$
Leek	$F(4,104)=86.508$, $p<0.01$	$F(4,104)=14.065$, $p<0.01$	$F(4,104)=67.312$, $p<001$	$F(4,104)=25.231$, $p<0.01$	$F(4,104)=14.409$, $p<0.01$	$F(4,104)=21.327$, $p<0.01$
Carrot	$F(4,104)=228.305$, $p<0.01$	$F(4,104)=19.160$, $p<0.01$	$F(4,104)=18.365$, $p<0.01$	$F(4,104)=21.848$, $p<0.01$	$F(4,104)=10.262$, $p<0.01$	$F(4,104)=21.225$, $p<0.01$
Onion	$F(4,104)=89.337$ $p<0.01$	$F(4,104)=17.964$, $p<0.01$	$F(4,104)=117.385$, $p<0.01$	$F(4,104)=14.571$, $p<0.01$	$F(4,104)=18.860$, $p<0.01$	$F(4,104)=19.190$, $p<0.01$
Red bell pepper	$F(4,104)=116.115$, $p<0.01$	$F(4,104)=83.982$, $p<0.01$	$F(4,104)=17.088$, $p<0.01$	$F(4,104)=18.959$, $p<0.01$	$F(4,104)=11.642$, $p<0.01$	$F(4,104)=17.101$, $p<0.01$
French Bean	$F(2,52)=66.705$, $p<0.01$	$F(2,52)=11.012$, $p<0.01$	$F(2,52)=34.823$, $p<0.01$	$F(2,52)=16.721$, $p<0.01$	$F(2,52)=15.912$, $p<0.01$	$F(2,52)=48.763$, $p<0.01$
Tomato	$F(3,87)=140.300$, $p<0.01$	$F(3,87)=296.445$, $p<0.01$	$F(3,87)=40.165$, $p<0.01$	$F(3,87)=182.187$, $p<0.01$	$F(3,87)=24.742$, $p<0.01$	$F(3,87)=34.583$, $p<0.01$
Cucumber	$F(3,78)=83.703$, $p<0.01$	$F(3,78)=30.892$, $p<0.01$	$F(3,78)=24.429$, $p<0.01$	$F(3,78)=8.255$, $p<0.01$	$F(3,78)=14.174$, $p<0.01$	$F(3,78)=21.136$, $p<0.01$
Iceberg lettuce	$F(3,87)=122.972$, $p<0.01$	$F(3,87)=27.245$, $p<0.01$	$F(3,87)=57.006$, $p<0.01$	$F(3,87)=9.562$, $p<0.01$	$F(3,87)=10.779$, $p<0.01$	$F(3,87)=28.144$, $p<0.01$

Appendix B

Supplementary table

Chapter 3. The role of smell, taste, flavour and texture cues in the identification of vegetables

Table B1. Mean intensities (± SD) of sensory cues for the smell, taste, flavour and flavour-texture condition of vegetables, intensity of vegetable averaged over four conditions (smell condition: participants rated perceived smell intensity; taste condition: participants rated perceived taste intensity; flavour and flavour-texture conditions: participants rated perceived flavour intensity and intensity averaged over ten vegetables per condition). Letters A-C indicate significant differences in intensities ($p < 0.05$) between test conditions within a vegetable. Same letters indicate no significant difference between mean intensities. Numbers 1-6 indicate significant differences between vegetable intensities averaged over the four conditions.

	Mean intensity (± SD) of sensory cue per condition and intensity averaged over four conditions				
Vegetable	**Smell**	**Taste**	**Flavour**	**Flavour-Texture**	**Average over conditions**
Broccoli	49.8 ± 21.0^{A}	31.8 ± 18.5^{B}	46.9 ± 18.9^{A}	51.6 ± 19.7^{A}	45.2 ± 20.8^{5}
Cauliflower	53.5 ± 20.6^{A}	41.1 ± 23.6^{B}	54.9 ± 19.8^{A}	55.3 ± 18.6^{A}	51.3 ± 21.4^{3,4}
French bean	38.3 ± 22.2^{B}	32.1 ± 20.8^{B}	51.7 ± 21.5^{A}	59.5 ± 19.5^{A}	45.5 ± 23.5^{5}
Leek	59.9 ± 21.7^{A}	34.9 ± 19.9^{C}	51.4 ± 19.7^{AB}	46.9 ± 21.7^{B}	48.1 ± 22.4^{3,4,5}
Bell pepper	48.2 ± 23.5^{BC}	43.2 ± 22.4^{C}	59.9 ± 23.6^{AB}	65.8 ± 16.9^{A}	54.6 ± 23.4^{2,3}
Carrot	26.2 ± 23.0^{C}	39.2 ± 21.8^{B}	64.8 ± 18.2^{A}	65.6 ± 16.4^{A}	49.1 ± 26.0^{3,4,5}
Cucumber	52.4 ± 20.6^{A}	28.5 ± 18.3^{B}	54.2 ± 17.8^{A}	56.6 ± 22.1^{A}	48.2 ± 22.7^{3,4,5}
Lettuce	30.5 ± 18.8^{B}	28.6 ± 20.7^{B}	42.4 ± 19.8^{A}	50.6 ± 23.7^{A}	38.4 ± 22.7^{6}
Onion	65.8 ± 21.2^{C}	77.0 ± 19.7^{BC}	85.6 ± 11.3^{A}	83.0 ± 9.9^{AB}	77.5 ± 18.8^{1}
Tomato	51.4 ± 21.8^{B}	48.8 ± 23.5^{B}	68.8 ± 16.3^{A}	63.0 ± 20.3^{A}	57.9 ± 21.9^{2}
Average over vegetables	47.6 ± 24.4^{B}	40.5 ± 25^{C}	58.1 ± 22.2^{A}	59.8 ± 21.3^{A}	-

