CONSUMERS & VEGETABLES: Effects of domestic processing on sensory and health properties

Radhika Bongoni

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CONSUMERS & VEGETABLES:
Effects of domestic processing
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Effects of domestic processing on sensory and health properties

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Chapter 1

General Introduction

1. FOOD QUALITY

Quality is a multifaceted concept, perceived differently by actors along the food chain. The consumer, the final actor of the food chain, buys and consumes food products for varied reasons associated to the characteristics of the product and the changes in those characteristics as a consequence of the applied domestic processing conditions. Food quality can be differentiated into *extrinsic* quality e.g., referring to production system characteristics, and *intrinsic* quality, directly related to the physical product properties. *Intrinsic* quality embraces perceivable *sensory* properties such as appearance, texture, colour and flavour; and 'hidden' *health* properties such as safety and nutritional value (1). The significance of every aspect of quality differs for every food and at all stages of the food chain.

Quality aspects related to vegetables are discussed in this thesis, as vegetables are vital components of a balanced diet. Nutritionists generally recommend an intake of 400 – 500 g/d of fruits and vegetables for their richness in nutrients, dietary fibers and an array of phytochemicals. Though not unequivocal (2), some studies have shown an inverse association between the consumption of a high amount of vegetables and the occurrence of cancers and cardiovascular diseases (3-7).

At the end of the food chain, the perception of quality differs between the time of purchase and consumption. It is likely that when purchasing vegetables, a consumer assesses both the *extrinsic* and *intrinsic* quality, i.e., the firmness, colour, flavour, appearance, price, and sometimes the brand or production process e.g., whether or not it is GMO, organic, association to child labour and fair trade marketing. At the time of domestic processing and consumption, it can be hypothesised that mainly *intrinsic* quality (8), i.e., *sensory* and *health* properties of vegetables play a key role.

2. VEGETABLES AND HUMAN HEALTH

Vegetables in a diet play an important role in the well-being of humans. They add flavour, colour and texture to the food and contribute a variety of phytochemicals and nutrients, alongside being low in caloric value and high in water content (9, 10). Many of these nutrients and phytochemicals exhibit various health-protective activities such as antioxidant, anti-inflammatory and anti-carcinogenic activity (2-4, 11, 12).

2.1 Nutritive value

The nutritive value varies substantially between vegetables. Most vegetables possess a range of vitamins (vitamin C, E, K, B6, B9, etc.), pro-vitamins, minerals (Fe, K, Mg, etc.) and dietary fibers (13). Vitamin B9 (folate) controls DNA methylation, synthesis and repair (14). Vitamin A (and β-carotene) plays an active role in the growth and differentiation of cells, vision and in enhancing immunity (7, 15). Minerals like potassium play a role in hypertension and heart-stroke (13). In addition to these nutrients, vegetables are also a rich source of dietary fibers, which are reported to play a role in the well-being of the gastrointestinal tract, binding and excretion of cholesterol, diabetes type II and weight management (16).

2.2 Phytochemicals

Phytochemicals are non-nutrient chemical compounds occurring in plants, and are known to have biological significance, such as antioxidant activity. Some examples of phytochemicals are terpenes like carotenes in carrots (15), phenolic compounds like flavonoids in berries (17), isoflavones in soy (18), sulphur compounds like glucosinolates in brassica vegetables (12) and betalains like betanin in beet root (19). Phenolic compounds and carotenoids are some of the compounds that were shown to act against the oxidative stress caused by free radicals produced during metabolic activities within the human cells and lower the risk of cancers (2, 3, 5, 20). The breakdown products of glucosinolates are reported to block the phase 1 enzymes (activating pro-carcinogens) and to induce the phase 2 enzymes (deactivating carcinogens) during carcinogen metabolism in the human body (12, 21-23).

The intake amount, inhibiting factors, co-components of the meal and the health status of the individual will determine the extent of previously mentioned health promoting properties of nutrients and phytochemicals on vegetable consumption (9). Domestic processing conditions applied by consumers is among the stages of the food chain, which influence the intake amount of phytochemicals from vegetables (24).

3. VEGETABLES ALONG THE FOOD CHAIN

Like most other foods, vegetables pass through several steps of the food chain before reaching the consumer. Before the point of sale (POS), specific conditions are controlled or modified by the postharvest and logistic actors to control the physiological changes of vegetables (25, 26). These modified conditions (for instance, packaging material and conditions and storage temperature and time), however, do not necessarily extend after the POS, where the consumer transports, stores, and processes the vegetable in a manner that is influenced by situational factors, habits, etc., all of which will cumulatively determine the quality of the vegetable at the time of consumption.

The consumer, as the final actor in the food chain, is hitherto somewhat neglected, while consumer behaviour – and the motives underlying them – determine the quality of vegetables at the time of consumption. Therefore, consumer behaviour towards food, i.e., domestic food processing conditions, is central in this thesis.

4. DOMESTIC PROCESSING OF BROCCOLI AND CARROTS

A variety of processing methods and conditions are applied by consumers in order to meet their and their family's sensory preferences towards vegetables. Domestic processing brings about significant changes in *sensory* and *health* properties of vegetables. These influences are often two-sided. On the one hand, cooking increases food safety, increases bioaccessibility of compounds like carotenes, and formation of flavour and colour compounds. On the other hand, cooking induces damage to nutritional quality by physical and chemical changes to phytochemicals, nutrients and formation of undesired compounds (e.g., acrylamide in French fries), and loss of texture and discolouration.

In this thesis, quality of vegetables is studied using two types of vegetables: broccoli and carrots. These vegetables are among the commonly consumed vegetables in the Netherlands. They differ morphologically and in the type of phytochemical (glucosinolates in broccoli and β-carotene in carrots; either water or fat soluble). Domestic processing conditions of these vegetables can be diverse and can result in varying influences on *sensory* and *health* properties (10). As an illustration for the sensory properties, changes in texture, colour, overall liking and attribute intensity rating of broccoli and carrots as a function of applied domestic processing conditions are studied. For the health property of vegetables, changes in the amount of glucosinolates in broccoli and carotenes in carrots are examined.

4.1 Sensory properties

It can be hypothesised that food quality in the consumer's eye is mainly sensorial with little attention given towards the health property of vegetables. Further, sensory properties are assumed to determine the overall liking and acceptability of vegetables (27-29). The sensory property of prepared vegetables (e.g., perceived texture, colour and overall liking) is assumed to depend on the applied domestic processing conditions such as cooking method, time, and size of the vegetables and so on.

4.1.1 Colour

Several phytochemicals are responsible for the colour and organoleptic properties of vegetables, i.e., chlorophyll for greenness in broccoli and carotenes for yellowness to redness in carrots. Depending on the intensity of the processing conditions, these compounds degrade and lead to colour loss or discolouration of the processed vegetable (27, 30-32). It is expected that consumers control the domestic processing conditions of vegetables by following the changes in the colour of the vegetable.

4.1.2 Texture

Pectin in the plant cell wall gives firmness to vegetables like broccoli and carrots (28, 33). Heating reduces the texture of the vegetable by loss of turgor pressure, degradation and solubilisation of pectin by β-eliminative degradation (28, 33, 34). It is expected that consumers control the domestic processing conditions to obtain vegetables with firmness (texture) of their preference.

4.2 Health properties

Raw vegetables are relatively higher in phytochemicals when compared to processed vegetables, as phytochemicals are sensitive to most processing conditions. In general, leaching into the cooking water, thermal degradation and isomerisation, evaporation, sensitivity to light, oxidation, and enzymatic and non-enzymatic degradation are some of the processes through which phytochemicals and nutrients are destroyed or degraded during domestic processing. These influences are dependent on conditions like method of cooking, type/amount of phytochemicals in the vegetable and matrix of the vegetable, water/oil-vegetable ratio and time-temperature profile (12, 27, 31).

Changes in glucosinolates in broccoli and β-carotene in carrots as a function of domestic processing are studied in this thesis.

4.2.1 Glucosinolates

Glucosinolates are the water-soluble sulphur-containing secondary plant metabolites of Brassicaceae vegetables, such as cauliflower, broccoli, cabbage, Brussels sprouts and kale (12). Depending on the side chain amino acid, glucosinolates can be classified into aliphatic (e.g., glucoiberin, glucoraphanin, sinigrin, gluconapin), aromatic (e.g., glucotropaeolin, gluconasturitiin) and indolic (e.g., glucobrassicin, 4-hydroxy-glucobrassicin, 4-methoxy-glucobrassicin, neo-brassicin) (12). On damaging the plant tissue by processes like chewing, cutting and heating, glucosinolates come into contact with the endogenous enzyme myrosinase (thioglucoside glucohydrolase, EC 3.2.1.147), which is normally localised and stored in the vacuoles of the plant cell (12, 35-37). Myrosinase rapidly hydrolyses glucosinolates into glucose, sulphate and isothiocyanates, thiocyanates, nitriles, or oxazolidine-2-thiones. The isothiocyanates are considered to exhibit the anti-carcinogenic activity in the human body (12, 21). Processing like blanching, high pressure cooking, boiling and microwaving (depending on the time and treatment intensity) reduce glucosinolates substantially, while steaming and stir frying are either reported with no or lesser losses (12). The fate of glucosinolates by the processing methods along the food chain is also predicted using mathematical modelling (24, 38).

4.2.2 Carotenoids

Carotenoids are C_{40} tetraterpenoids with conjugated double-bonds. Hydrocarbon carotenoids (made of only hydrogen and carbon) are collectively called carotenes, e.g., β-carotene, α-carotene and lycopene; and those with oxygen are called xanthophylls, e.g., lutein and zeaxanthin. Carotenoids are hydrophobic compounds present as lipoprotein complexes within chromoplasts deposited in crystalline form in carrots. The most abundant carotenes in carrots are α- and β-carotene. Both carotenes exhibit pro-vitamin A activity and also act as antioxidants (3, 7, 15, 39). Carotenes however need to be micellarised in order to be bioavailable in the human body (40). Methods like boiling, frying and steaming are reported to decrease total carotenes from carrots (41-43). Nevertheless, processing improves the bioavailability of compounds like carotenoids, by breaking the plant cell wall and the protein-chlorophyll complex in which they are localised (40, 44).

5. INTERDISCIPLINARY APPROACH FOR OPTIMISING DOMESTIC PROCESSING

Acknowledging the changes in sensory and health properties and the assumed significance of these properties in determining the overall liking of vegetables, domestic processing conditions should be optimised for the societal well-being. Process optimisation in this case will aim to develop or redefine the 'current' product into a product that aligns with consumer's sensory preferences but possesses higher amounts of phytochemicals. For optimisation, processing conditions of vegetables applied by consumers and their consecutive influences on the *sensory* (including the liking and attribute intensity ratings) and *health* properties must be known. The majority of the studies which examined the influences of domestic processing on the quality of vegetable are based on the conditions assumed by the researcher/s and do not represent the conditions applied by the consumer at domestic level. This signals a gap between food technology and consumer science research and the need for an interdisciplinary research approach to optimise domestic processing of vegetables.

By the conventional approach, food technologists examined the influences of 'assumed' domestic processing conditions on the quality of vegetable, whereas, consumer scientists studied behaviour towards food (mainly meat and seldom vegetables). Consumers are advised on the domestic processing of foods based on the findings of food technological studies. An example of such an advice is the instruction on meat handling practices. However, these advices do not automatically lead to a change in behaviour (45). Domestic processing conditions applied by consumers are hypothesised to be controlled mainly by habits, convenience and changes in perceivable sensory property like texture and colour during processing (8), while changes in health property are not perceivable.

Collaboration between consumer science and food technology research is suggested in this thesis to address such societally-relevant issues, which require comprehensive analysis in social and technical dimensions (Figure 1).

