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Taste intensities of ten vegetables commonly consumed in the Netherlands

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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 is 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 (cauliflower, broccoli, leek, carrot, onion, red bell pepper, French beans, tomato, cucumber and iceberg lettuce) by a panel ($n = 9$) trained in a modified Spectrum method. Each vegetable was assessed prepared by different methods (raw, cooked, 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.

1. 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 (Van Rossum, De Boer, & Ocke, 2009). Especially for children, taste is an important driver for preference and food choice (Drewnowski, 1989, 2000). Bitterness has been suggested to cause the rejection of many vegetables (Ames, Profet, & Gold, 1990; Drewnowski & Gomez-Carneros, 2000). 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 (Birch, 1999; Steiner, Glaser, Hawilo, & Berridge, 2001). 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 (Drewnowski & Gomez-Carneros, 2000).

Several studies investigated taste profiles of various vegetables using different sensory methodologies. Dinehart, Hayes, Bartoshuk, Lanier, and Duffy (2006) 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 (Dinehart et al., 2006). van Dongen, van den Berg, Vink, Kok, and de Graaf (2012) 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 (van Dongen et al., 2012). Martin, Visalli, Lange, Schlich, and Issanchou (2014) 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 (Martin et al., 2014).

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 (Bongoni, Stieger, Dekker, Steenbekkers, & Verkerk, 2014; Bongoni, Verkerk, Steenbekkers,

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Dekker, & Stieger, 2014; Zeinstra, Koelen, Kok, & de Graaf, 2010). Nutrient content of vegetables can differ depending on the preparation methods used (Bernhardt & Schlich, 2006; Pellegrini et al., 2010). As nutrient content has been linked to taste (Drewnowski & Gomez-Carneros, 2000; Schiffman & Dackis, 1975; van Dongen et al., 2012), 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 (Drewnowski, 2003). Preparation method can alter vegetable texture and might influence acceptance by altering perceived energy density (Drewnowski, 2003; Poelman, Delahunty, & de Graaf, 2013; Zeinstra et al., 2010).

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.

2. Materials and methods

2.1. Subjects

Subjects 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 subjects ($n = 9$), two males and seven females (mean age 36.3 ± 13.3 yrs.) with a normal BMI (18.5–25 kg/m^2). All subjects 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.

2.1.1. 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 trained 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 fixed 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 (Martin et al., 2014).

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

2.1.2. 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 rating 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 will be provided elsewhere.

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 min.

2.2. Vegetable selection and preparation

Ten vegetables were selected based on consumption frequency in the Netherlands reported in the Dutch national food consumption survey (Van Rossum et al., 2009): cauliflower, broccoli, leek, carrot,

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

Vegetable	Epic-classification and Latin names	Country of origin	Variation	Preparation method
Cauliflower	Cabbage *Brassica oleracea*	Spain	Meridien	Raw Juice[a] Cooked — 8 min in boiling water (212 g vegetable/500 g water)[b] Mashed — Cooked, drained and 30 s blend
Broccoli	Cabbage *Brassica oleracea*	Spain	Parthenon	Raw Juice Cooked — 8 min in boiling water (212 g/500 g) Mashed — cooked, drained and 30 s blend
Leek[c]	Stalk vegetable *Allium ampeloprasum* L.	Holland	Vitaton	Raw Juice Cooked — 8 min in boiling water (238 g/500 g) Mashed — cooked, drained and 30 s blend
Carrot	Root vegetable *Daucus carota*	Spain	Naval	Raw Juice Cooked — 10 min in boiling water (220 g/500 g) Mashed — cooked, drained and 30 s blend
Onion	Onion, garlic *Allium oepg* L.	Holland	Centro	Raw Juice Cooked — 10 min in boiling water (238 g/500 g) Mashed — cooked, drained and 30 s blend
Red bell pepper	Fruiting vegetable *Capsicum annuum*	Spain	Lazaro	Raw Juice Cooked — 5 min in boiling water (226 g/500 g) Mashed — cooked, drained and 30 s. blend
French beans	Fruiting vegetable *Phaseolus vulgaris*	Egypt	Elhama	Cooked — 10 min in boiling water (224 g/500 g) Mashed — cooked, drained and 30 s blend
Tomato	Fruiting vegetable *Solanum lycopersicum* L.	Morocco	Pitenza	Raw Juice Cold mash — 30 s blend
Cucumber	Fruiting vegetable *Cucumis sativus*	Holland	Proloog	Raw Juice Cold mash — 30 s blend
Iceberg lettuce	Leafy vegetable *Lactuca satica* L.	Spain	Botiola	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.