Appendix C

Supplementary tables

Chapter 6. Combining vegetables with other vegetables influences sensory properties and can increase acceptance

Table C1. Mean intensity scores with standard deviation for all attributes (n = 24 trained participants, Quantitative Descriptive Analysis) and acceptance (n = 83 naïve consumers, hedonic evaluation) of samples containing carrot (n = 10). Letters A-D indicate significant differences ($p < 0.05$) between vegetables for each attribute. Same letters indicate no significant difference between vegetables.

Attribute	F-value	Carrot	Carrot -Cucumber	Carrot -Cucumber	Carrot - Green bell pepper	Carrot - Green bell pepper	Carrot - Red bell pepper	Carrot - Red bell pepper	Carrot-Cucumber -Green bell pepper	Carrot -Cucumber - Red bell pepper	Carrot - Green bell pepper - Red bell pepper
		NA	2:1	1:2	2:1	1:2	2:1	1:2	1:1:1	1:1:1	1:1:1
Firmness	$F(9,207)=10450.73$ $p < 0.01$	73 ± 18^{A}	70 ± 15^{A}	66 ± 13^{A}	74 ± 15^{A}	69 ± 16^{A}	71 ± 16^{A}	69 ± 17^{A}	67 ± 15^{A}	66 ± 14^{A}	64 ± 18^{A}
Crunchiness	$F(9,207)=11962.76$ $p = 0.09$	76 ± 18^{A}	73 ± 17^{A}	69 ± 16^{A}	73 ± 16^{A}	70 ± 18^{A}	70 ± 19^{A}	68 ± 16^{A}	67 ± 16^{A}	67 ± 16^{A}	69 ± 17^{A}
Juiciness	$F(9,207)=2904.64$ $p < 0.01$	36 ± 18^{C}	$45\ 19^{ABC}$	44 ± 17^{ABC}	37 ± 16^{BC}	46 ± 19^{ABC}	40 ± 20^{ABC}	42 ± 18^{ABC}	41 ± 21^{ABC}	49 ± 17^{A}	48 ± 21^{AB}
Chewiness	$F(9,207)=512.89$ $p < 0.05$	21 ± 20^{AB}	20 ± 17^{AB}	10 ± 12^{B}	20 ± 18^{AB}	22 ± 15^{A}	20 ± 19^{AB}	18 ± 16^{AB}	18 ± 19^{AB}	16 ± 16^{AB}	16 ± 15^{AB}
Sweetness	$F(9,207)=3684.22$ $p < 0.01$	55 ± 18^{A}	46 ± 19^{ABCD}	43 ± 17^{BCD}	48 ± 18^{ABC}	37 ± 22^{D}	51 ± 20^{AB}	48 ± 18^{ABC}	39 ± 18^{CD}	47 ± 21^{ABCD}	37 ± 21^{D}
Sourness	$F(9,207)=421.47$ $p < 0.01$	6 ± 13^{C}	9 ± 14^{ABC}	8 ± 9^{BAC}	7 ± 10^{BC}	14 ± 16^{AB}	13 ± 15^{ABC}	15 ± 17^{A}	9 ± 13^{ABC}	9 ± 14^{ABC}	14 ± 16^{AB}
Bitterness	*$F(9,207)=428.03$ $p < 0.01$*	9 ± 11^{B}	12 ± 13^{AB}	15 ± 17^{AB}	17 ± 16^{AB}	22 ± 18^{A}	16 ± 16^{AB}	22 ± 25^{A}	21 ± 20^{AB}	21 ± 20^{AB}	21 ± 17^{AB}
Umami	$F(9,207)=280.96$ $p = 0.11$	10 ± 14^{A}	10 ± 15^{A}	11 ± 16^{A}	16 ± 19^{A}	14 ± 16^{A}	10 ± 14^{A}	15 ± 17^{A}	16 ± 14^{A}	19 ± 21^{A}	13 ± 16^{A}

Table continues

Attribute	F-value	Carrot	Carrot -Cucumber	Carrot -Cucumber	Carrot - Green bell pepper	Carrot - Green bell pepper	Carrot - Red bell pepper	Carrot - Red bell pepper	Carrot-Cucumber -Green bell pepper	Carrot -Cucumber - Red bell pepper	Carrot - Green bell pepper - Red bell pepper
Saltiness	F(9,207)=326.19 p = 0.77	6 ± 10^{A}	8 ± 11^{A}	8 ± 13^{A}	8 ± 12^{A}	8 ± 11^{A}	7 ± 12^{A}	6 ± 9^{A}	9 ± 13^{A}	8 ± 10^{A}	7 ± 8^{A}
Flavour	F(9,207)=5251.37 p =0.05	59 ± 15^{A}	51 ± 16^{A}	50 ± 17^{A}	57 ± 17^{A}	53 ± 17^{A}	56 ± 17^{A}	60 ± 17^{A}	53 ± 12^{A}	58 ± 13^{A}	54 ± 19^{A}
Astringent	F(9,207)=516.94 p = 0.50	12 ± 19^{A}	15 ± 19^{A}	16 ± 22^{A}	14 ± 21^{A}	18 ± 18^{A}	14 ± 16^{A}	16 ± 20^{A}	17 ± 22^{A}	13 ± 19^{A}	13 ± 17^{A}
Filming	F(9,207)=361.68 p = 0.34	14 ± 17^{A}	11 ± 14^{A}	9 ± 12^{A}	10 ± 14^{A}	10 ± 13^{A}	10 ± 16^{A}	11 ± 15^{A}	11 ± 16^{A}	14 ± 18^{A}	9 ± 14^{A}
Acceptance	F(9,738)=6.813, p < 0.01	6.4 ± 2.0^{A}	6.1 ± 1.8^{AB}	6.3 ± 1.4^{A}	5.4 ± 1.9^{C}	5.4 ± 1.7^{C}	6.1 ± 1.8^{AB}	5.9 ± 1.9^{ABC}	6.0 ± 1.4^{ABC}	6.4 ± 1.4^{A}	5.6 ± 1.7^{BC}