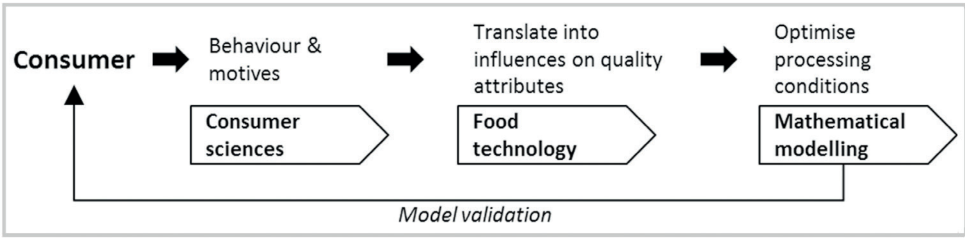

Figure 1. Integrating information from different disciplines to optimise domestic food processing conditions.

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Consumer studies would reveal the information on consumer behaviour towards vegetables and motives for this behaviour. This behaviour can be translated into changes in sensory (texture, colour, etc.) and health properties (vitamins, carotenes, glucosinolates, etc.) through food technological studies. Mathematical models can be used to capture these changes into equations containing parameters describing the final quality. Mathematical modelling is thus a tool to get grip on what is happening to the sensory and health properties as a function of applied processing conditions such as time, temperature and amount of water used; and to optimise domestic processing (24, 46, 47).

6. OBJECTIVES AND OUTLINE OF THE THESIS

The objective of this thesis is to gain insights into consumer behaviour towards vegetables and to optimise domestic processing conditions applied by consumers for vegetables which are liked equally but are higher in degree of healthiness. There is a lack of information on consumer behaviour towards vegetables and the influences of this behaviour on the final quality. Therefore this thesis **aims**: **first**, to identify a research method that is most reliable, valid and practical, to collect information on consumer behaviour towards vegetables and motives. **Second**, to use this research method to collect information on domestic processing conditions of broccoli and carrot applied by Dutch households. **Third**, to study influences of these processing conditions applied by consumers on the *s*ensory and health properties of broccoli and carrots. **Finally**, to identify processing condition at which these vegetables are liked but are also higher in amount of phytochemicals.

The *Consumer-Orientated Food Technology* research approach was developed to propose a way to integrate information from different disciplines, i.e., consumer sciences with food technology using mathematical modelling as a tool, to identify optimised domestic processing conditions of vegetables. This approach is described in **Chapter 2**.

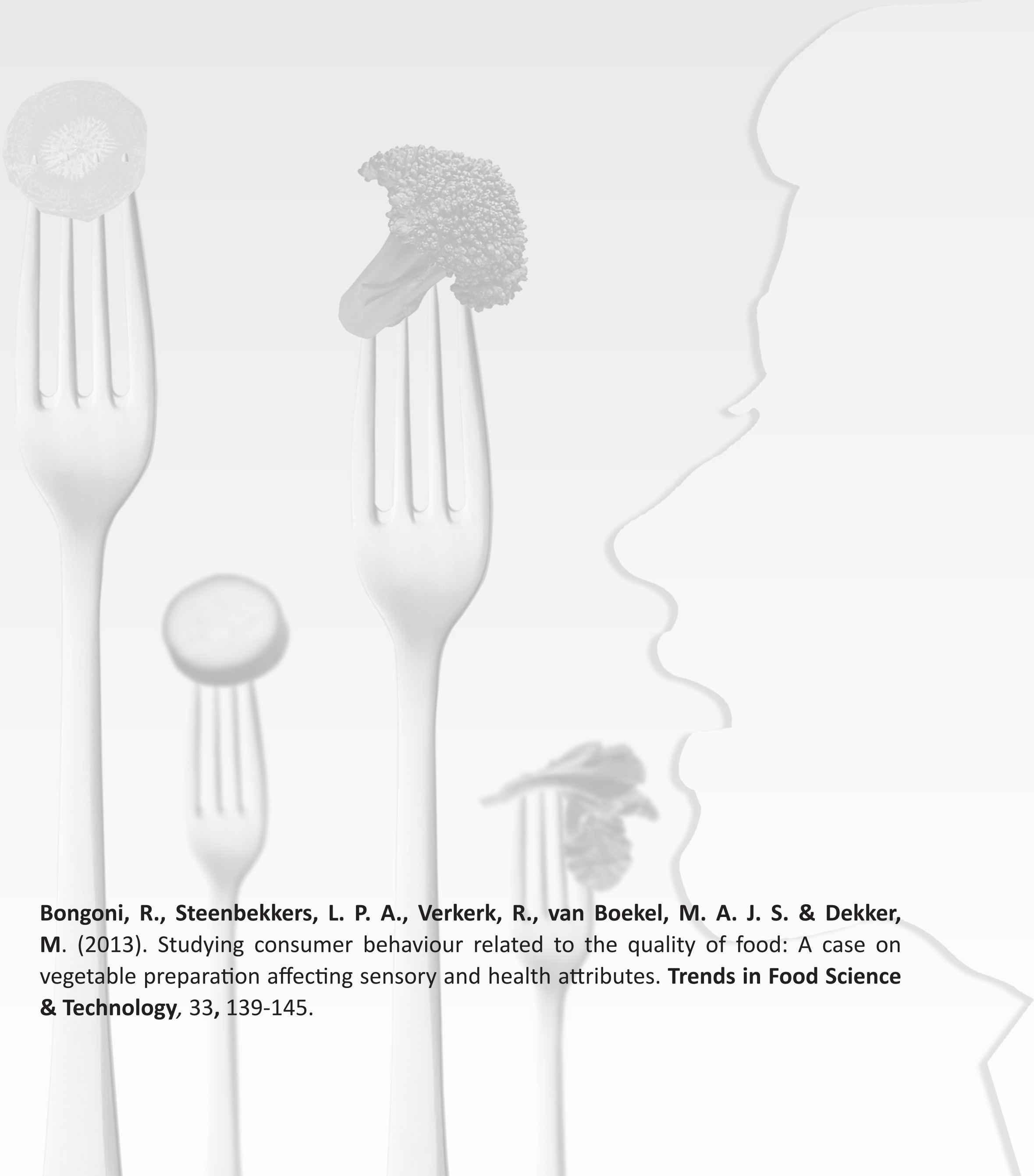
There is a lack of information on consumer behaviour towards vegetables and their consequent influences on the final quality. Therefore in **Chapter 3**, three research methods are evaluated, i.e., direct in-home observations; indirect-observations using cameras in a model-kitchen environment; and self-reporting questionnaires, on domestic processing conditions of broccoli, to identify a reliable, valid and practical method for data collection. This research method was used in **Chapter 4**, to identify domestic processing conditions (and underlying motives) of broccoli and carrots by Dutch households. Further, the information obtained was used to cluster Dutch households into groups with comparable behaviour and underlying motives.

Influences of domestic processing conditions of broccoli **(Chapter 5)** and carrots **(Chapter 6)** applied by consumers, on instrumentally measured firmness, colour and phytochemicals, and on sensory evaluation for overall liking and attribute intensity were assessed, to know the processing conditions that will yield these vegetables that are liked equally and are higher in the amount of phytochemicals.

In **Chapter 7**, the main findings are summarised. Along with optimising domestic processing using mathematical models, methodological considerations are presented and the interpretation of the findings are discussed. Further, the scope of future research is also discussed.

Chapter 2

Studying consumer behaviour related to the quality of food: a case on domestic processing of vegetable affecting sensory and health properties



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ABSTRACT

The domestic processing of vegetables induces a significant change in their sensory and health properties. These processing conditions applied by consumers are likely to be controlled by assessing perceivable (sensory) quality properties such as colour and texture because other quality properties, including the amount of phytochemical (health), cannot be directly assessed. 'Consumer-Orientated Food Technology' is introduced herein as a research approach for the 'multi-criteria optimisation' of vegetable quality after domestic processing. Mathematical modelling for 'multi-criteria optimisation' is proposed as a tool to meet consumer sensory preferences while optimising health benefits. This approach is valuable for consumer-based strategies for healthy, tasty vegetables.

Keywords: Mathematical Modelling; Food Technology; Consumer Science; Interdisciplinary Approach; Multi-Criteria Optimisation.

1. INTRODUCTION

Vegetables and fruits are rich sources of a variety of phytochemicals. Though not unequivocal, the consumption of vegetables and fruits has been associated with increased health benefits, e.g., decreased risk of the occurrence of chronic diseases such as cancers, cardiovascular diseases, diabetes type II, and obesity (42). Studies have shown that many phytochemicals possess biological activities that are related to such health benefits (12, 48).

Often, vegetables are processed (e.g., cutting and cooking) at the domestic level before consumption. The behaviour of consumers related to the domestic processing of vegetables might be determined by a variety of factors, e.g., habits, sensory preferences, situational factors and perceived health benefits. Handling practices during the domestic processing of vegetables by consumers can be hypothesised to be mainly controlled by the perceivable quality attributes (regarded as sensory property) such as colour and texture as changes in other quality attributes, such as the amount of phytochemicals and vitamins (regarded as health property), during cooking cannot be directly perceived.

Domestic processing induces a significant change in the physical and chemical properties of vegetables. On the one hand, during domestic processing, the texture, colour, and flavour improve towards the consumer's preferences. On the other hand, the amount of phytochemicals, which are sensitive to most processing conditions (37), largely decreases upon processing, although their bioaccessibility can increase (24, 42). In fact, every step in the food chain, including domestic processing, has a substantial influence on the health and sensory properties of vegetables. Mathematical modelling has estimated that large variations in the amount of compounds such as phytochemicals occur during the domestic processing of (fresh) vegetables (24, 49).

A study of the literature on the domestic processing of vegetables revealed that the domestic processing steps and conditions, i.e., the actual consumer behaviour and handling practices related to the vegetables from the time of purchase until the time of consumption, have never been explored by consumer scientists. Furthermore, studies conducted on the influences of selected domestic processing conditions on the health and sensory attributes of vegetables (42, 50-53) are always designed from a food technological point of view without addressing the consumer aspects. In other words, the range of domestic processing conditions in these studies is chosen by the technologists and does not necessarily reflect the domestic processing conditions applied by consumers.

Food technologists aim to optimise the processing conditions of foods to achieve higher nutritional value of the processed food. Alterations in the sensory properties are a barrier for the consumer to adopt the messages from food technologists in processing the specific food (vegetable). Thus, sensory alterations remain a challenge in optimising the processing conditions.

Consumer scientists merely report behaviour that might rarely be used by the other actors, such as food technologists, in product development as their reports lack the required details. With the exception of packaging, convenience and marketing strategies, food technologists barely focus on optimising the last part of the food chain, i.e., the domestic processing conditions of vegetables that meet the consumers' sensory preferences in addition to possessing higher health benefits upon consumption. Food technologists need information from consumer scientists, and consumer scientists need food technological information that can be communicated to the consumers. Food technologists often do not collect information on consumer behaviour, and consumer scientists often do not collect information on the food technological aspects of a product. A joint project is necessary for collaborative action between consumer scientists, who would gather detailed information from consumers on their vegetable processing conditions, and food technologists, who would assess the quality parameters and optimise the processing conditions. This integrated information should reach consumer scientists to evaluate the sensory acceptability of the vegetable cooked under optimised conditions and to later forward the information to consumers.

To obtain a product with the desired sensory preferences (e.g., texture, colour, and taste) and maximum health benefits upon consumption (e.g., higher vitamin and phytochemical amounts), the processing conditions must be optimised using multiple criteria. Associating changes in sensory properties with changes in health properties to indicate ways to improve the final quality of domestic processed vegetables by such a '*multi-criteria optimisation*' approach has not yet been reported in the literature.

The objective of this viewpoint paper is to elucidate the need to study the details of the domestic processing of vegetables by consumers from purchase to consumption and its influence on the health and sensory properties of the vegetables. This viewpoint paper proposes to use mathematical modelling of the changes in the quality of vegetables to perform '*multi-criteria optimisation'* to identify ways to satisfy consumer sensory preferences for cooked vegetables while optimising the health benefits from vegetable consumption. *Consumer-Orientated Food Technology* (COFT) is introduced as a research strategy that integrates information and knowledge from the consumer science domain with those from the food technology domain. With such information, strategies to create awareness among consumers and to design and develop vegetable products and kitchen appliances that assist consumers in a science-based method to prepare tasty and healthy vegetable dishes can be developed.