onion, red bell pepper, French beans, tomato, cucumber and iceberg lettuce. 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, cooked, 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 cooking was not desired for certain vegetables (tomato, iceberg lettuce and cucumber). Standardized procedures were applied for the different preparation methods based on a cooking book (Henderson, 1999) 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.

After preparation, the cooked 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.

2.3. Data analysis

Data were processed using IBM SPSS Statistics 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

Table 3
Mean intensities and standard deviations per taste modality and fattiness per preparation method averaged overall vegetables*.

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

* Letters A–E indicate significant differences ($p < 0.05$) between preparation methods per taste modality and fattiness. Same letters mean no significant difference between means.

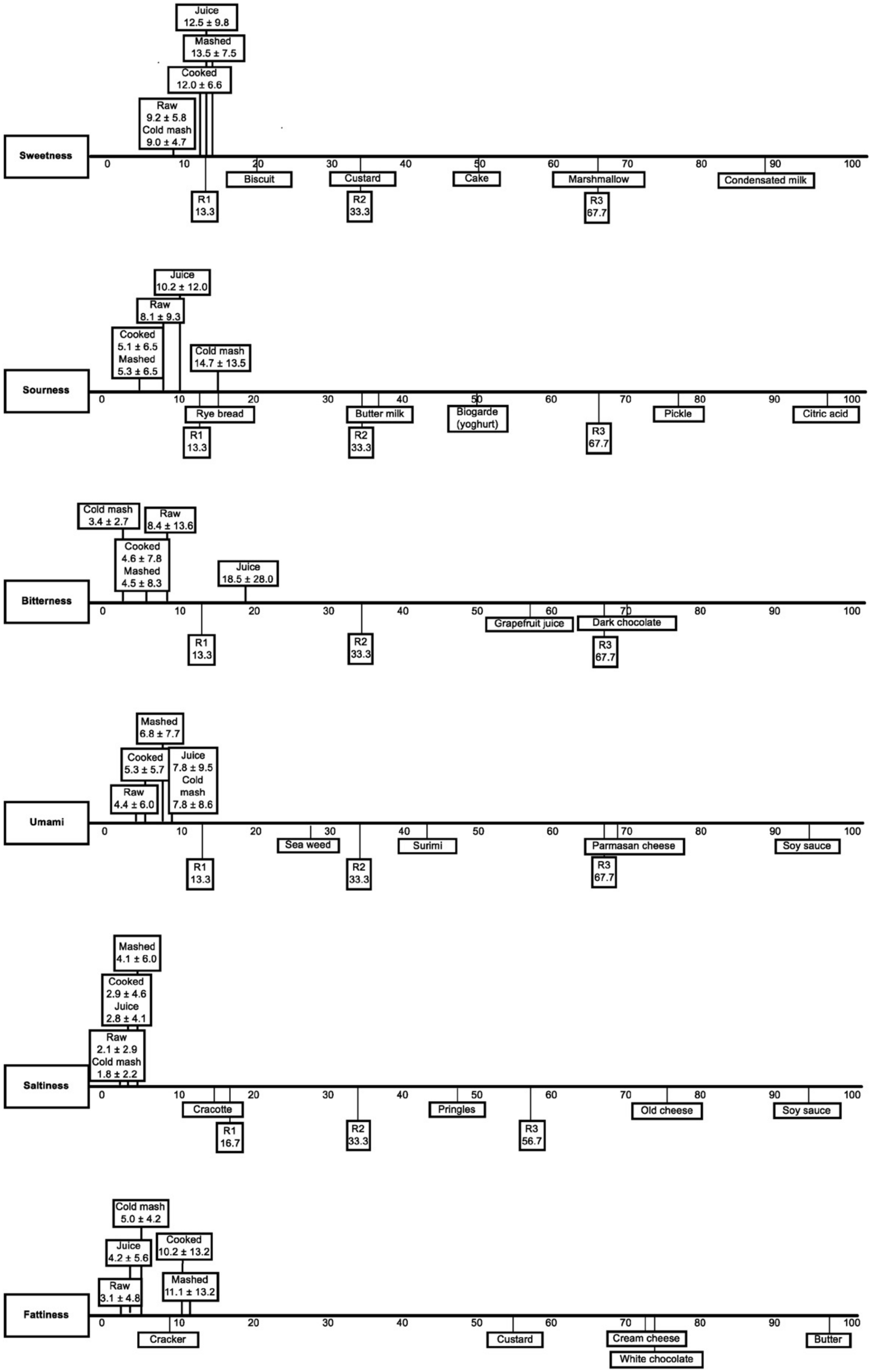

Fig. 1. Mean tastes and fattiness intensities of ten vegetables commonly consumed in the Netherlands averaged over type of preparation method with fixed intensities of reference solutions and reference products.

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 $p < 0.05$.

3. Results

3.1. 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, Fig. 1).

Preparation method significantly affected 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. Cooked 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.

3.2. 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 Appendix A.

For cauliflower, broccoli, carrot and 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, tomato and cucumber. Mashed

Table 4
Mean intensities and standard deviations per taste modality and fattiness per preparation method of ten vegetables commonly consumed in the Netherlands*.