Table C2. Mean intensity scores with standard deviation for all attributes (n = 24 trained participants, Quantitative Descriptive Analysis) and acceptance (n = 83 naïve consumers, hedonic evaluation) of samples containing cucumber (n = 10). Letters A-C indicate significant differences (p < 0.05) between vegetables for each attribute. Same letters indicate no significant difference between vegetables.

Attribute	F-value	Cucumber	Carrot - Cucumber	Carrot - Cucumber	Cucumber -Green bell pepper	Cucumber - Green bell pepper	Cucumber - Red bell pepper	Cucumber - Red bell pepper	Carrot – Cucumber -Green bell pepper	Carrot – Cucumber Red bell pepper	Cucumber -Green bell pepper - Red bell pepper
		NA	1:2	2:1	2:1	1:2	2:1	1:2	1:1:1	1:1:1	1:1:1
Firmness	F(9,207)=8906.94 p < 0.01	59 ± 18^{B}	66 ± 3^{AB}	70 ± 15^{A}	57 ± 13^{B}	63 ± 16^{AB}	58 ± 17^{B}	58 ± 16^{B}	67 ± 15^{AB}	66 ± 14^{AB}	59 ± 17^{B}
Crunchiness	F(9,207)=7307.86 p < 0.01	61 ± 17^{B}	69 ± 6^{AB}	73 ± 17^{A}	61 ± 16^{B}	64 ± 17^{AB}	60 ± 20^{B}	60 ± 19^{B}	67 ± 16^{AB}	67 ± 16^{AB}	59 ± 22^{B}
Juiciness	F(9,207)=3485.10 p < 0.01	48 ± 20^{ABC}	44 ± 7^{BC}	45 ± 19^{ABC}	50 ± 18^{ABC}	46 ± 20^{ABC}	50 ± 16^{ABC}	53 ± 18^{AB}	41 ± 21^{C}	49 ± 17^{ABC}	56 ± 19^{A}

Table continues

Attribute	F-value	Cucumber	Carrot - Cucumber	Carrot - Cucumber	Cucumber -Green bell pepper	Cucumber - Green bell pepper	Cucumber - Red bell pepper	Cucumber - Red bell pepper	Carrot – Cucumber -Green bell pepper	Carrot – Cucumber Red bell pepper	Cucumber -Green bell pepper - Red bell pepper
Chewiness	$F(9,207)=524.99$ $p = 0.10$	21 ± 21^{A}	10 ± 12^{B}	20 ± 17^{AB}	17 ± 15^{AB}	17 ± 14^{AB}	19 ± 20^{AB}	18 ± 17^{AB}	18 ± 19^{AB}	16 ± 16^{AB}	15 ± 15^{AB}
Sweetness	$F(9,207)=2485.08$ $p < 0.01$	37 ± 20^{ABC}	43 ± 17^{A}	46 ± 19^{A}	28 ± 17^{C}	28 ± 21^{C}	37 ± 17^{ABC}	38 ± 19^{ABC}	39 ± 18^{AB}	47 ± 21^{A}	33 ± 18^{BC}
Sourness	$F(9,207)=414.04$ $p < 0.01$	12 ± 14^{AB}	8 ± 9^{B}	9 ± 14^{B}	11 ± 12^{B}	11 ± 13^{AB}	15 ± 14^{AB}	20 ± 18^{A}	9 ± 13^{B}	9 ± 14^{B}	13 ± 13^{AB}
Bitterness	$F(9,207)=612.40$ $p < 0.01$	16 ± 17^{BC}	15 ± 7^{C}	12 ± 13^{C}	23 ± 18^{ABC}	31 ± 23^{A}	19 ± 17^{BC}	21 ± 19^{ABC}	21 ± 20^{ABC}	21 ± 20^{ABC}	27 ± 17^{AB}
Umami	$F(9,207)=304.61$ $p = 0.14$	12 ± 8^{A}	11 ± 16^{A}	10 ± 15^{A}	11 ± 14^{A}	15 ± 20^{A}	17 ± 22^{A}	17 ± 19^{A}	16 ± 14^{A}	19 ± 21^{A}	15 ± 17^{A}
Saltiness	$F(9,207)=319.62$ $p = 0.67$	8 ± 9^{A}	8 ± 13^{A}	8 ± 11^{A}	6 ± 8^{A}	8 ± 11^{A}	10 ± 12^{A}	7 ± 9^{A}	9 ± 13^{A}	8 ± 10^{A}	7 ± 10^{A}
Flavour	$F(9,207)=4774.84$ $p < 0.01$	42 ± 21^{B}	50 ± 17^{AB}	51 ± 16^{AB}	50 ± 18^{AB}	54 ± 17^{A}	49 ± 18^{AB}	54 ± 16^{A}	53 ± 12^{AB}	58 ± 13^{A}	52 ± 15^{AB}
Astringent	$F(9,207)=453.66$ $p = 0.44$	17 ± 23^{A}	16 ± 22^{A}	15 ± 19^{A}	12 ± 19^{A}	17 ± 16^{A}	11 ± 16^{A}	16 ± 20^{A}	17 ± 22^{A}	13 ± 19^{A}	17.4 ± 16.1^{A}
Filming	$F(9,207)=380.44$ $p = 0.35$	11 ± 15^{A}	9 ± 12^{A}	11 ± 14^{A}	10 ± 13^{A}	12 ± 14^{A}	15 ± 16^{A}	10 ± 14^{A}	11 ± 16^{A}	14 ± 18^{A}	10.1 ± 14.8^{A}
Acceptance	$F(9,738)=4.824$ $p < 0.01$	6.7 ± 1.6^{A}	6.3 ± 1.4^{AB}	6.1 ± 1.8^{ABC}	6.1 ± 1.3^{ABC}	5.5 ± 1.5^{C}	6.4 ± 1.4^{AB}	6.3 ± 1.7^{AB}	6.0 ± 1.4^{ABC}	6.4 ± 1.4^{AB}	5.9 ± 1.7^{BC}