2. QUALITY OF VEGETABLES ALONG THE FOOD CHAIN

Quality is a complex term perceived differently by each actor in the food chain (54). The quality of vegetables can be distinguished into *extrinsic* and *intrinsic* quality. *Intrinsic* quality is the inherent physico-chemical characteristics of the vegetables, and *extrinsic* quality is associated with the production process and packaging (and brand) and not with the vegetables themselves. *Intrinsic* quality can be further distinguished into *health* properties (e.g., vitamins, minerals, fibre, and phytochemicals), *sensory* properties (e.g., texture and colour), and other properties such as safety and shelf life (12, 55).

Along the food chain (from the point of harvest through postharvest handling until the processed vegetables are ready for consumption), the health and sensory properties of the vegetables may change. Before the point of sale, specific conditions such as temperature, time and packaging, are controlled or modified by actors in the food chain to control the physiological changes and some sensory properties of the vegetables (25). After the point of sale, consumers transport, store, and process the vegetables based on their sensory preferences, situational factors, and habits. Therefore, the health and sensory properties of vegetables after the point of sale are affected mainly by the consumers via their domestic processing steps and conditions. Consumer behaviour is expected to differ greatly among age groups, ethnicities and cultures, adding further variation in the domestic processing conditions of vegetables.

3. ESTIMATING VARIATION IN QUALITY ATTRIBUTES OF VEGETABLES

Mathematical modelling is a tool that can be used to study the influences of cooking methods and conditions on the change in the quality of vegetables. A mathematical model for food quality consists of a set of equations to describe the changes in several quality properties, e.g., colour, texture, and the amount of a certain compound. In a mechanistic model, the equations describe the essential sub-processes that affect dynamic changes in a relevant aspect of quality as a function of various processing conditions (56, 57). Changes in these quality attributes as a function of the processing conditions should be modelled to estimate the final quality of the food (vegetable), which determines its acceptability by consumers. In this paper, the amount of important health-promoting phytochemicals (glucosinolates) of *Brassicaceae* vegetables and the texture of the vegetable will be taken as examples of product properties related to health and sensory quality, respectively.

Mathematical model equations describing the amount of glucosinolates are derived from the relevant mechanisms affecting the amount in the plant tissue during domestic processing. Existing models on the processing of *Brassicaceae* vegetables (38, 57) can be applied to estimate the effect of different vegetable processing conditions by consumers on the amount of glucosinolates in the final product. These equations are based on differential equations to describe biochemical reactions and diffusion rates, mass balances to describe the partitioning between different compartments, and Arrhenius-like equations to describe the effect of temperature on all rate constants in a model. The sub-processes that are described by the model employed in this paper are cell lysis, leaching, and chemical degradation of the phytochemical. Any enzymatic (myrosinase) activity affecting the glucosinolates is ignored as during most cooking conditions, the temperature will rapidly exceed the denaturation temperature of the enzyme (58). Cell lysis is described by a first order breakdown of the intact cells in the vegetable. Leaching occurs as a consequence of cell lysis. Glucosinolates are assumed to partition between the water phase trapped in the lysed part of the vegetable tissue and the water phase outside the vegetable. Chemical degradation is described by a first order reaction (59). In the study of Sarvan et al. (38), the brassica vegetable was boiled at different temperature-time profiles, and the results showed different values for the rate constants of the breakdown of glucosinolates in the intact vegetables and in the cooking water. The parameter estimation for the model is described by Sarvan et al. (38).

As an input for simulating the effect of consumer behaviour on the amount of glucosinolate, having information on the vegetable processing conditions, such as cooking times and water-vegetable ratios, that are applied by consumers is necessary. Because this information is not available in the literature, several *assumptions* have been made based on preliminary observational research on domestic processing of broccoli by consumers in the Netherlands (60). The maximum boiling time for brassica vegetables observed in the research that compared different research methods for data collection on consumer vegetable processing conditions was 50 minutes, and the maximum water-vegetable (W:V) ratio *(w/w)* measured in that study was approximately 4. A W:V ratio of up to 4.5 may be required to completely submerge the brassicas (e.g., broccoli) under the water while boiling. For simulations, these ranges were somewhat extended to present a hypothetical situation that shows variation in only two domestic processing conditions, i.e., the W:V ratio (*w/w)*, and cooking time. Influences only on the texture change will be considered as a part of this hypothetical situation. The *assumptions* on the frequencies of the *cooking time* and *water-vegetable ratio* for *boiling* brassica vegetables that were used in the simulations are given in Figure 2a and 2b, respectively.

By using the model equation from Sarvan et al. (38) with the *assumed* frequencies of the domestic processing conditions, the effects on the amount of glucosinolates in brassica vegetables were estimated (Figure 3a) with the software package Athena Visual Workbench (www.athenavisual.com).

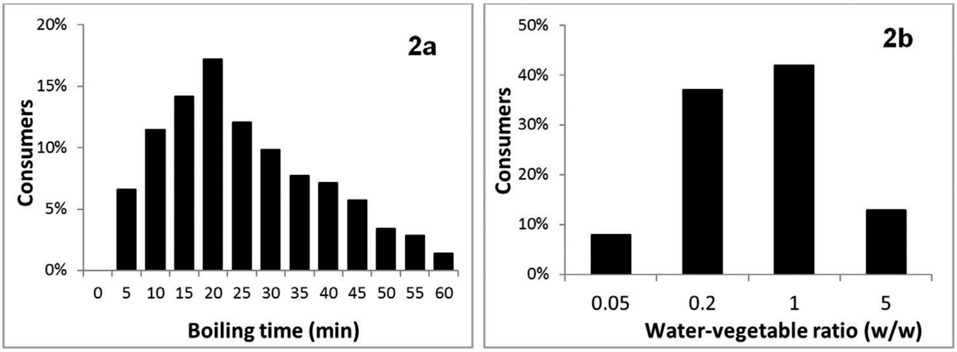

Figure 2. Assumed frequencies of consumer behaviour when boiling the brassica vegetables: (a) assumed boiling times, (b) assumed water-vegetable ratios.

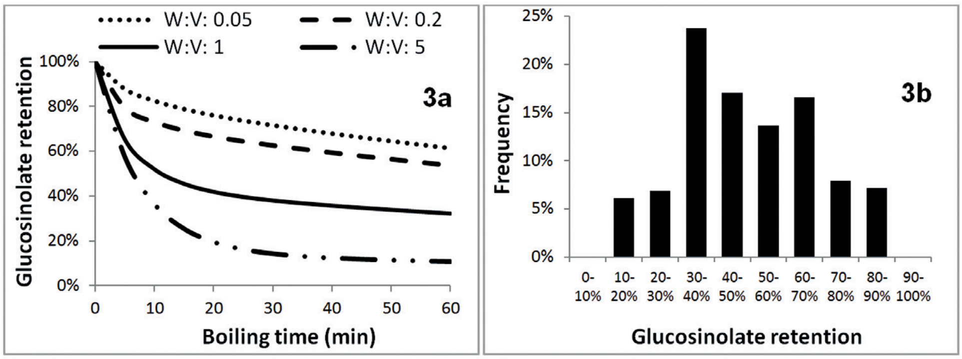

Figure 3. (a) Simulating the effect of the assumed cooking time and assumed water-vegetable ratios on the percentage of glucosinolate retention in brassica vegetables using a mathematical model of the vegetable processing. (b) Estimation of the variability in the consumed levels of glucosinolates (expressed as the percentage of the amount in the fresh vegetables) with the assumed domestic processing conditions used for Brassicaceae vegetables.

With information from Figure 3a, it appears a straightforward approach to directly inform consumers to adapt their domestic processing conditions, i.e., reducing the W:V ratio to increase the intake of phytochemicals from the vegetables, as consumers mainly control the domestic processing of vegetables via changes in the sensory properties of the vegetable and not by changes in health properties. From the food technologist's perspective, reducing the W:V ratio for boiling, e.g., by steaming, can reduce the loss of glucosinolates in the boiled brassicas. However, compared with other motives the consumers might have, the sensory properties such as the colour, texture, and flavour of the vegetable differ greatly at different W:V ratios. Thus, from the consumer scientist's perspective, this change in processing condition appears not to be feasible advice to the consumer, especially for those consumers who boil at a high W:V ratio to obtain vegetables with a softer texture.

Although health is mentioned by consumers as one of the important factors that determines their domestic processing of vegetables (61), the presented variation in the intake amount of phytochemicals (Figure 3b) is not perceivable by consumers in the kitchen, in contrast to the sensory changes. In this viewpoint paper, a strategy to meet consumer sensory preferences while optimising the amount of phytochemicals is given, using the texture changes in brassica vegetables during boiling as an example. Texture was reported by approximately 65 % of the consumers as the method to determine the doneness of their prepared vegetables (61).To illustrate this issue, texture changes and sensory evaluations by the consumers of broccoli boiled at different times were used from the unpublished data of Jasper et al. (62). The *range of texture changes acceptable* for a given group of consumers is assumed based on this information (Figure 4). The change in texture could be described by a fractional conversion-first order model (Risvi & Tong, 1997), as depicted in Figure 4. Again, for this example, texture change is assumed to be independent of the W:V ratio.

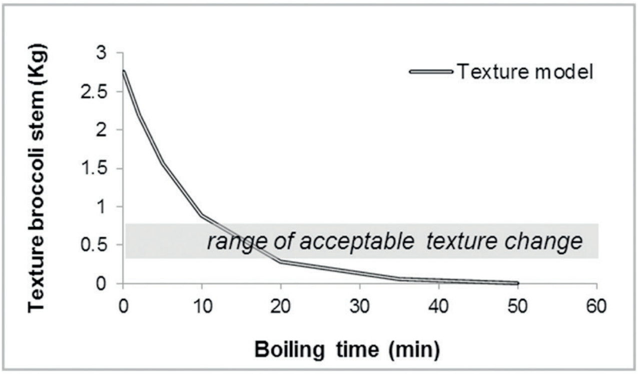

Figure 4. Texture change during the boiling of (broccoli) brassica vegetables.

Superposing information from Figure 3a with information from Figure 4, a boiling time range can be identified with the acceptable texture by consumers for boiled *brassica* vegetables (Figure 5). By changing the W:V ratio, the retention of glucosinolates can subsequently be optimised for the presented hypothetical situation.

The below graph (Figure 5) is a simplified example of *multi-criteria optimisation* applied to a hypothetical situation with variation in only two domestic processing conditions (time and water/vegetable ratio). *Multi-criteria optimisation* in this hypothetical situation aims to identify a range of boiling times to meet the consumer texture preferences while optimising the amount of phytochemical by adjusting to a lower water-vegetable ratio. In a more realistic situation, domestic processing involves many more variations in the conditions (e.g., size of the vegetable pieces, time-temperature profile, cooking method and medium, and influence of other ingredients) that all affect the final quality of the vegetables. Therefore, to optimise the processing conditions for higher health benefits and sensory properties of cooked vegetables, food technologists should integrate the information on consumer behaviour towards vegetables, which is often collected by consumer scientists. Furthermore, to advise consumers on the optimised processing conditions for vegetables, consumer scientists need information from the food technologists. *Multi-criteria optimisation* in a realistic situation will aim to identify the domestic processing conditions that can meet several sensory preferences (e.g., colour, texture, and flavour) of the consumers for cooked vegetables with maximum health benefits upon vegetable consumption. To estimate such outcomes on the variation in the final quality of the vegetables with mathematical models, quantitative and qualitative information on the domestic processing conditions of vegetables by consumers (consumer behaviour) and their sensory preferences (reasons) is required, e.g., Figure 2a, 2b, 4.

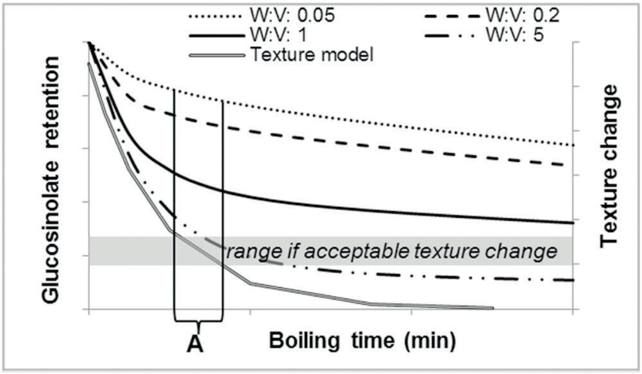

Figure 5. Identifying the time range to be optimised for the amount of glucosinolates, given the consumer sensory (texture) preferences for boiled brassica vegetables. A: Range of boiling times for the identified acceptable texture range.