Vegetable	Sweetness *Mean ± SD*	Sourness *Mean ± SD*	Bitterness *Mean ± SD*	Umami *Mean ± SD*	Saltiness *Mean ± SD*	Fattiness *Mean ± SD*
Cauliflower						
Raw	7.6 ± 5.1^{A}	3.6 ± 4.6^{A}	3.6 ± 3.5^{A}	3.4 ± 3.6^{A}	2.1 ± 3.0^{A}	3.7 ± 5.7^{A}
Cooked	$10.0 \pm 4.2^{A,B}$	3.8 ± 4.7^{A}	4.1 ± 4.2^{A}	5.0 ± 4.3^{A}	2.0 ± 2.4^{A}	$11.6 \pm 15.0^{A,B}$
Mashed	$12.3 \pm 5.4^{B,C}$	3.3 ± 3.7^{A}	2.9 ± 3.0^{A}	5.3 ± 5.9^{A}	2.7 ± 4.1^{A}	13.1 ± 14.7^{B}
Juice	14.2 ± 8.0^{C}	3.7 ± 5.1^{A}	11.5 ± 15.7^{B}	6.5 ± 5.5^{A}	3.9 ± 5.2^{A}	$7.6 \pm 8.5^{A,B}$
Broccoli						
Raw	6.2 ± 5.2^{A}	6.3 ± 7.3^{A}	9.3 ± 5.8^{A}	6.4 ± 7.7^{A}	2.3 ± 3.1^{A}	1.7 ± 2.0^{A}
Cooked	11.5 ± 5.3^{B}	5.7 ± 7.3^{A}	4.7 ± 4.0^{B}	7.3 ± 7.9^{A}	5.9 ± 8.9^{A}	$11.4 \pm 15.5^{B,C}$
Mashed	11.2 ± 5.1^{B}	5.3 ± 7.0^{A}	5.0 ± 4.9^{B}	8.9 ± 8.5^{A}	4.2 ± 4.6^{A}	14.6 ± 15.8^{C}
Juice	11.2 ± 6.2^{B}	6.6 ± 6.7^{A}	12.8 ± 9.4^{A}	9.8 ± 12.7^{A}	5.2 ± 6.8^{A}	$5.7 \pm 6.7^{A,B}$
Leek						
Raw	5.1 ± 3.4^{A}	4.2 ± 5.8^{A}	16.7 ± 12.4^{A}	1.8 ± 1.9^{A}	1.5 ± 2.3^{A}	3.0 ± 4.7^{A}
Cooked	9.1 ± 4.5^{B}	4.3 ± 5.9^{A}	10.1 ± 15.7^{A}	6.1 ± 6.3^{B}	3.5 ± 5.0^{A}	12.3 ± 15.7^{B}
Mashed	9.0 ± 4.0^{B}	7.7 ± 7.9^{A}	8.5 ± 14.3^{A}	6.3 ± 6.2^{B}	3.8 ± 5.2^{A}	15.2 ± 16.2^{B}
Juice	4.1 ± 3.4^{A}	5.5 ± 7.3^{A}	54.4 ± 28.1^{B}	2.1 ± 2.2^{A}	1.6 ± 2.0^{A}	2.4 ± 2.5^{A}
Carrot						
Raw	16.1 ± 6.7^{A}	2.0 ± 1.8^{A}	2.0 ± 2.2^{A}	2.5 ± 2.2^{A}	1.7 ± 1.9^{A}	2.8 ± 4.8^{A}
Cooked	$19.5 \pm 7.2^{A,B}$	1.4 ± 1.6^{A}	0.8 ± 9.0^{A}	$4.8 \pm 5.3^{A,B}$	2.2 ± 3.7^{A}	$10.5 \pm 13.9^{A,B}$
Mashed	$23.3 \pm 0.8.8^{B}$	1.4 ± 1.7^{A}	1.4 ± 1.3^{A}	$6.3 \pm 6.6^{A,B}$	3.0 ± 5.2^{A}	13.4 ± 15.0^{B}