Table C3. Mean intensity scores with standard deviation for all attributes (*n* = 24 trained participants, Quantitative Descriptive Analysis) and acceptance (*n* = 83 naïve consumers, hedonic evaluation) of samples containing green bell pepper (*n* = 10). Letters A-D indicate significant differences ($p < 0.05$) between vegetables for each attribute. Same letters indicate no significant difference between vegetables.

Attribute	F-value	Green bell pepper	Carrot - Green bell pepper	Carrot - Green bell pepper	Cucumber -Green bell pepper	Cucumber -Green bell pepper	Green bell pepper - Red bell pepper	Green bell pepper - Red bell pepper	Carrot -Cucumber - Green bell pepper	Carrot - Green bell pepper - Red bell pepper	Cucumber-Green bell pepper - Red bell pepper
		NA	1:2	2:1	1:2	2:1	2:1	1:2	1:1:1	1:1:1	1:1:1
Firmness	$F(9,207)=7959.38$ $p < 0.01$	68 ± 15^{ABC}	69 ± 16^{AB}	74 ± 15^{A}	63 ± 16^{BCD}	57 ± 13^{D}	61 ± 16^{BCD}	58 ± 21^{CD}	67 ± 15^{ABCD}	64 ± 18^{ABCD}	59 ± 17^{BCD}
Crunchiness	$F(9,207)=8443.05$ $p < 0.01$	71 ± 16^{AB}	70 ± 18^{ABC}	73 ± 16^{A}	64 ± 17^{ABCD}	61 ± 16^{BCD}	66 ± 15^{ABCD}	60 ± 23^{CD}	67 ± 16^{ABCD}	69 ± 17^{ABCD}	59 ± 22^{D}
Juiciness	$F(9,207)=3433.83$ $p < 0.01$	49 ± 19^{AB}	46 ± 19^{ABC}	37 ± 16^{C}	46 ± 20^{ABC}	50 ± 18^{AB}	47 ± 16^{ABC}	52 ± 17^{AB}	41 ± 21^{BC}	48 ± 21^{ABC}	56 ± 19^{A}
Chewiness	$F(9,207)=514.63$ $p = 0.25$	22 ± 23^{A}	22 ± 15^{A}	20 ± 18^{A}	17 ± 14^{A}	17 ± 15^{A}	24 ± 20^{A}	18 ± 16^{A}	18 ± 19^{A}	16 ± 15^{A}	15 ± 15^{A}
Sweetness	$F(9,207)=2029.91$ $p < 0.01$	24 ± 18^{D}	37 ± 22^{BC}	48 ± 18^{A}	28 ± 21^{CD}	28 ± 17^{CD}	32 ± 21^{BCD}	39 ± 19^{AB}	39 ± 18^{AB}	37 ± 21^{BC}	33 ± 18^{BCD}
Sourness	$F(9,207)=565.89$ $p < 0.01$	12 ± 15^{AB}	14 ± 16^{AB}	7 ± 10^{B}	11 ± 13^{AB}	11 ± 12^{AB}	13 ± 14^{AB}	16 ± 17^{A}	9 ± 13^{AB}	14 ± 16^{AB}	13 ± 13^{AB}
Bitterness	$F(9,207)=852.72$ $p < 0.01$	39 ± 24^{A}	22 ± 18^{CD}	17 ± 16^{D}	31 ± 23^{ABC}	23 ± 18^{BCD}	36 ± 23^{AB}	31 ± 21^{ABC}	21 ± 20^{CD}	21 ± 17^{CD}	27 ± 17^{ABCD}
Umami	$F(9,207)=359.77$ $p = 0.26$	20 ± 23^{A}	14 ± 16^{A}	16 ± 19^{A}	15 ± 20^{A}	11 ± 14^{A}	14 ± 14^{A}	11 ± 13^{A}	16 ± 14^{A}	13 ± 16^{A}	15 ± 17^{A}
Saltiness	$F(9,207)=394.95$ $p = 0.38$	10 ± 11^{A}	8 ± 11^{A}	8 ± 12^{A}	8 ± 11^{A}	6 ± 8^{A}	9 ± 11^{A}	7 ± 10^{A}	9 ± 13^{A}	7 ± 8^{A}	7 ± 10^{A}
Flavour	$F(9,207)=4206.31$ $p = 0.78$	55 ± 19^{A}	53 ± 17^{A}	57 ± 17^{A}	54 ± 17^{A}	50 ± 18^{A}	55 ± 18^{A}	55 ± 19^{A}	53 ± 12^{A}	54 ± 19^{A}	52 ± 15^{A}