4. CONSUMER RESEARCH

The lack of detailed information in the literature on the domestic handling practices of vegetables and on the motives for these practices has made it impossible for food technologists to optimise the domestic processing conditions of vegetables. With such information, food technologists can predict the influences on the final quality of vegetables and propose optimised processing conditions using mathematical models. A sensory study on the acceptability of vegetables prepared under the optimised conditions can be used to validate these models.

Consumer scientists investigate consumer behaviour by investigating how, what, when, and why consumers behave the ways they do. Several research methods have been proposed to study consumer behaviour and the reasons for their behaviour.

Observations, interviews (structured or unstructured), focus group discussions, and self-reported questionnaires are among the suggested methods (63, 64). Each method provides different types of information, either qualitative or quantitative and occasionally both. Depending on the research questions, the most suitable method can be selected. Focus group discussions or self-reported questionnaires asking about consumer behaviour and the reasons for that behaviour or a combination of methods, such as observations with interviews, are among the proposed methods for data collection (Figure 6).

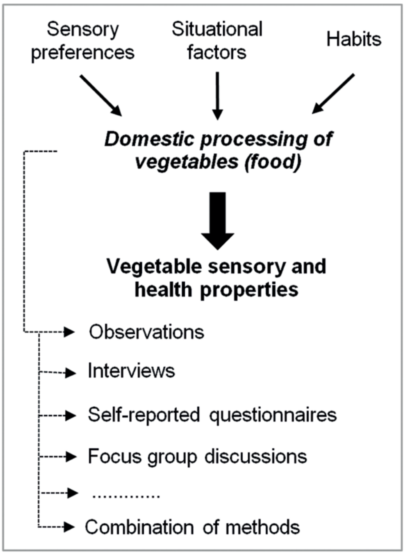

Figure 6. Research methods for consumer behaviour and motives.

Self-reporting questionnaires have the advantage of being able to reach large sample sizes in a rather short period of time, in contrast to direct observations, focus group discussions and interviews. Although self-reports have been questioned for the reliability and validity of the collected information (63, 65), *validated* self-reports have been suggested as an alternative to observations (66). Because of such conflicting findings on the reliability and validity of these research methods from the literature, research has been conducted to compare direct observations, observations in a model-kitchen provided with cameras and a self-reported questionnaire to identify a reliable, valid and practical research method for data collection on the domestic processing of vegetables by consumers (60).

5. THE CONSUMER-ORIENTATED FOOD TECHNOLOGY (COFT) RESEARCH APPROACH

Traditionally, consumer science research (for information on consumer behaviour related to foods, e.g., domestic processing conditions) and food technology research (for information on the influences of domestic processing on the quality attributes of foods) have been approached from different perspectives. For example, consumer scientists aim to merely explore the relationship between the consumer and the food by studying and reporting the identified behaviour towards food, occasionally supported by identifying the reasons for this consumer behaviour, without presenting the information in a way that enables the use of the information by food technologists. Similarly, food technologists investigate the influences of domestic processing on the quality of foods (vegetables) without knowing the real consumer behaviour and without understanding the needs and expectations of the consumers.

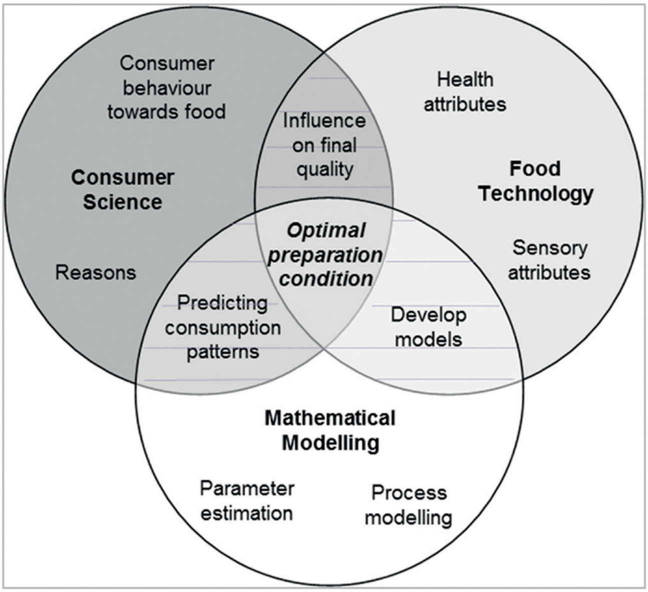

Figure 7. The consumer-orientated food technology research approach.

Consumer science research with a suitable method to answer the research question will provide qualitative and qualitative data, i.e., the consumer behaviour and reasons, such as the sensory preferences of the consumers. Food technology provides quantitative data, such as the influences of possible consumer behaviour on the health and sensory properties of the foods (vegetables). The core of the suggested COFT approach in this paper is to integrate the information from consumer science and food technology using mathematical modelling as a tool to connect the information from both fields (Figure 7). A sensory study asking about the liking and preferences of the chosen vegetable cooked under optimised conditions as proposed by the mathematical model of the COFT approach can validate such a model. COFT has been illustrated in this paper by the simplified example of reaching consumer texture preferences while optimising the amount of glucosinolates in the cooked vegetable through *multi-criteria optimisation*. Such an optimisation may lead to new insights useful for the development of new vegetable products and new kitchen appliances (e.g., using sensor technology to control the domestic processing) and for the improvement of information directed at consumers to help them make healthier choices. Furthermore, mathematical models estimating the variation in the amount of phytochemical in cooked vegetable are an important contribution to a more realistic estimation of the intake of phytochemicals for epidemiological studies on the health effects related to vegetable consumption (24).

6. CONCLUSION

In the past decades, consumer views, needs and expectations on food have changed drastically. In addition to sensory preferences, the health benefits of foods are an increasingly important factor for the choice of products. A strategic integration is needed to translate consumer sensory preferences and food handling practices to obtain food products with increased healthiness. The *Consumer-Orientated Food Technology research* approach is a collective idea integrating two or more disciplines to meet the needs of the present day consumer. The suggested use of mathematical modelling and the introduced *COFT* research approach in this paper propose ways to study consumer behaviour and estimate the influence on the final quality of cooked vegetables, finally suggesting methods for the *multi-criteria optimisation* of the final quality of the vegetables. *Multi-criteria optimisation* for food (vegetable) quality produces information that can steer the product and process design for new food (vegetable) products with direct health benefits for consumers. This science-based information can be used to improve dietary habits and to inform consumers about domestic processing conditions. Using mathematical models to estimate the amount of phytochemicals in epidemiological studies can provide estimates of the more realistic intake of phytochemicals from prepared vegetables. The COFT approach, although illustrated herein for vegetables, can be used for many types of food to aid food product and process design and to develop kitchen appliances that can assist consumers to prepare tasty and healthy foods. For other types of food, the issues to be solved will be different. The adaptations will thus include different technical details, different consumer research questions and data collection methods, and different mathematical models and parameters to be estimated for the model. The approach, however, will be similar.

7. ACKNOWLEDGEMENTS

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Chapter 3

Evaluation of research methods to study domestic food processing

Bongoni, R., Verkerk, R., Dekker, M. & Steenbekkers, L. P. A. (2014). Evaluation of Research Methods to Study Domestic Food Preparation (*accepted*). **British Food Journal.**

ABSTRACT

Domestic processing conditions influence the sensory properties and nutritional composition of food products. Information on the variability in domestic processing conditions is needed to assess the influence of applied conditions on the sensory and nutritional quality of food. The collection of such information requires a reliable, valid and practical research method. Direct in-home observations, observations in a model-kitchen using cameras, and a self-reporting questionnaire were evaluated for reliability and validity, to study domestic food processing by consumers. Domestic processing of broccoli by Dutch consumers was checked by these three methods in this research paper. All three research methods were found to be test-retest, inter-observer, parallel-form reliable; and face, content and concurrent valid. However, the self-reporting questionnaire is the most practical research method that can be administered on a large number of respondents in a short time to capture the wide variations in processing conditions.

Keywords: Reliability; Validity; Food processing; Self-reporting questionnaire; Observation (through cameras); Consistency in behaviour.

Abbreviations:

MK	Model-Kitchen
RoF	Restaurant of the Future
ICC	Intraclass Correlation Coefficient

1. INTRODUCTION

Acceptability of processed food depends mainly on the sensory, safety and health properties (67). These properties are, to a large extent, determined by the final processing conditions applied to the food by the consumer. Therefore, domestic processing conditions determine the final quality of the food. Several research methods are available to gather information on food processing conditions applied by consumers like (self-reporting) questionnaires, in-depth interviews, focus group discussions and (in)direct observations (63). However, prior to data collection, a research method should be tested for its reliability and validity, in order to decrease the disparity in the information obtained using different research methods (66, 68). Reliability is the extent to which a research method produces the same results upon repeated administration, and validity is the extent to which a research method actually measures what it is supposed to measure (69, 70). Redmond et al. (63) summarised types of reliability and validity tests for research methods commonly used to gather information on consumer meat handling practices. Besides reliability and validity of the method, data should be gathered from a large sample to generalise the findings to the population level (71, 72). Despite these concerns, research methods are hardly ever compared prior to data collection to use the most reliable, valid and practical method appropriate for a given consumer research.

Vegetable processing is an illustration of consumers' food handling practices in the kitchen. Domestic processing of vegetables, determined by the dynamic interaction of factors such as habits, sensory preferences and household composition, have a significant effect on the sensory properties of cooked vegetable (10, 42). Vegetables are a rich source of nutrients and phytochemicals (non-nutrient health promoting compounds). Processing conditions, such as cooking method, medium of cooking (e.g. water, oil, condiments), cooking time-temperature profile, size of the vegetable, determine the final amount of these compounds in the prepared vegetables (12, 50, 51, 57, 73, 74).

Consumers can be assisted on domestic processing conditions that reach their sensory preferences (e.g., texture, colour) as well as have health benefits on consumption (75). For this, domestic processing conditions of vegetables should be known. In the scientific literature, information is lacking on domestic processing conditions of vegetables. This information can be used as an input for food (vegetable) product development, which satisfies e.g., the consumers' texture and colour preferences of the final product while simultaneously having a high nutritional quality.

For domestic food-handling practices, frequently used data collection methods are observations (direct or by cameras), self-reporting questionnaires, interviews, focus-group discussions, and food diaries (63, 64). Observations and self-reporting questionnaires have been used to explore consumer behaviour towards food, e.g., meat handling practices, food (cross-) contamination, food preferences and consumption frequency (66, 68, 76-78), but never for vegetable processing conditions.

Observations (direct or through cameras) capture an individual's actual behaviour (66, 79-81). Observation is time consuming, relatively expensive and reaches a small sample size in a given period of time (80). Observer bias, inaccurate coding or recording, inadequate understanding on coding behaviour, and the influence of the presence of an observer or camera (reactivity) are concerns associated with observations (82).

A self-reporting questionnaire on consumer behaviour can be administered on a large sample in a short period of time at a relatively low price (66, 76). However, a self-reporting questionnaire is reported to show disparity between observed and reported behaviour (65, 68).

This research paper evaluates three methods to study domestic processing conditions of vegetables (broccoli) among Dutch households: 1: Direct in-home observations, 2: Observations in a model-kitchen equipped with cameras, and 3: A self-reporting questionnaire, for reliability, validity and practicality in use. Broccoli is among the commonly consumed vegetables in Dutch households (83) and is rich in a specific group of phytochemicals called glucosinolates (12). Several *in-vitro* and *in-vivo* studies suggest that glucosinolates and their breakdown products exhibit anti-carcinogenic activity on consumption (84, 85) and that domestic processing conditions highly influence the amount of glucosinolates in prepared vegetables (12, 38). Broccoli is therefore a good example where handling practices are important for both the sensory and the nutritional quality of the final product.