Juice	30.1 ± 7.6^{C}	1.2 ± 1.3^{A}	1.7 ± 1.9^{A}	9.8 ± 9.7^{B}	3.3 ± 4.4^{A}	$8.5 \pm 7.8^{A,B}$
Onion						
Raw	$8.9 \pm 4.6^{A,B}$	7.7 ± 9.9^{A}	31.0 ± 28.5^{A}	$2.8 \pm 3.9^{A,B}$	3.4 ± 4.1^{A}	$3.4 \pm 6.5^{A,C}$
Cooked	9.4 ± 5.2^{A}	4.4 ± 6.8^{A}	4.5 ± 8.0^{B}	$4.5 \pm 5.7^{A,B}$	2.2 ± 2.5^{A}	$9.2 \pm 11.2^{A,B}$
Mashed	12.1 ± 5.5^{A}	4.9 ± 7.7^{A}	7.1 ± 14.9^{B}	7.3 ± 10.5^{A}	9.7 ± 10.7^{A}	3.1 ± 3.5^{B}
Juice	5.8 ± 4.9^{B}	9.7 ± 9.1^{A}	74.5 ± 21.1^{C}	2.5 ± 3.0^{B}	2.7 ± 2.8^{A}	1.5 ± 2.1^{C}
Bell pepper						
Raw	14.5 ± 5.0^{A}	10.2 ± 6.1^{A}	4.8 ± 5.3^{A}	5.4 ± 6.5^{A}	2.7 ± 4.4^{A}	4.6 ± 8.6^{A}
Cooked	$16.8 \pm 6.0^{A,B}$	$12.8 \pm 7.6^{A,B}$	5.9 ± 8.1^{A}	5.9 ± 6.2^{A}	2.9 ± 4.2^{A}	11.8 ± 15.8^{A}
Mashed	$17.8 \pm 7.0^{A,B}$	$11.1 \pm 6.2^{A,B}$	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^{B}	15.7 ± 5.7^{B}	5.4 ± 5.1^{A}	7.6 ± 8.1^{A}	3.1 ± 4.8^{A}	5.5 ± 6.3^{A}
French beans						
Cooked	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}
Tomato						
Raw	7.9 ± 2.6^{A}	26.4 ± 7.2^{A}	3.0 ± 2.2^{A}	14.3 ± 6.5^{A}	2.6 ± 2.9^{A}	$4.5 \pm 3.2^{A,B}$
Cold mash	7.7 ± 3.5^{A}	$31.0 \pm 7.9^{A,B}$	3.9 ± 2.9^{A}	$16.6 \pm 5.6^{A,B}$	2.3 ± 2.2^{A}	5.6 ± 4.4^{A}
Juice	9.3 ± 4.7^{A}	35.1 ± 12.2^{B}	2.8 ± 2.1^{A}	20.3 ± 7.9^{B}	2.2 ± 4.4^{A}	2.7 ± 3.2^{B}
Cucumber						
Raw	6.0 ± 3.7^{A}	6.5 ± 5.6^{A}	2.9 ± 2.6^{A}	0.6 ± 0.4^{A}	1.5 ± 2.2^{A}	$2.5 \pm 2.8^{A,B}$
Cold mash	7.1 ± 3.6^{A}	7.8 ± 5.8^{A}	2.3 ± 2.7^{A}	$1.9 \pm 3.6^{A,B}$	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^{B}	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^{A}
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^{B}
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^{A}