Table continues

Attribute	F-value	Green bell pepper	Carrot - Green bell pepper	Carrot - Green bell pepper	Cucumber -Green bell pepper	Cucumber -Green bell pepper	Green bell pepper - Red bell pepper	Green bell pepper - Red bell pepper	Carrot -Cucumber - Green bell pepper	Carrot - Green bell pepper - Red bell pepper	Cucumber-Green bell pepper - Red bell pepper
Astringent	$F(9,207)=468.93$ $p=0.24$	21 ± 24^{A}	18 ± 18^{A}	14 ± 21^{A}	17 ± 16^{A}	12 ± 19^{A}	14 ± 18^{A}	18 ± 16^{A}	17 ± 22^{A}	13 ± 17^{A}	17 ± 16^{A}
Filming	$F(9,207)=394.64$ $p = 0.51$	10 ± 16^{A}	10 ± 13^{A}	10 ± 14^{A}	12 ± 14^{A}	10 ± 13^{A}	13 ± 16^{A}	14 ± 17^{A}	11 ± 16^{A}	8.5 ± 13.6^{A}	10 ± 15^{A}
Acceptance	$F(9,738)=4.402$, $p < 0.01$	5.1 ± 1.9^{C}	5.4 ± 1.7^{BC}	5.4 ± 1.6^{BC}	5.5 ± 1.5^{ABC}	6.1 ± 1.3^{A}	5.6 ± 1.9^{ABC}	5.8 ± 2.0^{AB}	6.0 ± 1.4^{AB}	5.6 ± 1.7^{ABC}	5.9 ± 1.7^{AB}

Table C4. Mean intensity scores with standard deviation for all attributes (n = 24 trained participants, Quantitative Descriptive Analysis) and acceptance (n = 83 naïve consumers, hedonic evaluation) of samples containing red bell pepper (n = 10). Letters A-D indicate significant differences (p < 0.05) between vegetables for each attribute. Same letters indicate no significant difference between vegetables.

Attribute	F-value	Red bell pepper	Carrot - Red bell pepper	Carrot - Red bell pepper	Cucumber - Red bell pepper	Cucumber - Red bell pepper	Green bell pepper - Red bell pepper	Green bell pepper - Red bell pepper	Carrot - Cucumber - Red bell pepper	Carrot - Green bell pepper - Red bell pepper	Cucumber -Green bell pepper - Red bell pepper
		NA	1:2	2:1	1:2	2:1	1:2	2:1	1:1:1	1:1:1	1:1:1
Firmness	$F(9,207)=6848.79$ $p < 0.01$	62 ± 17^{AB}	69 ± 17^{AB}	71 ± 16^{A}	58 ± 16^{B}	58 ± 17^{B}	58 ± 21^{B}	61 ± 16^{AB}	66 ± 14^{AB}	64 ± 18^{AB}	59 ± 17^{B}
Crunchiness	$F(9,207)=7779.25$ $p < 0.01$	62 ± 23^{B}	68 ± 16^{AB}	70 ± 19^{A}	60 ± 19^{AB}	60 ± 20^{B}	60 ± 23^{AB}	66 ± 15^{AB}	67 ± 16^{AB}	69 ± 17^{AB}	59 ± 22^{B}
Juiciness	$F(9,207)=5227.92$ $p < 0.01$	58 ± 17^{A}	42 ± 18^{C}	40 ± 20^{C}	53 ± 18^{AB}	50 ± 16^{ABC}	52 ± 17^{AB}	47 ± 16^{BC}	49 ± 17^{ABC}	48 ± 21^{BC}	56 ± 19^{AB}
Chewiness	$F(9,207)=481.20$ $p = 0.42$	21 ± 21^{A}	18 ± 16^{A}	20 ± 19^{A}	18 ± 17^{A}	19 ± 20^{A}	18 ± 16^{A}	24 ± 20^{A}	16 ± 16^{A}	16 ± 15^{A}	15 ± 15^{A}
Sweetness	$F(9,207)=2573.85$ $p < 0.01$	42 ± 2^{ABCD}	48 ± 18^{AB}	51 ± 20^{A}	38 ± 9^{BCD}	37 ± 17^{BCD}	39 ± 19^{BCD}	32 ± 21^{D}	47 ± 21^{ABC}	37 ± 21^{CD}	33 ± 18^{D}