2. METHODOLOGY

2.1 Research design and rationale

Three different research methods are compared in this research (Figure 8).

i. *In-home observations - Study 1:* two direct in-home observations were conducted on 15 participants, with a gap of at least 4 days between every observation

ii. *Observations through cameras in a model-kitchen - Study 2:* six repeated observations were conducted on 10 participants (different from the participants of the direct in-home observations), with a gap of at least 4 days between every observation. The first five observations were conducted in a model-kitchen (MK) equipped with cameras to assess intra-individual variability over time, followed by one direct in-home observation to assess the influence of the environment

iii. *Self-reporting questionnaire - Study 3:* a self-reporting questionnaire was administered on all the 25 participants from *Study 1* and *Study 2,* at least 3 months after the last (in-home) observation.

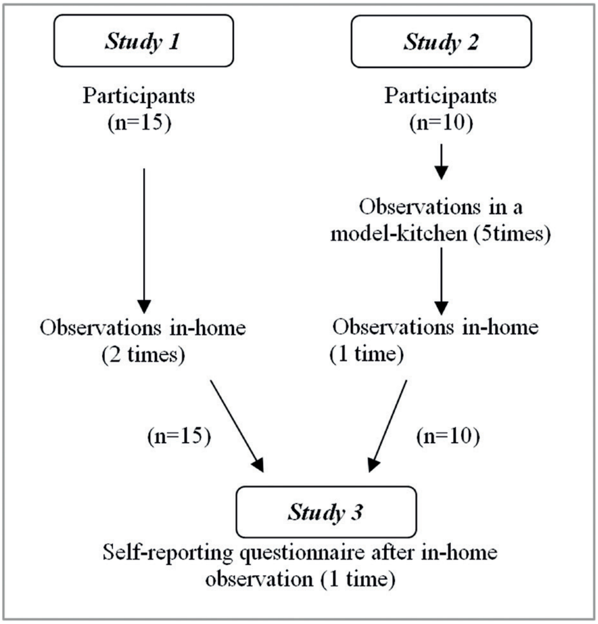

Figure 8. Research design to compare research methods on domestic processing of vegetable as a meal component.

Consumers are expected to have routine behaviour in habitual domestic activities like preparing a meal (in our case: vegetables). Observing participants (i) on different days, i.e., 15 participants of *Study 1* observed on 2 different days and 10 participants of *Study 2* observed on 6 different days, gives an insight into the consistency of the participant's habitual behaviour; (ii) by different methods, i.e., in-home and camera observations on the 10 participants of *Study 2,* gives an insight into the influence of the observation environment by comparing the consistency in participants' behaviour in the MK and in-home. *Study 3* aims to compare direct-observed and self-reported vegetable processing conditions by the participants.

2.2 Participants

Our target group consisted of the main meal preparers of Dutch households with children aged between 4 and 16 years, from Wageningen, the Netherlands. The participants were recruited through the database of Food & Biobased Research (FBR), Wageningen UR. In total, 25 participants (3 men and 22 women aged between 32 and 52 years) agreed to take part in the research. The sample size was restricted considering the time required to conduct and assess the intensive observations, videotape and self-reported questionnaire data for every participant. All the participants were given a gift voucher at the end of the study. The participants of *Study 2* could either take the prepared meal home or invite their family to have the prepared meal at the restaurant attached to the MK of Wageningen University and Research Centre.

The focus of the research, namely domestic processing conditions of broccoli was revealed to the participants only at the end of the last (in-home) observation.

2.3 Data collection and coding behaviour

For observations, participants were provided with the meal components, which included a variety of meat each day, pre-cooked potatoes, broccoli and sauce mix, sufficient as dinner for the whole family.

Participants were asked to prepare the complete meal as they usually do at home. Broccoli processing conditions were recorded on a predefined checklist (Table 1) that includes several conditions that are known to affect the amount of glucosinolates in the product. A pilot prior to the real observations was conducted using the predefined checklist, to check for the visibility of the broccoli handling practices and completeness of the checklist. The self-reporting questionnaire contained questions based on the checklist items mentioned in Table 1.

Table 1. Predefined checklist used for recording processing of broccoli.

Question of the predefined checklist on the processing of broccoli (abbreviation used in the following tables)	Choice of the answers
Wash broccoli before processing (Wash broccoli)	*Yes* *No*
Part of the broccoli used (Part of the broccoli)	*Florets without stalks* *Florets with stalks* *Florets with stalks and the sliced stem*
Amount of broccoli used, in grams (Weight of broccoli)	*Weight of broccoli minus weight of the waste*
Cooking method (Cooking method)	*Boiling* *Steaming* *Stir frying* *Others*
Amount of water used for boiling (Water level)	*Water level in the pan relative to the level of broccoli (Figure 9)*
Initial temperature of the water used for boiling broccoli (Type of start)	*'Cold start'- cold water from the tap* *'Warm start'- warm water from the tap* *'Boiling start'- boiling water*
Lid placed on the pan while preparing broccoli (Use of lid)	*Yes* *No*
Addition of salt while preparing broccoli (Addition of salt)	*Yes* *No*
Total broccoli cooking time, in minutes (Cooking time)	*Time since when the broccoli was under heat till broccoli was considered done*

Ways to check the doneness of the broccoli (Doneness)	*'Texture'- pricking with knife/fork* *'Colour change'- visual* *'Taste'- eating* *'Time'- check time for preparing broccoli*
Fate of the water left after boiling the broccoli (Water left)	*Used: for sauce or soup* *Thrown away* *Not applicable*

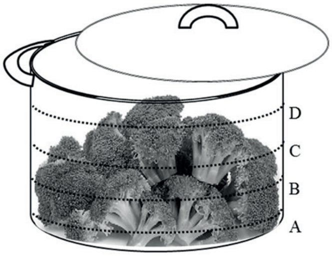

Figure 9. Water levels in the pan containing broccoli.

2.3.1 In-home observations – Study 1

Observations were done by a researcher at the participant's home, using the checklist. Short informal talks between the observer and the participant were allowed during the observations.

2.3.2 Observations through cameras in a model-kitchen – Study 2

Observations were conducted in the model-kitchen (MK) of the Restaurant of the Future (RoF), Wageningen University and Research Centre, which was self-sufficient with necessary utensils and ingredients as in a usual kitchen. The MK was equipped with two cameras fixed in the ceiling of the kitchen. A researcher observed and coded the behaviour 'real-time' from the monitor in the control room, where the participants' behaviour was also being videotaped (The Observer XT, Noldus Information Technology). The video recordings were double reviewed and analysed: (i) by the researcher to compare 'real-time' and 'videotape' coding and, (ii) by another researcher, for inter-observer reliability.

2.3.3 Self-reporting questionnaire – Study 3

A self-reporting questionnaire, in Dutch, consisting of 27 questions (open- and closed-ended) on broccoli processing conditions was posted to the participants' home address (n = 25) three months after the last (in-home) observation. It was instructed that the participant of the observational study should fill in the questionnaire and that the answers should be given about the processing of fresh broccoli. Prior to administering the questionnaire, the clarity of questions was tested by researchers (n = 12) from different specialisations of Wageningen University. Of all 25 participants, 23 participants returned the completed self-reported questionnaire.

2.4 Reliability and validity of research methods

There are several types of reliability and validity for a given research method (63, 69, 70). Selected types of reliability (i.e., test-retest, inter-observer, and parallel-forms), and validity (i.e., face, content and concurrent) are used to discuss the findings in this paper.

Test-retest reliability is the consistency in a participant's behaviour on different days (63, 70). For this, a participant's behaviour during:

- two in-home observations was compared with each other (*Study 1*)
- five MK observations was compared with each other (*Study 2*)

Inter-observer reliability is the consistency in a participant's behaviour coded by different observers (63, 70). For this, the participant's behaviour during five MK observations coded by two different observers was compared (*Study 2*).

Parallel-forms reliability is the consistency in a participant's behaviour assessed with different research methods (63, 70). For this, the participant's behaviour:

3

- during the last MK and the in-home observation was compared with each other (*Study 2*)
- coded 'real-time' and after reviewing the 'videotape' was compared with each other (*Study 2*)
- observed directly in-home and self-reported was compared with each other (*Study 3*)

Face validity is the subjective assessment of the relevance of a question and its presentation in the questionnaire and the checklist (63, 70). The questions and the checklist items followed different stages of the domestic processing of broccoli in a logical sequence and allowed for variation in each processing step. The face validity of the self-reporting questionnaire appeared reasonable and appropriately phrased in terms of language, checklist items, and questions related to broccoli processing conditions.

Content validity is the extent to which the self-reporting questionnaire and observations are representative for broccoli processing conditions as a routine behaviour by participants (63, 70). This was checked by conducting pilot observations in the MK and pre-administering the self-reporting questionnaire prior to administering to the participants and was judged to be appropriate.

Concurrent validity is the extent to which MK observations and/or a self-reporting questionnaire can replace direct in-home observations (63, 70), considering direct-home observation as a reliable and valid research method for information on domestic food-handling practices (63).

2.5 Data analysis

Descriptive statistics (i.e., frequencies) were done using IBM SPSS statistics 19. Test-retest reliability was established by the Friedman test with corrected *p*-value, by the Bonferroni coefficient, and by the Wilcoxon-signed rank test. Inter-observer reliability and parallel-forms reliability for continuous data was checked by the Intraclass Correlation Coefficient (ICC); and for categorical (ordinal) data by Cohen's kappa coefficient. An ICC of < 0.4 is poor, 0.4-0.75 is fair to good, and > 0.75 is an excellent measure of observer agreement (86). A Cohen's kappa value of 0-0.2 is slight, 0.21-0.4 is fair, 0.41-0.6 is moderate, 0.61-0.8 is substantial and 0.81-1.00 is an almost perfect measure of observer agreement (87). Concurrent validity of categorical data was checked by Spearman's rho and of scale data by the Pearson correlation coefficient.

3. RESULTS AND DISCUSSION

3.1 Consistency in participant's behaviour on different observation days: *Study 1 and 2*

3

The majority of the participants were consistent in most of their observed broccoli processing conditions on different days, except for 'cooking time' and 'weight of broccoli' (Table 2). Behaviour was considered to be consistent when at least 80 % of the participants were consistent in their respective behaviour on different observation days.

Detailed behaviour of the participants in *Study 1* and *Study 2* are summarised in Table 3 and Table 4 respectively.

'Cooking time' of broccoli was the least consistent item of the checklist, and is assumed to be dependent on the 'weight of broccoli', 'water level', 'type of start' and the (in)consistency in coding by the observer, i.e., 'real-time' and 'videotape'. 'Weight of broccoli' was one of the inconsistent variables in *Study 2*. 'Water level', to determine the 'amount of water used' for processing broccoli, as defined in Figure 9, was found to be rather subjectively assessed. A slight shift in the 'water level' in the pan, as perceived by the observer might be considered a different 'water level'. 'Cooking time' is an example of the variable which apparently showed greater variability between consumers (inter-individual variability) compared to within a consumer (intra-individual variability). Figure 10 is a concise representation of the variable 'cooking time' observed for the respective participants on different observation days. The longer the 'cooking time', higher is the expected losses of several water soluble nutrients, such as glucosinolates, vitamin C and folates from vegetables by thermal degradation. This nutrient losses can be further aggravated by the large amount of water used, temperature profile and size of the vegetable piece, all of which facilitate leaching of the nutrients into the cooking water (12).

Table 2. Comparison of information on participants' broccoli processing conditions obtained through different research methods.