* Letters A-D indicate significant differences ($p < 0.05$) between preparation methods within one vegetable. Same letters mean no significant difference between means.

and cooked preparations were higher in fattiness than all other preparations for most vegetables.

3.3. Cluster analysis

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

The most discriminative taste modalities were bitterness (63%) and sourness (24%). 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 83% 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 sourness 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.

4. 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.

4.1. 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 (Martin et al., 2014; van Dongen et al., 2012). However, results about the most intensive taste of vegetables show differences between studies. Dinehart et al. (2006), 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. (2014). Also broccoli, cauliflower and green beans (6% of all tested vegetables) were mainly bitter, all other tastes were below average in this food group. Martin et al. (2014) 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. (2006) and Martin et al. (2014) 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 none for saltiness. Martin et al. (2014) 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 (Abu-Reidah, Arraez-Roman, Lozano-Sanchez, Segura-Carretero, & Fernandez-Gutierrez, 2013; Baldwin et al., 1998; Padilla, Cartea, Velasco, de Haro, & Ordas, 2007; Tieman et al., 2012). These nutrient variations might cause differences in taste intensities between vegetable varieties. Martin et al. (2014); Dinehart et al. (2006) and van Dongen et al. (2012) did not specify the vegetable varieties used. Martin et al. (2014) 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 $r = 0.06$, $p < 0.05$ and saltiness-fattiness $r = 0.64$, $p < 0.01$).

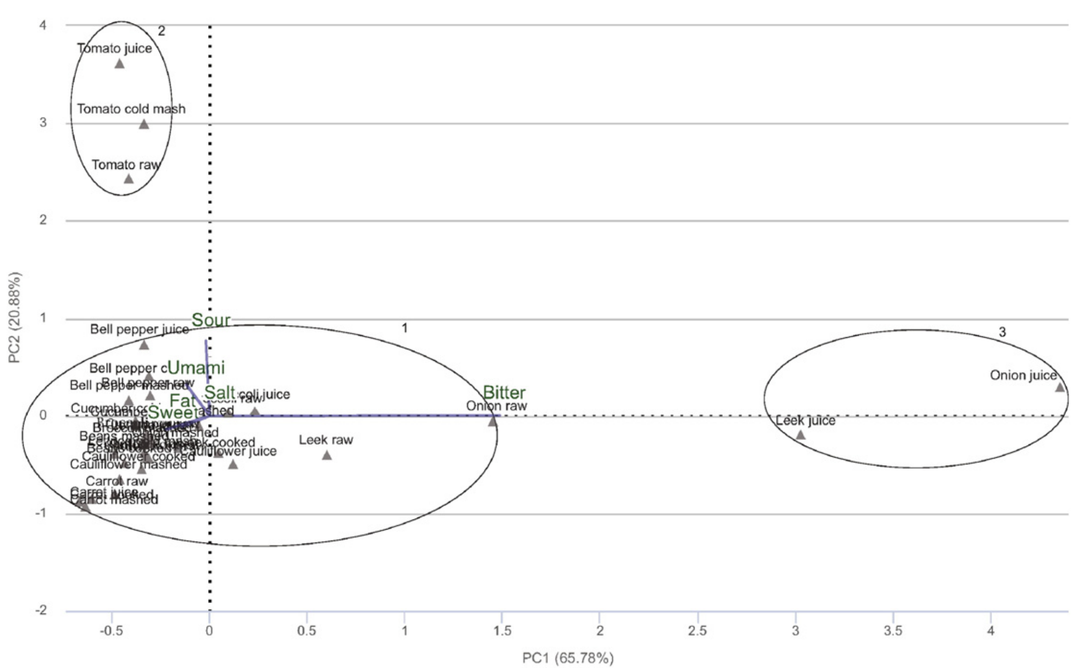

Fig. 2. PCA biplot of vegetables per preparation method (covariance matrix) together with visualization of three vegetable clusters.