Table continues

Attribute	F-value	Red bell pepper	Carrot - Red bell pepper	Carrot - Red bell pepper	Cucumber - Red bell pepper	Cucumber - Red bell pepper	Green bell pepper - Red bell pepper	Green bell pepper - Red bell pepper	Carrot - Cucumber - Red bell pepper	Carrot - Green bell pepper - Red bell pepper	Cucumber -Green bell pepper - Red bell pepper
Sourness	$F(9,207)=519.63$ $p < 0.05$	18 ± 16^{AB}	15 ± 17^{AB}	13 ± 15^{AB}	20 ± 18^{A}	15 ± 14^{AB}	16 ± 17^{AB}	13 ± 14^{AB}	9 ± 14^{B}	14 ± 16^{AB}	13 ± 13^{AB}
Bitterness	$F(9,207)=708.95$ $p < 0.01$	21 ± 18^{BC}	22 ± 25^{BC}	16 ± 16^{C}	21 ± 19^{BC}	19 ± 17^{BC}	31 ± 21^{AB}	36 ± 23^{A}	21 ± 20^{BC}	21 ± 17^{BC}	27 ± 17^{ABC}
Umami	$F(9,207)=378.56$ $p = 0.15$	13 ± 17^{A}	15 ± 17^{A}	10 ± 14^{A}	17 ± 19^{A}	17 ± 22^{A}	11 ± 13^{A}	14 ± 14^{A}	19 ± 21^{A}	13 ± 16^{A}	15 ± 17^{A}
Saltiness	$F(9,207)=403.40$ $p = 0.14$	5 ± 8^{A}	6 ± 9^{A}	7 ± 12^{A}	7 ± 9^{A}	10 ± 12^{A}	7 ± 10^{A}	9 ± 11^{A}	8 ± 10^{A}	7 ± 8^{A}	7 ± 10^{A}
Flavour	$F(9,207)=5177.75$ $p = 0.15$	54 ± 17^{AB}	60 ± 17^{A}	56 ± 17^{AB}	54 ± 16^{AB}	49 ± 18^{B}	55 ± 19^{AB}	55 ± 18^{AB}	58 ± 13^{AB}	54 ± 19^{AB}	52 ± 15^{AB}
Astringent	$F(9,207)=564.26$ $p = 0.35$	16 ± 18^{A}	16 ± 20^{A}	14 ± 16^{A}	16 ± 20^{A}	11 ± 16^{A}	18 ± 16^{A}	14 ± 18^{A}	13 ± 19^{A}	13 ± 17^{A}	17 ± 16^{A}
Filming	$F(9,207)=450.00$ $p = 0.15$	12 ± 7^{A}	11 ± 5^{A}	10 ± 16^{A}	10 ± 14^{A}	15 ± 16^{A}	14 ± 17^{A}	13 ± 16^{A}	14 ± 18^{A}	9 ± 14^{A}	10 ± 15^{A}
Acceptance	$F(9,738)=4.203$, $p < 0.01$	6.0 ± 2.3^{AB}	5.9 ± 1.9^{AB}	6.1 ± 1.8^{AB}	6.3 ± 1.7^{A}	6.4 ± 1.4^{A}	5.8 ± 2.0^{AB}	5.6 ± 1.9^{B}	6.4 ± 1.4^{A}	5.6 ± 1.7^{B}	5.9 ± 1.7^{AB}

Acknowledgements

Acknowledgements

Nu is het dan echt klaar, mijn proefschrift. Evenals het verhaal beschreven in dit proefschrift, is het afronden van het promotieonderzoek bitterzoet. Aan de ene kant vind ik het jammer, want ik heb veel geleerd en ik vond het erg leuk om onderzoek op te zetten, resultaten te analyseren en artikelen te schrijven. Aan de andere kant ben ik ook blij, trots en opgelucht dat het erop zit. Hoewel ik de afgelopen jaren hard aan het onderzoek heb gewerkt had ik het zonder de steun van anderen niet gered.

Om te beginnen wil ik mijn promotors en copromotor bedanken. Markus Stieger, I cannot imagine a better supervisor than you. You are precise, let me come up with my own thoughts and I never have to wait long for a response. Not only did you help improve my research, you were also a great example for me as a teacher. I try to use what I have learned from you as my supervisor in my work as a teacher for which I am grateful and probably my students too. Kees de Graaf, wij hebben elkaar voor het eerst ontmoet in februari 2014. Ik had veel plannen, maar duidelijk was dat het onderzoek over smaak en groenten moest gaan. Jij kwam met het idee om te werken met het SVT-panel, en zo geschiedde. Die resultaten gaven vorm aan de rest van mijn onderzoek. Bedankt voor je ideeën en discussies over de betekenis van resultaten. Olaf van Kooten, onder andere jouw vermogen om contacten te leggen heeft ertoe geleid dat ik kon starten met dit onderzoek. Je hebt altijd volledig vertrouwen in mij gehad. Na vier jaar zijn we er nog niet uit hoe we iedereen aan voldoende groenten krijgen, dus we hebben nog genoeg te doen in vervolgonderzoek.

Edith Feskens, Marion Hetherington, Herman Peppelenbos and Astrid Postma-Smeets, thank you for partaking in the committee and for critically evaluating my thesis.

Ik wil mijn werkgever, Hogeschool Inholland bedanken voor het faciliteren van het promotieonderzoek. Inholland heeft mij deze kans gegeven en gedurende het traject vertrouwen in mijn kennis en vaardigheden gehad. Ik krijg bij Inholland de mogelijkheid mijzelf te ontwikkelen als onderzoeker en docent, maar ook op persoonlijk vlak door o.a. flexibel om te gaan met mijn reislust. Ik kan niet genoeg benadrukken hoezeer ik dat waardeer. Ik wil mijn collega's van Inholland bedanken voor de leuke sfeer in ons team, de interesse in mijn onderzoek en voor het rekening houden met mijn soms drukke schema en afwezigheid door het onderzoek. Een aantal van jullie waren mijn docent toen ik nog zelf op Inholland studeerde, mede door jullie leuke lessen heb ik de richting sensoriek en gezondheid gekozen in dit promotieonderzoek.