Checklist item on processing of broccoli	No. of participants consistent in behaviour: On different observation days: 2 in-home observations (n = 15): Study 1	5 model-kitchen observations (n = 10)[a]: Study 2	Between the model-kitchen and in-home observation (n = 9): (Study 2)	Between observed (in-home) and self-reported broccoli processing conditions (n = 23): (Study 3)
Wash broccoli	14 (93 %)	8 (80 %)	9 (100 %)	-
Part of broccoli used	15 (100 %)	9 (90 %)	9 (100 %)	20 (87 %)
Weight (grams) of broccoli ± SD[b]	15 (100 %)	5 (50 %)	9 (100 %)	23 (100 %)
Cooking method	14 (93 %)	10 (100 %)	9 (100 %)	22 (96 %)
Water level	11[c] (92 %)	8 (80 %)	9 (100 %)	21 (91 %)
Type of start	10[c] (83 %)	9 (90 %)	7 (78 %)	22 (96 %)
Use of lid	15 (100 %)	10 (100 %)	9 (100 %)	23 (100 %)
Addition of salt	15 (100 %)	9 (90 %)	9 (100 %)	23 (100 %)
Cooking time ± SD[d]	11 (73 %)	5 (50 %)	7 (78 %)	21 (91 %)
Doneness	14 (93 %)	10 (100 %)	8 (89 %)	21 (91 %)
Water left	12[c] (100 %)	10 (100 %)	9 (100 %)	21 (91 %)

[a] All participants cooked broccoli by 'boiling'.

[b] 'Weight of broccoli' used by the participant was considered consistent when it fell within the average ± standard deviation 'weight of broccoli' used.

[c] n = 12 as only these participants used a 'cooking method' of broccoli that involved the use of water in *Study 1*

[d] 'Cooking time' taken by the participant was considered consistent when it fell within the average ± standard deviation 'cooking time' taken.

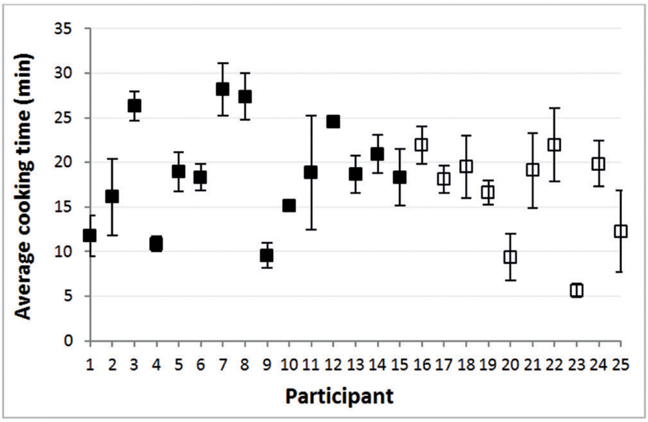

Figure 10. 'Average cooking time' taken by the participant of *Study 1* and *Study 2* to cook broccoli during observations. Filled squares represent the participants of *Study 1*. Empty squares represent the participants of *Study 2*.

Table 3. Details on observed broccoli processing conditions during two in-home observations of participants of Study 1.

Checklist item of processing of broccoli	Frequency of occurrence (n = 15)	Description of the activity on 2 different observation days in in-home (*Study 1*)
Wash broccoli	14	Washed broccoli before use
	1	Did not wash broccoli on the second observation day
Part of broccoli used	6	Used inflorescence with stalks
	5	Used whole broccoli i.e., inflorescence with stem
	4	Used inflorescence only
Weight of broccoli	15	Weight (amount) of broccoli used by a participant during every observation fell between the participant's average ± standard deviation in the 'weight of broccoli'
Cooking method	11	Boiled broccoli
	2	Steamed broccoli
	1	Pressure cooked broccoli
	1	Steamed on the first observation day and boiled on the second day
Water level	6	'Water level' in the pan with broccoli was at 'level B'
	2	'Water level' in the pan with broccoli was at 'level C'
	2	'Water level' in the pan with broccoli was at 'level D'
	1	'Water level' in the pan with broccoli was at 'level A'
	1	Changed the 'water level' from 'water level B' to 'water level A' during second observation day
Type of start	6	Used a 'cold start' i.e., cold water from the tap
	4	Used a 'warm start' i.e., warm water from the tap
	2	Changed from 'cold' to 'warm start' on the second observation day
Use of lid	15	Used lid while cooking broccoli
Addition of salt	12	Added salt while cooking broccoli
	3	Did not add salt while cooking broccoli
Cooking time	11	The average broccoli 'cooking time' by all participants was 21 ± 4min
	4	'Cooking time' of broccoli was out of the range of average ± standard deviation
Doneness	9	Assessed 'texture changes' for checking the 'doneness'
	4	Assessed 'colour changes' for checking the 'doneness'
	1	Assessed 'time' for checking the 'doneness'
	1	Changed the way the 'doneness' was checked from 'texture' to 'time' during the second observation
Water left	7	Did not use (discarded) 'water left' after boiling broccoli
	5	Used 'water left' after boiling broccoli to make a sauce

Table 4. Details on observed broccoli processing conditions during five in-home observations of participants of Study 2.

Checklist item of processing of broccoli	Frequency of occurrence (n = 10)	Description of the activity on 5 different observation days in the model-kitchen (*Study 2*)
Wash broccoli	8	Washed broccoli before processing
	2	Washed broccoli in at least 2 out of the 5 observations
Part of broccoli used	6	Used 'inflorescence' with stalk
	2	Used 'inflorescence' only
	1	Used 'whole broccoli' i.e., inflorescences with stalk and the stem
	1	Used 'whole broccoli' in the first observation and 'inflorescence with stalk' in the following 4 observation days
Weight of broccoli	5	'Weight (amount) of broccoli' used by a participant during every observation fell between the participant's average ± standard deviation in the 'weight of broccoli'
	5	Amount of broccoli used by a given participant during each observation was different from participant's average ± standard deviation at least in one observation
Cooking method	9	'Boiled' broccoli
	1	'Stir fried' broccoli after 'boiling'
Water level	3	'Water level' in the pan with broccoli was at 'level A'
	3	'Water level' in the pan with broccoli was at 'level C'
	2	'Water level' in the pan with broccoli was at 'level B'
	2	Participants switched 'water level' twice among all 5 observations : from 'water level A' to 'B' and from 'water level D' to 'C'
Type of start	5	Used a 'cold start' i.e., cold water from tap to boil broccoli
	2	Used a 'boiling start' i.e., boiled water first, then added broccoli into the pan with water
	2	Used 'warm start', i.e., warm water from the tap or cold water from tap for few minutes before adding broccoli into the pan with water
	1	Participant switched between 'cold', 'warm' and 'boiling start' always
Use of lid	9	Used lid while cooking broccoli
	1	Did not use lid while cooking broccoli
Addition of salt	6	Added salt while cooking broccoli
	3	Did not add salt
	1	Participant was inconsistent in adding salt on different observation days
Cooking time	5	The average broccoli 'cooking time' taken by all participants was 16 ± 3min
	5	'Cooking time' was out of the range of average ± standard deviation at least once among all 5 observations - two of these 5 participants' cooking time varied in the first 2 observation days, the following 3 observation days were in the range of 16 ± 3min of cooking time - one of these 5 participants had difficulty in handling the stove on one day
Doneness	7	Assessed 'texture changes' for checking the 'doneness'
	2	Assessed 'time' for checking the 'doneness'
	1	Assessed 'colour change' for checking the 'doneness'
Water left	9	Discarded the 'water left' after boiling broccoli
	1	Used 'water left' after boiling broccoli for making sauce

The Wilcoxon-signed rank test between the two in-home observations ($p < 0.05$), and the Friedman test between the five MK observations ($p < 0.01$), for test-retest reliability, showed no significant differences in behaviour over different observation days, except for ‘cooking time’. ICC of ‘cooking time’ and Cohen’s kappa of ‘water level’ for inter-observer reliability are 0.884 and 0.882 respectively, both indicating an almost perfect agreement. ICC of ‘cooking time’ coded ‘real-time’ and ‘videotaped’ for parallel-forms reliability was 0.970 indicating an almost perfect consistency in coding.

The fact that participants of *Study 1* and *Study 2* were consistent in most of their behaviour on different days, in a given environment, indicates that observation (both direct in-home and by cameras in the MK) is a reliable and valid method to capture vegetable processing conditions of consumers, even when studied as part of a multifaceted task like preparing a complete meal. The current consistency in simple food processing like cooking broccoli is comparable to the results found for other routine behaviour of consumers (88). Greater variation in behaviour might be found when preparation of the complete meal would have been analysed.

3.2 Comparison of participant’s behaviour between model-kitchen and in-home: *Study 2*

Participants were consistent in their behaviour over five observation days in the MK. Therefore, behaviour in the last MK observation was compared to behaviour in the in-home observation of the respective participant.

One participant of the MK observations switched the ‘cooking method’ from ‘boiling’ (which was consistent during all MK observations), to ‘stir frying’ during in-home observation. This change in ‘cooking method’ obviously resulted in an inconsistency in most broccoli processing conditions for this participant, except for ‘use of lid’, and ‘addition of salt’. Therefore, Table 2 compares the other 9 participants’ behaviour towards broccoli in the last MK observation and in-home.

All but three broccoli processing conditions in the in-home observation were the same as in the last MK observation (Table 2). Eight out of nine participants were consistent in the ways to check the ‘doneness’ of broccoli and seven out of nine participants in ‘type of start’ and ‘cooking time’. Once again, ‘cooking time’ showed greater variability between consumers (inter-individual variability) compared to within a consumer (intra-individual variability). ‘Cooking time’ of broccoli by participants in the last MK and in-home observations is presented in Figure 11.

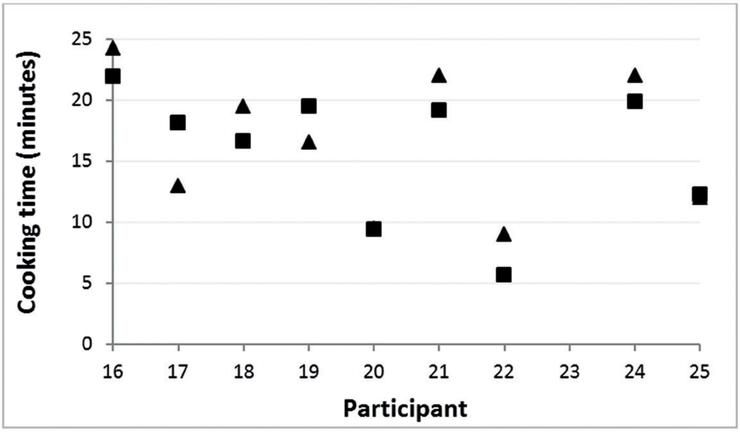

Figure 11. Broccoli 'cooking time' during the last model-kitchen (MK) and in-home observations. Squares correspond to the 'cooking time' during the last MK observation. Triangles correspond to the 'cooking time' during the in-home observation.

The Wilcoxon-signed rank test, for test-retest reliability, showed no significant differences in behaviour between the last MK and in-home observations ($p < 0.05$). ICC (i.e., the consistency value) of 'cooking time' between MK and in-home is 0.779 and Cohen's kappa for 'water level' is 0.824, both pointing at an almost perfect consistency. Concurrent validity of 'water level' (Spearman's rho r = 0.947, $p = 0.000$) and 'cooking time' (Pearson correlation r = 0.679, $p = 0.031$) between in-home and MK observation were insignificant, indicating that MK and in-home observations are interchangeable.

Observation of the same participant in different environments on different days showed that MK had minimum influence on the participant's routine behaviour. The presence of an observer could influence a participant's routine behaviour (82, 89). It should be noted that the participant's behaviour towards broccoli was recorded with cameras in a new 'kitchen-like' setting, i.e., in the MK. The participants were aware that their food handling behaviour was being videotaped (the participant was unaware of the focus of the researcher was on domestic processing of broccoli). Both these factors can create an unintended 'observer effect' on the behaviour of the participant (90), specially towards meat handling. Nevertheless, the participant was unaware of the aim of the research. The 'observer effect' or the 'social desirability bias' is therefore expected to not have influenced the processing conditions of broccoli in this study. This hypothesis is further supported by the consistency in the majority of the applied broccoli processing conditions over 5 observation days in the MK and by the consistency of this behaviour between MK and in-home observations. From the findings in the current paper, observation through cameras in a MK is therefore recommended as an alternative to direct in-home observation, especially when the given task is simple and when the aim of the research has not been disclosed to the participant. Representativeness of

MK observations to in-home observations has been previously reported for key meat handling practices (63, 76, 91). In addition, participants tend to forget the presence of cameras after a while (92), especially in the presence of family members in the participants' vicinity, easing the 'feeling of being observed' (82).