4.2. Influence of preparation method on taste and fattiness intensity

Our study showed significant taste differences between preparation methods. The effect of preparation method on taste differed per vegetable. Cooking decreased taste intensity for some vegetables, mainly in vegetables where the raw preparation method and the juice had higher intensities compared to cooked and mashed preparation methods. This decrease in taste intensity could be caused by the leaching of taste related nutrients in the water during cooking (Miglio, Chiavaro, Visconti, Fogliano, & Pellegrini, 2008; Pellegrini et al., 2009; Poelman et al., 2013). Poelman et al. (2013) and Bongoni et al. (2014a), Bongoni et al. (2014b) found that nutrients probably leach in the water during cooking 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 cooked 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 cooking some vegetables have an increase of their total antioxidant capacity (TAC) probably due to the formation of antioxidant compounds (Bernhardt & Schlich, 2006; Pellegrini et al., 2010), 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 (Bernhardt & Schlich, 2006). The difference in taste intensity between cold and warm preparation methods might also have to do with tasting temperature. Cooked 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 (Schiffman et al., 2000; Talavera, Ninomiya, Winkel, Voets, & Nilius, 2007). Increased taste intensity between cold and warm preparation methods might be caused by textural changes. Zeinstra et al. (2010) compared the liking for several preparation methods and found that cooking was the most preferred preparation method. The preference for cooked 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 (Drewnowski, 1997, 2003; Zeinstra et al., 2010).

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 (Wootton-Beard, 2011). 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.

4.3. 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 (Bouhlal, Issanchou, & Nicklaus, 2011; Capaldi & Privitera, 2008; Fisher et al., 2012; Sharafi, Hayes, & Duffy, 2013). Interestingly, the two most consumed vegetables in the Netherlands, onion and tomato (Van Rossum et al., 2009) displayed the most intense and most discriminating tastes in our study. This might be the reason for their frequent consumption.

4.4. 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.

5. 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.

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Appendix A. F values per taste modality for ten vegetables

Vegetable	Sweetness	Sourness	Bitterness	Umami	Saltiness	Fattiness
Cauliflower	$F(4104) = 98.902$, $p < 0.01$	$F(4104) = 15.077$, $p < 0.01$	$F(4104) = 16.670$, $p < 0.01$	$F(4104) = 24.575$), $p < 0.01$	$F(4104) = 11.830$, $p < 0.01$	$F(4104) = 20.009$, $p < 0.01$)
Broccoli	$F(4104) = 84.910$, $p < 0.01$	$F(4104) = 15.811$, $p < 0.01$	$F(4104) = 37.051$, $p < 0.01$	$F(4104) = 19.876$, $p < 0.01$	$F(4104) = 16.576$, $p < 0.01$)	$F(4104) = 19.953$, $p < 0.01$
Leek	$F(4104) = 86.508$, $p < 0.01$	$F(4104) = 14.065$, $p < 0.01$	$F(4104) = 67.312$, $p < 001$	$F(4104) = 25.231$, $p < 0.01$	$F(4104) = 14.409$, $p < 0.01$	$F(4104) = 21.327$, $p < 0.01$
Carrot	$F(4104) = 228.305$, $p < 0.01$	$F(4104) = 19.160$, $p < 0.01$	$F(4104) = 18.365$, $p < 0.01$	$F(4104) = 21.848$, $p < 0.01$	$F(4104) = 10.262$, $p < 0.01$	$F(4104) = 21.225$, $p < 0.01$
Onion	$F(4104) = 89.337$, $p < 0.01$	$F(4104) = 17.964$, $p < 0.01$	$F(4104) = 117.385$, $p < 0.01$	$F(4104) = 14.571$, $p < 0.01$	$F(4104) = 18.860$, $p < 0.01$	$F(4104) = 19.190$, $p < 0.01$
Bell pepper	$F(4104) = 116.115$, $p < 0.01$	$F(4104) = 83.982$, $p < 0.01$	$F(4104) = 17.088$, $p < 0.01$	$F(4104) = 18.959$, $p < 0.01$	$F(4104) = 11.642$, $p < 0.01$	$F(4104) = 17.101$, $p < 0.01$
French Beans	$F(2.52) = 66.705$, $p < 0.01$	$F(2.52) = 11.012$, $p < 0.01$	$F(2.52) = 34.823$, $p < 0.01$	$F(2.52) = 16.721$, $p < 0.01$	$F(2.52) = 15.912$, $p < 0.01$	$F(2.52) = 48.763$, $p < 0.01$