Ook studenten wil ik bedanken voor het enthousiast meedoen en meehelpen met (pilot) studies. Shuna, Annelies, Linda, Nicole, Carlijn en Abel, dankzij jullie kon al het praktische werk uitgevoerd worden. Bedankt voor de gezelligheid tijdens de testen en jullie inzet.

Ik wil ook mijn collega's in Wageningen bedanken voor het meedenken en helpen de afgelopen jaren. Apple, Astrid, Korrie en Monica, bedankt dat jullie me een aantal maanden hebben laten meedraaien in het SVT-panel. Ik voelde me daardoor welkom in de eerste maanden van mijn onderzoek, wat erg fijn was omdat ik toen nog vrij onbekend was met de Wageningen Universiteit. Het secretariaat van Humane Voeding en Gezondheid, bedankt voor jullie praktische ondersteuning tijdens het onderzoek en het beantwoorden van mijn vele vragen.

Ik wil Rob Wessels van Bakker Barendrecht bedanken voor het leveren van het grootse deel van de ongeveer 700 kg groenten die ik heb gebruikt tijdens de verschillende onderzoeken en alle leuke discussies. TOP bv wil ik bedanken voor het produceren van het groentesap en alle hulp bij het maken van komkommer en paprikapuree, wat was dat veel werk! Zonder jullie had ik het nooit gered.

Astrid Poelman, bedankt dat ik een deel van mijn onderzoek mocht uitvoeren bij CSIRO in Australië. Ik snap goed waarom je daar woont, wat een fantastisch land. Ik vond het erg leuk om met kinderen te werken en het was fijn om geholpen te worden door een team dat daar al ervaring mee had. Other colleagues at CSIRO, thank you for helping me during the study and for making me feel welcome. My Aussie and Dutch-Aussie friends, thank you for making my stay Down Under amazing. I especially enjoyed the brekkies, barbies and coldies.

Mijn goede vriendinnen en paranimfen, Annemieke Mack en Sandra Taal wil ik in het bijzonder bedanken. Annemieke, wij snappen elkaar helemaal. We delen al zo lang alles en het kon daarom niet anders dat jij mijn paranimf zou zijn. Sandra, ik zal me altijd ons gesprek herinneren tijdens een van onze eerste koffiepauzes in Den Haag over post-hoc testen. Je was toen met je eigen promotieonderzoek bezig en tijdens dat gesprek begrepen we elkaar als geen ander. Lief dat jullie stukjes van mijn proefschrift hebben doorgenomen om de laatste foutjes eruit te halen en voor het organiseren van leuke verrassingen. Het is fijn om te weten dat ik altijd op jullie kan rekenen.

Astrid van Langeveld, toen onze vakgroep nog in het Biotechnion zat heb je mij aangeboden bij jou op kantoor te komen werken. Ik was er niet vaak, maar als ik er was zorgde jij voor gezelligheid. Daarnaast hebben we samen internationale conferenties bezocht, wat was het leuk om met jou te 'netwerken' in Dijon en Providence!

Bedankt ook aan de deelnemers van mijn onderzoeken, maar vooral de vrienden, familieleden en kennissen die naar Delft of Wageningen zijn gekomen om mee te doen met een onderzoek, jullie weten wie jullie zijn. Dapper dat jullie je lieten blinddoeken en je verschillende groenten lieten voeren. Ik vond het heel lief dat jullie de moeite namen om mee te doen met mijn onderzoek. De vrienden die ervoor hebben gezorgd dat ik ook voldoende heb genoten de afgelopen jaren, bedankt voor de vele koffiepauzes, etentjes, (golf) tripjes en drankjes.

Dan mijn familie, of beter gezegd 'het gezinnetje'. Papa en mama, ooit was ik ervan overtuigd dat ik nooit naar de universiteit zou gaan en kijk waar ik nu ben, dat is dankzij jullie. Ik kan me geen betere en leukere ouders voorstellen. Ik denk dat jullie best verrast waren dat uitgerekend ik een onderzoek naar groenten ging doen, want een lastige eter was ik zeker (en soms nog steeds). Mijn lieve zussen, Inge en Anouk, wat ben ik blij met jullie. Soms kan ik niet geloven hoe anders we zijn en toch lijken we ook erg op elkaar. Als ik jullie zie is het altijd gezellig, of we nu op reis zijn in bijvoorbeeld Namibië (wat was dat bijzonder) of gewoon thuis bij papa en mama aan tafel met een lekker glas wijn. Sander en Menno, daar horen jullie natuurlijk ook bij. De momenten met iedereen samen zijn heel waardevol voor mij. Oma, wat bent u toch een bijzonder mens. Bedankt voor alle bezoekjes naar musea, spelletjesavonden en indrukwekkende reisverhalen.

Mijn lieve vriend Menno, bedankt voor al je hulp met computers en die lastige softwareprogramma's. Wat is het fijn om een vriend te hebben die verstand heeft van IT. Bedankt dat je ook in de meest stressvolle periodes hebt gezorgd voor gezelligheid thuis. Als ik weer bedacht dat ik naar Australië wilde voor onderzoek en dan weer naar Cuba voor mijn proefschrift heb je me altijd ondersteund en maakten we er samen een mooie reis van. Ik hoop dat we bijzondere reizen blijven maken, maar ook blijven genieten van de kleine, simpele, dagelijkse dingen in ons leven.