3.3 Comparison of participant's behaviour between direct observation and self-report: *Study 3*

Behaviour during the last observation (in-home) was compared to self-reported behaviour of the respective participant (n = 23). Again, behaviour was considered to be consistent when at least 80 % of the participants were consistent between directly observed and self-reported behaviour. All participants were consistent in every broccoli processing practice, indicating an agreement between self-reported and observed behaviour (Table 2).

In contrast to studies comparing observed and self-reported food handling practices, specifically meat handling practices (63, 68, 76, 77), the self-reporting questionnaire on vegetable processing practices in this research gave rather reliable results. ICC (i.e., consistency value) of 'cooking time' and Cohen's kappa of 'water level' between observed and self-reported behaviour is 0.715 and 0.602, respectively. Spearman's rho of 'water level' (r = 0.889, p = 0.000) and the Pearson correlation of 'cooking time' (r = 0.715, p = 0.001), between self-reported and directly observed behaviour was insignificant, thus establishing the concurrent validity of the self-reporting questionnaire against observation. When a research method is content validated by operationalising behaviour accurately, the research method measures what it is supposed to measure. The self-reporting questionnaire on vegetable processing conditions developed and administered in this research, proved to be a reliable and valid method for data collection, which is in agreement with other studies (66, 78, 93). Where observations give an opportunity to capture key behaviour that the researcher might not have anticipated, especially when the task is multifaceted, self-reporting questionnaires fail to capture such (possibly important) behaviour.

Although the participants were aware of the aim of the study while answering the questionnaire, the self-reporting questionnaire was administered at least three months after the last observations. It is hard to expect that the participants precisely recalled the broccoli processing conditions which they applied more than three months ago during observations and accurately reported this behaviour in the questionnaire.

The consistency between observed and self-reported vegetable processing conditions in this study indicate that consumers are rather consistent in their routine or habitual behaviour with respect to the broccoli processing in the kitchen and that a validated self-reporting questionnaire is a reliable tool for collection of such data.

4. CONCLUSION

The quality of any research depends in the first instance on the quality of the research method used to obtain data. Thus, there is a need for a reliable and valid research method for obtaining meaningful findings from a research, although the researcher has a key role to play in handling the data. Research on consistency in behaviour over time and across situations to identify a reliable and valid research method to assess vegetable processing conditions is rather new and hardly explored. Since vegetable processing conditions are assumed to be mainly determined by habits, sensory preferences and/or convenience, a large variation in domestic vegetable processing conditions is expected and confirmed in this study. It is evident from this research that either observations in-home, observations through cameras in a model-kitchen, or administering a self-reporting questionnaire are reliable and valid research methods for gathering information on vegetable processing conditions among households of families with children. When comparing the three methods on efficiency and practical considerations, the self-reporting questionnaire has large advantages over the other two methods. Self- reporting questionnaires can be used to reach a larger number of participants in a shorter time and are relatively inexpensive compared to observations. In addition, self-reports can capture a wide variation in vegetable processing conditions from different groups of consumers and a well-designed self-reporting questionnaire seems to be the recommended and most practical method. A self-reporting questionnaire for a relatively simple task like cooking vegetables, as illustrated in this study, can be used for many other types of foods to identify variations in (critical) aspects of domestic processing that can influence the health and sensory properties of prepared foods. For this, the behaviour variables and research questions to be focussed on will be different and the questionnaires should thus be checked again for reliability, validity and practicality before administration.

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Chapter 4

Consumer behaviour towards vegetables: a study on domestic processing of broccoli and carrot by Dutch households

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ABSTRACT

Preferences for sensory properties, e.g., taste and texture, are assumed to control vegetables cooking behaviour. Conditions such as cooking method, amount of water used and the time-temperature profile determine the nutritional quality (e.g., vitamins and phytochemicals) of cooked vegetables. Information on domestic processing and underlying motives can be used to inform consumers about cooking for vegetables that are equally liked and are nutrient-rich. Two online self-reporting questionnaires were used to identify domestic processing conditions of broccoli and carrot by Dutch households. Questions on various aspects of domestic processing and consumer motives were included. Descriptive data analysis and hierarchical cluster analysis were performed for both vegetables separately to group consumers with similar motives and behaviour towards vegetables. About 70 % of the consumers boiled, 8-9 % steamed, 10-15 % stir fried the raw and 8-10 % stir fried the boiled vegetables. Mainly texture was used to decide on doneness of the vegetables. For both vegetables, three clusters of consumers were identified: texture-orientated, health-orientated, or taste-orientated. The texture-orientated consumers are identified as the most prevalent (56-59 %) group in our study. Statistically significant associations are found between domestic processing conditions and clusters, whereas, no such association are found between demographic details and clusters. A wide variation in domestic processing of broccoli and carrots is found in this study. Mainly sensory properties i.e., texture and taste determined the domestic processing. The findings of this study can be used to optimise cooking to yield vegetables that meet consumer's specific sensory preferences and are higher in nutrients; and to communicate with target consumer groups.

Keywords: Domestic processing; Self-reporting questionnaire; Cluster analysis; Texture; Taste; Health.

1. INTRODUCTION

Vegetables are processed at the domestic level before consumption. Domestic processing brings about a significant change in the sensorial properties and nutritional quality of vegetables (10). Depending on the conditions applied, nutritional quality, in terms of amount of nutrients and phytochemicals decreases, although the bioavailability of certain compounds like carotenes increases (24). Meanwhile, changes in the sensorial properties like texture and colour are assumed to be controlled by consumers to meet their (and their family's) sensory preferences. Therefore, it can be hypothesised that motives such as, sensory preferences towards vegetables and habits of consumers, determine the cooking conditions (8, 94). When such motives and consumer behaviour towards vegetables are known, food technologists can assess optimised cooking that will give vegetables (products) which are liked equally but are at the same time higher in nutritional quality (75). However, for process optimisation, detailed information on consumer behaviour towards vegetables and the underlying motives must be known. To our knowledge, there is a lack of such information in the literature. In addition to process optimisation, such information can also be used to cluster consumers into homogenous groups, comparable in behaviour and motives (95-98).

Two separate online self-reporting questionnaires are used to identify domestic processing conditions for broccoli and carrot among Dutch households. Broccoli and carrots are chosen for this study as they are among the commonly consumed vegetables in the Netherlands (99) and differ morphologically from each other. Both vegetables are rich in a variety of phytochemicals such as polyphenols, glucosinolates and vitamin C in broccoli (12); and phytochemicals such as β-carotene, falcarinol, polyphenols in carrots (7, 43), which are reported to exhibit anti-oxidant and anti-carcinogenic activity (12, 99). In the first part of the paper, domestic processing of broccoli and carrots applied by consumers is reported. In the second part, results of cluster analysis identifying groups of consumers with comparable domestic processing conditions and motives are shown for both vegetables separately.

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2. MATERIALS & METHODS

2.1 Online self-reporting questionnaire

Two separate online self-reporting questionnaires, which were adapted from the validated questionnaire described by Bongoni et al. (60) were used to identify domestic processing conditions of broccoli and carrot among Dutch households. Thirteen closed-ended questions were used on: cooking method, part/size of the vegetable pieces, water level and type of start used while boiling, cooking time, addition of salt, and ways to decide the doneness of the vegetable. Water level in the pan for boiling is categorised as: low or high water level (Figure 12). The type of start in this study is categorised as: cold or hot start. In a cold start, cooking time commences as the vegetable along with the tap water (approximately 22 °C) in a pan is heated; while in a hot start, cooking time commences with the addition of the vegetable into the boiling water. Questions related to the motives for some practises, e.g., water level, type of start, addition of salt, were included. Demographic details, e.g., age, gender, family composition, education were asked at the end of the questionnaire. The web links to the online surveys were spread among the personal contacts and through the database of Food and Biobased Research (FBR), Wageningen UR, the Netherlands to obtain a large number and maximum variation (in terms of geographical location) of respondents.

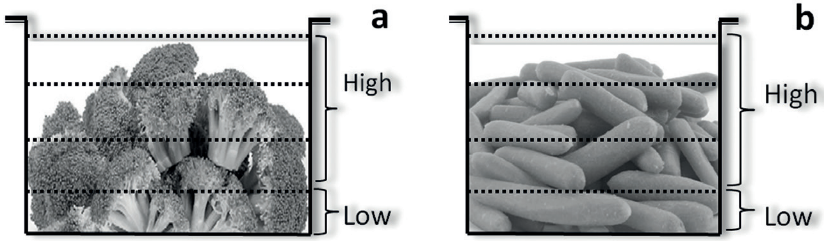

Figure 12. Picture depicting the water level used to boil (a) broccoli (b) carrots. Low: represents that a small layer of water was used to boil vegetables; High: represents that the vegetables were submerged in more than a small layer of water.

2.2 Participants

The target group comprised the main meal preparer of Dutch households. In total, the data from 567 consumers on broccoli and the data from 348 consumers on domestic carrot processing conditions and underlying motives were used for this study. In case of broccoli, 12 respondents microwaved and three respondents pressure-cooked the vegetable. In case of carrots, three respondents microwaved, two pressure-cooked the vegetable and 74 ate carrots as raw (and consequently answered all the other questions as 'none of the above' or 'not-applicable'). Given the frequency of these cooking methods and that the questionnaire asked for domestic processing conditions of vegetables, the data from these participants along with data from incomplete questionnaires was excluded, resulting 567 respondents for broccoli and 348 for carrots. The characteristics of the study sample are shown in Table 5.

Table 5. Characteristics of the study sample.

Demographic variable	n (%) Broccoli (n = 567)	n (%) Carrots (n = 348)
Gender		
Male	198 (35 %)	100 (29 %)
Female	369 (65 %)	248 (71 %)
Household type		
Students (20-25 years)	62 (11 %)	38 (11 %)
One-person household	60 (11 %)	27 (8 %)
Couple with children	208 (35 %)	131 (37 %)
Couple without children	116 (22 %)	96 (28 %)
Elderly (> 65 years)	121 (21 %)	56 (16 %)
Education level		
Secondary vocational	132 (23 %)	96 (28 %)
Higher professional	215 (38 %)	132 (38 %)
University	220 (39 %)	120 (34 %)

2.3 Data analysis

Statistical analysis was performed using IBM SPSS Statistics 21. Descriptive statistical analysis was performed to summarise domestic processing of broccoli and carrot. Cluster analysis was performed to identify consumer groups with similar characteristics (96), i.e., domestic processing conditions. Hierarchical cluster analysis was performed with Ward's method at Squared Euclidean distance (97) on variables: part of the vegetable piece, cooking method, water level used for boiling, type of start for boiling and cooking time. The number of clusters was decided based on the dendrogram and logical interpretations of the solutions. There was no substantial correlation (< 0.5 at $p < 0.05$) between the input variables. A Chi-square test was performed to determine statistically significant association between the clusters and domestic processing variables ($p < 0.05$).

2.4 Ethical approval

The research used online self-reporting questionnaires for information on domestic processing of vegetables, for which the respondents were free to participate. As the research is non-invasive and the details of the participants undisclosed, this research does not fall within the remit of the Helsinki Declaration. However, this research was given an ethical approval from the Social Sciences Ethics Committee, Wageningen University, the Netherlands and the project complies with the Netherlands Code of Conduct for Scientific Practice.

3. RESULTS

3.1 Domestic processing of vegetables by consumers

Table 6 presents the domestic processing conditions of vegetables applied by Dutch households.

Table 6. Summary of domestic processing of vegetables applied by Dutch households.