Appendix A (*continued*)

Vegetable	Sweetness	Sourness	Bitterness	Umami	Saltiness	Fattiness
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	$F(3.87) = 122.972$, $p < 0.01$	$F(3.87) = 27.245$, $p < 0.01$	$F(3.87) = 57.006$, $p < 0.01$	$F(3.87) = 9.562$, $p < 0.01$	$F(3.87) = 10.779$, $p < 0.01$	$F(3.87) = 28.144$, $p < 0.01$

References

Abu-Reidah, I. M., Arraez-Roman, D., Lozano-Sanchez, J., Segura-Carretero, A., & Fernandez-Gutierrez, A. (2013). Phytochemical characterisation of green beans (*Phaseolus vulgaris* L.) by using high-performance liquid chromatography coupled with time-of-flight mass spectrometry. *Phytochemical Analysis*, *24*(2), 105–116.

Ames, B. N., Profet, M., & Gold, L. S. (1990). Dietary pesticides (99.99% all natural). *Proceedings of the National Academy of Sciences of the United States of America*, *87*(19), 7777–7781.

Baldwin, E. A., Scott, J. W., Einstein, M. A., Malundo, T. M. M., Carr, B. T., Shewfelt, R. L., & Tandon, K. S. (1998). Relationship between sensory and instrumental analysis for tomato flavor. *Journal of the American Society for Horticultural Science*, *123*(5), 906–915.

Bernhardt, S., & Schlich, E. (2006). Impact of different cooking methods on food quality: Retention of lipophilic vitamins in fresh and frozen vegetables. *Journal of Food Engineering*, *77*(2), 327–333.

Birch, L. L. (1999). Development of food preferences. *Annual Review of Nutrition*, *19*, 41–62.

Bongoni, R., Stieger, M., Dekker, M., Steenbekkers, B., & Verkerk, R. (2014a). Sensory and health properties of steamed and boiled carrots (*Daucus carota* ssp *sativus*). *International Journal of Food Sciences and Nutrition*, *65*(7), 809–815.

Bongoni, R., Verkerk, R., Steenbekkers, B., Dekker, M., & Stieger, M. (2014b). Evaluation of different cooking conditions on broccoli (*Brassica oleracea* var. *italica*) to improve the nutritional value and consumer acceptance. *Plant Foods for Human Nutrition*, *69*(3), 228–234.

Bouhlal, S., Issanchou, S., & Nicklaus, S. (2011). The impact of salt, fat and sugar levels on toddler food intake. *The British Journal of Nutrition*, *105*(4), 645–653.

Capaldi, E. D., & Privitera, G. J. (2008). Decreasing dislike for sour and bitter in children and adults. *Appetite*, *50*(1), 139–145.

Dinehart, M. E., Hayes, J. E., Bartoshuk, L. M., Lanier, S. L., & Duffy, V. B. (2006). Bitter taste markers explain variability in vegetable sweetness, bitterness, and intake. *Physiology & Behavior*, *87*(2), 304–313.

Drewnowski, A. (1989). Sensory preferences for fat and sugar in adolescence and adult life. *Annals of the New York Academy of Sciences*, *561*, 243–250.

Drewnowski, A. (1997). Why do we like fat? *Journal of the American Dietetic Association*, *97*(7 Suppl), S58–S62.

Drewnowski, A. (2000). Sensory control of energy density at different life stages. *The Proceedings of the Nutrition Society*, *59*(2), 239–244.

Drewnowski, A. (2003). The role of energy density. *Lipids*, *38*(2), 109–115.

Drewnowski, A., & Gomez-Carneros, C. (2000). Bitter taste, phytonutrients, and the consumer: A review. *The American Journal of Clinical Nutrition*, *72*(6), 1424–1435.