Na ruim vier jaar onderzoek zijn er veel mensen om te bedanken, te veel om op te noemen. Tegen iedereen die heeft geholpen, op wat voor manier dan ook, zeg ik:

BEDANKT!

About the author

Curriculum vitae

Vera Lisanne van Stokkom was born on July 12th, 1987 in Rijswijk, The Netherlands. She grew up in Delft and after completing secondary school at Stanislascollege Westplantsoen she started nursing school at the University of Applied Sciences Leiden in 2005. After one year she decided to make a change and started with the study Food and Business at Inholland University of Applied Sciences in Delft. As part of the bachelor's programme she attended several courses at University of Copenhagen. After obtaining her bachelor's degree in 2011, she followed the premaster Health Sciences at the Vrije Universiteit Amsterdam. The subsequent year she continued with the master Health Sciences specializing in nutrition and health. For her master thesis, she performed a study at the National Institute for Public Health and the Environment (RIVM), analysing the association between sugar containing beverages and asthma. After receiving her master's degree in 2013, Vera started working as a teacher at Inholland University of Applied Sciences teaching courses such as research methodology, sensory science and nutrition and health. Next to teaching, she started as an external PhD candidate at the chair of Sensory Science and Eating Behaviour, part of the Division of Human Nutrition and Health of Wageningen University in 2014. Her research focused on the role of taste in the acceptance of vegetables. During her PhD, Vera joined the educational programme of the graduate school VLAG. She attended several (inter)national conferences and supervised bachelor and master students from both Inholland University of Applied Sciences and Wageningen University. Currently, Vera still works as a teacher and researcher at Inholland University of Applied Sciences and is involved in sensory and food-health related projects. She wants to continue with research aimed at improving public health.

List of publications

Publications in peer reviewed journals

Van Stokkom VL, Teo PS, Mars M, de Graaf C, van Kooten O, Stieger M. Taste intensities of ten vegetables commonly consumed in the Netherlands. *Food Research International*. 2016;87:34-41.

Van Stokkom VL, Blok AE, van Kooten O, de Graaf C, Stieger M. The role of smell, taste, flavour and texture cues in the identification of vegetables. *Appetite*. 2018;121:69-76.

Van Stokkom VL, de Graaf C, van Kooten O, Stieger M. Effect of taste enhancement on consumer acceptance of pureed cucumber and green capsicum. *Journal of Food Science*. 2018;83(10):2578-2585.

Van Stokkom VL, Poelman AAM, de Graaf C, van Kooten O, Stieger M. Sweetness but not sourness enhancement increases acceptance of cucumber and green capsicum purees in children. *Appetite*. 2018;131:100-107.

Van Stokkom VL, de Graaf C, Wang S, van Kooten O, Stieger M. Combinations of vegetables can be more accepted than individual vegetables. *Food Quality and Preference*. 2019;72:147-158.

Publication outside this thesis

Berentzen NE, **van Stokkom VL**, Gehring U, Koppelman GH, Schaap LA, Smit HA, et al. Associations of sugar-containing beverages with asthma prevalence in 11-year-old children: the PIAMA birth cohort. *European Journal of Clinical Nutrition*. 2015;69(3):303-308.

Overview of completed training activities

Discipline specific courses and activities

2014	Sensory researcher B certificate	NL	
2014	HabEat symposium	FR	
2014	6th European Conference on Sensory and Consumer Research	DK	
2015	39th annual meeting of the British Feeding and Drinking group	NL	
2015	11th Pangborn Sensory Science Symposium	SW	Poster
2016	Sensory Perception and Food Preference course	NL	
2016	ICH Good Clinical Practice basics course	NL	
2016	Masterclass Dilemmas in Food Science	NL	
2016	7th European conference on Sensory and Consumer Research	FR	Poster
2016	Dutch Nutrition Science Days	NL	Oral
2017	12th Pangborn Sensory Science Symposium	US	Posters
2017	Healthy Food Congress	NL	
2017	Big data in the life sciences course	NL	
2018	Healthy Food Design course	NL	
2018	8th European conference on Sensory and Consumer Research	IT	Flash presentation, poster

General courses and activities

2014	Multivariate analysis for food data/sciences course	NL	
2015	VLAG Graduate School PhD week	NL	
2015	Scientific Writing course	NL	
2016	NAV workshop Communication with media	NL	
2017	Efficient Writing Strategies course	NL	
2018	Introduction to R course	NL	

Optional courses and activities

2014	Preparation of research proposal	NL	
17-18	Didactics course (basiskwalificatie didactische bekwaamheid)	NL	
2018	Organization Healthy Product Design with Vegetables masterclass	NL	Oral

Colophon

Research described in this thesis was financially supported by Inholland University of Applied Sciences, Wageningen University (Division of Human Nutrition and Health), Centre of Expertise Food (Ministry of Economic Affairs) and Centre of Expetise Greenport (Ministry of Economic Affairs). CSIRO, Sydney, Australia supported the research described in Chapter 5. Chapters 2, 4 and 6 were supported by Bakker Barendrecht, Ridderkerk, The Netherlands. Chapters 2 and 4 were supported by TOP bv, Wageningen, The Netherlands. Financial support for printing this thesis from Inholland University of Applied Sciences and Wageningen University is gratefully acknowledged.

Illustrations: Amaya Monyet
Layout: Loes Kema
Printing: GVO Drukkers & Vormgevers, Ede