Fisher, J. O., Mennella, J. A., Hughes, S. O., Liu, Y., Mendoza, P. M., & Patrick, H. (2012). 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*, *112*(2), 235–245.

Henderson, H. H. F. (1999). *Het nieuwe kookboek*. Utrecht: Kosmos Z&K Uitgevers.

Martin, C., Visalli, M., Lange, C., Schlich, P., & Issanchou, S. (2014). Creation of a food taste database using an in-home "taste" profile method. *Food Quality and Preference*, *36*, 70–80.

Miglio, C., Chiavaro, E., Visconti, A., Fogliano, V., & Pellegrini, N. (2008). Effects of different cooking methods on nutritional and physicochemical characteristics of selected vegetables. *Journal of Agricultural and Food Chemistry*, *56*(1), 139–147.

Padilla, G., Cartea, M. E., Velasco, P., de Haro, A., & Ordas, A. (2007). Variation of glucosinolates in vegetable crops of *Brassica rapa*. *Phytochemistry*, *68*(4), 536–545.

Pellegrini, N., Chiavaro, E., Gardana, C., Mazzeo, T., Contino, D., Gallo, M., & Porrini, M. (2010). Effect of different cooking methods on color, phytochemical concentration, and antioxidant capacity of raw and frozen brassica vegetables. *Journal of Agricultural and Food Chemistry*, *58*(7), 4310–4321.

Pellegrini, N., Miglio, C., Del Rio, D., Salvatore, S., Serafini, M., & Brighenti, F. (2009). Effect of domestic cooking methods on the total antioxidant capacity of vegetables. *International Journal of Food Sciences and Nutrition*, *60*(Suppl. 2), 12–22.

Poelman, A. A. M., Delahunty, C. M., & de Graaf, C. (2013). Cooking time but not cooking method affects children's acceptance of brassica vegetables. *Food Quality and Preference*, *28*(2), 441–448.

Schiffman, S. S., & Dackis, C. (1975). Taste of nutrients - amino-acids, vitamins, and fatty-acids. *Perception & Psychophysics*, *17*(2), 140–146.

Schiffman, S. S., Sattely-Miller, E. A., Graham, B. G., Bennett, J. L., Booth, B. J., Desai, N., & Bishay, I. (2000). Effect of temperature, pH, and ions on sweet taste. *Physiology & Behavior*, *68*(4), 469–481.

Sharafi, M., Hayes, J. E., & Duffy, V. B. (2013). Masking vegetable bitterness to improve palatability depends on vegetable type and taste phenotype. *Chemosensory Perception*, *6*(1), 8–19.

Steiner, J. E., Glaser, D., Hawilo, M. E., & Berridge, K. C. (2001). Comparative expression of hedonic impact: Affective reactions to taste by human infants and other primates. *Neuroscience and Biobehavioral Reviews*, *25*(1), 53–74.

Talavera, K., Ninomiya, Y., Winkel, C., Voets, T., & Nilius, B. (2007). Influence of temperature on taste perception. *Cellular and Molecular Life Sciences*, *64*(4), 377–381.

Tieman, D., Bliss, P., McIntyre, L. M., Blandon-Ubeda, A., Bies, D., Odabasi, A. Z., ... Klee, H. J. (2012). The chemical interactions underlying tomato flavor preferences. *Current Biology*, *22*(11), 1035–1039.

van Dongen, M. V., van den Berg, M. C., Vink, N., Kok, F. J., & de Graaf, C. (2012). Taste-nutrient relationships in commonly consumed foods. *The British Journal of Nutrition*, *108*(1), 140–147.

Van Rossum, C. T., De Boer, E. J., & Ocke, M. C. (2009). Dutch National Food Consumption Survey-Young Children 2005/2006. *Annals of Nutrition and Metabolism*, *55*, 521–522.

Wootton-Beard, P. C. (2011). Improving public health?: The role of antioxidant-rich fruit and vegetable beverages. *Food Research International*, *44*, 3135–3148.

Zeinstra, G. G., Koelen, M. A., Kok, F. J., & de Graaf, C. (2010). The influence of preparation method on children's liking for vegetables. *Food Quality and Preference*, *21*(8), 906–914.