Aspects on domestic processing of vegetables	Details for broccoli	Details for carrots
Cooking Method	Boiling (71 %) Steaming (9 %) Stir frying (10 %) Boiling followed by stir frying (10 %)	Boiling (69 %) Steaming (8 %) Stir frying (15 %) Boiling followed by stir frying (8 %)
Part of the vegetable used	Florets without stalks (10 %) Florets with stalks (72 %) Florets with stalks and the sliced stem (18 %)	Whole carrots (61 %) Cut into pieces (39 %)
Water level when vegetables were boiled	Low water level (18 %) High water level (82 %)	Low water level (17 %) High water level (83 %)
Type of start when boiling	Cold (60 %) Hot (40 %)	Cold (72 %) Hot (27 %)
Cooking time	1-5min (19 %) 6-10min (49 %) 11-15min (20 %) 16-20 min (8 %) > 20 min (4 %)	1-5 min (7 %) 6-10min (40 %) 11-15min (27 %) 16-20min (21 %) > 20 min (5 %)
Ways to decide doneness	Texture (64 %) Colour (6 %) Taste (19 %) Time (11 %)	Texture (65 %) Colour (2 %) Taste (25 %) Time (8 %)

As expected, a wide variation in the domestic processing of vegetables is observed (Table 6). About 70 % of the consumers of this study cooked broccoli and carrots mainly by boiling. Stir frying (10 % for broccoli and 15 % for carrots), boiling followed by stir frying (10 % for broccoli and 8 % for carrots) and steaming (9 % for broccoli and 8 for carrots) were the other cooking methods of broccoli and carrot. The majority (above 80 %) of the consumers reported to use a high water level to boil their vegetables. A cold start was applied by 60 % and 72 % of the consumers for boiling broccoli and carrots respectively. Texture is used by about 65 % of the consumers to determine the doneness of the vegetable during cooking. Except for the type of start, no substantial differences were found in domestic processing between the two vegetables.

3.2 Clustering consumers based on domestic processing of broccoli

Cluster 1: The consumers who are 'hard texture'-orientated

This cluster comprises 39 % (n = 221) of the consumers of the study sample and they are orientated towards having a 'hard' texture of the broccoli.

These consumers boiled the broccoli (100 %) using a high water level (100 %) and either a cold start (53 %) or a hot start (47 %). The water level and the type of start used were motivated as a habitual practice. Broccoli is cooked for 6-10 minutes (77 %). Texture change during cooking was assessed to decide on doneness of broccoli (65 %) and 28 % of the consumers of this group added salt.

Cluster 2: The consumers who are health-orientated

This cluster comprises 33 % (n = 188) of the consumers of the study sample and they are orientated towards having higher health benefits on consumption of broccoli.

This cluster constitutes consumers who use different cooking methods: boiling (40 %), steaming (27 %), stir frying (29 %), boiling followed by stir frying (4 %). When methods like boiling or boiling followed by stir frying were used, a low water level was used (100 %) to prevent nutrient losses into the cooking water. A cold start (100 %) was used as a habitual practice. Short to medium cooking times: 1-5 minutes (26 %) and 6-10 minutes (46 %) were used by this group of consumers. Again, texture of broccoli during cooking was used to decide on doneness (56 %). Compared to the total study sample a lower number of consumers (16 %) added salt to the broccoli. Motives for not adding salt were to restrict the salt intake and to perceive the vegetable taste.

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Cluster 3: The consumers who are 'medium to soft texture'-orientated

This cluster comprises 20 % (n = 114) of the consumers of the study sample and they are orientated towards having a 'medium to soft' texture of the broccoli.

These consumers too mostly boiled the broccoli (97 %) using a high water level (100 %) and a cold start (70 %). Again habit was the reason for applying this water level and the type of start. Broccoli was cooked for 11-15 minutes (57 %) or for 16-20 minutes (28 %) which can result in a 'medium to soft' texture of broccoli. Texture of broccoli during cooking was used to decide on doneness (66 %). In this cluster, 39 % of consumers added salt, which is a higher number than in the total sample (Table 6).

Cluster 4: The consumers who are taste-orientated

This cluster comprises 8 % (n = 44) of the consumers of the study sample and they are orientated towards taste of the broccoli.

These consumers used boiling followed by stir frying (100 %) to prepare the broccoli. When boiling, a high water level was used (10 0 %) as a habit and mainly a hot start was used (69 %) to speed-up the cooking process. Cooking times of 1-5 minutes (30

%) or 6-10 minutes (52 %) were used. Besides texture (55 %), taste (40 %) was used to assess doneness of the broccoli, which is different from the total sample (Table 6). In this cluster 39 % of the consumers used salt for taste reasons, which is a higher number than in the total sample (Table 6).

3.3 Clustering consumers based on domestic processing of carrots

Cluster 1: The consumers who are texture-orientated

This cluster comprises 56 % (n = 196) of the consumers of the study sample and they are orientated towards texture of the prepared carrots.

Carrots are prepared by boiling (100 %) using a high water level (100 %) and a cold start (100 %) as a habitual practice. Carrots are prepared over a range of cooking times that can result in 'hard to soft' carrots. In this cluster 35 % of the consumers cooked carrots for 6-10 minutes, 29 % for 11-15 minutes and 29 % for 16-20 minutes. Texture of carrots was assessed to decide on doneness by 71 % of the consumers. Salt was added habitually by 38 % of the consumers, which is higher than in the total sample (Table 6).

Cluster 2: The consumers who are health-orientated

This cluster comprises 18 % (n = 63) of the consumers of the study sample and they are orientated towards health benefits of consumption of carrots.

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Carrots were cooked either by: boiling (65 %), steaming (16 %) or stir frying (19 %). To boil, a low water level was used to prevent nutrient losses and a cold start was used as a habitual practice. Carrots were cooked for 6-10 minutes by 28 % of the consumers and for 11-15 minutes by 38 % of the consumers. Texture of the carrots was assessed (67 %) to decide on doneness. A relatively low number of consumers (13 %) used salt in comparison to the total sample (Table 6). Motives for not using salt were to restrict salt intake and to perceive the carrot taste.

Cluster 3: The consumers who are taste-orientated and want 'hard texture' carrots

This cluster comprises 18 % (n = 63) of the consumers of the study sample and they are orientated towards taste of the carrots that are 'hard' in texture.

Consumers of this cluster used different methods to cook carrots: stir frying (69 %), steaming (26 %), boiling followed by stir frying (5 %). A cooking time of 6-10 minutes was used by a majority of the consumers (69 %). Texture (42 %) or taste (40 %) was used to determine doneness of carrots. This cluster has a higher percentage of salt-users (37 %) compared to the total sample (Table 6).

Cluster 4: The consumers who are taste-orientated and want 'medium to soft texture' carrots

This cluster comprises 8 % (n = 26) of the consumers of the study sample and they are orientated towards taste of carrots that are 'medium to soft' in texture.

These consumers used boiling followed by stir frying (100 %) to cook carrots. They used a high water level (100 %) and either a cold start (53 %) or a hot start (47 %) as a habitual practice to cook carrots. The carrots were first boiled for 6-10 minutes (50 %) or for 11-15 minutes (27 %), which was followed by stir frying. Texture (46 %) or taste (54 %) of the carrots was used to decide on doneness. This cluster has the highest percentage salt-users (39 %) in comparison to the total sample (Table 6).

3.4 Association between the input variables of the cluster analysis and the clusters

The input variables of the cluster analysis, i.e., the domestic processing conditions (refer section 2.3), and the clusters from the cluster analysis showed a statistically significant association with each other, indicating that these variables and the clusters are related (Table 7), while for both vegetables the demographic details of the respondents did not show a statistically significant association with the clusters (Table 8).

Table 7. Chi-square association between the cluster membership and input variable for broccoli and carrots.

Variable	Chi square association	
	Broccoli	Carrots
Cooking method	χ^2 = 707.73, df = 9, p < 0.05	χ^2 = 577.99, df = 9, p < 0.05
Water level	χ^2 = 567.00, df = 6, p < 0.05	χ^2 = 487.98, df = 6, p < 0.05
Type of start	χ^2 = 304.67, df = 9, p < 0.05	χ^2 = 266.22, df = 9, p < 0.05
Cooking time	χ^2 = 367.01, df = 15, p < 0.05	χ^2 = 100.03, df = 15, p < 0.05
Deciding doneness	χ^2 = 23.29, df = 9, p < 0.05	χ^2 = 35.40, df = 9, p < 0.05
Use of salt	χ^2 = 23.79, df = 3, p < 0.05	χ^2 = 15.74, df = 3, p < 0.05

Table 8. Chi-square association between the cluster membership and demographic input variables for broccoli and carrots.

Variable	Chi square association	
	Broccoli	Carrots
Education level	χ^2 = 24.58, df = 9, p > 0.05	χ^2 = 12.51, df = 9, p > 0.05
Household type	χ^2 = 16.44, df = 12, p > 0.05	χ^2 = 18.75, df = 12, p > 0.05
Gender	χ^2 = 6.69, df = 3, p > 0.05	χ^2 = 2.74, df = 3, p > 0.05

4

4. DISCUSSION

This is the first study to our knowledge that investigated consumer behaviour toward vegetables, i.e., processing of vegetables at the domestic level, and that clustered consumers based on their reported behaviour and motives.

The majority (70 %) of the consumers cooked vegetables by boiling. Boiling compared to steaming results in a higher loss of (water soluble) phytochemicals by leaching into the cooking water (10). Leaching depends on the vegetable-water ratio used and the cooking time-temperature profile (12). Although steaming is reported to reduce the losses of phytochemicals (52, 100), only few consumers (8-9 %) in this study steamed vegetables. Stir frying, where the temperature of cooking reaches around 140 ^{o}C, is detrimental to a great extent for phytochemical stability (52) and about 10-15 % of the consumers of this study stir fried vegetables. Texture, which is reported to determine the acceptability of foods (101), is also used as the main indicator to determine the doneness of the vegetables in this study.

Weegels and van Veen (88) reported a wide variation in behaviour between consumers when performing the same household activity. Such wide variation in behaviour between consumers is also observed in processing vegetables at the domestic level. The quality of cooked vegetables at the time of consumption depend on the way they were processed (10), e.g., at the domestic level. The obtained information on variation in the domestic processing of vegetables will help to identify aspects of domestic processing that might determine the health and sensory properties of cooked vegetables.

In this study, cluster analysis presented three groups of consumers for both vegetables: those who are *texture-orientated*, *health-orientated*, or *taste-orientated*. In case of broccoli, the *texture-orientated* consumers and in the case of carrots, the *taste-orientated* consumers were divided further based on the applied cooking time that results in different textures.

The *texture-orientated* consumers (cluster 1 and 3 in the case of broccoli and cluster 1 in the case of carrots) are the most prevalent group consisting of 56-59 % of the study sample. This cluster of consumers mostly uses a high water level with a cold start and often cooks the vegetables longer than the total sample does, i.e., 6-10 minutes (Table 6), except for the 'hard texture' -orientated consumers of broccoli. Additionally, compared to the total sample, this cluster of consumers consists of a relatively high percentage of salt-users (28-39 %). The behaviour of these consumers comprises mostly habitual practices, which could arise due to performing a behaviour repeatedly over time (97). Furst et al. (102) described that a past behaviour or experience greatly influences the current behaviour of the consumer. The quality of a product a consumer experienced or gained (102), in this case, a specific texture of a vegetable that was obtained in previous cooking sessions, might have led to a repeated behaviour in the next cooking sessions.

This repeated behaviour probably turned into a habit, for which consumers find it difficult to explain details and specific factors that contribute to their behaviour (97, 103). Based on the prevalence of this group and the processing conditions that can be detrimental to (nutrients and) phytochemicals, these consumers can be assisted with information on optimised processing conditions which will give vegetables that is within the range of an 'acceptable texture' but at the same time is also higher in nutritional quality.

The *health-orientated* consumers counted for 20-30 % of the study sample for both vegetables. Steaming was used by a higher number of consumers in this group: 27 % for broccoli and 16 % for carrots, compared to the total sample (Table 6). When applicable, a low water level was used to prevent nutrient losses during cooking and shorter cooking times were applied for broccoli and slightly longer for carrots (with respect to the total sample as mentioned in Table 6), given the morphological difference between vegetables. Fewer consumers used salt to restrict their salt intake. Grunert (55) and Brunsø et al., (104) mentioned that consumers relate healthiness to eating healthy foods and to avoiding unhealthy foods, in order to fulfil their basic life values like good health, long life and family's welfare (105).

The *taste-orientated* consumers (cluster 4 for broccoli and cluster 3 and 4 for carrots) mainly stir fried the raw vegetables or stir fried the boiled vegetables, cooked with a high water level and mainly applied a hot start, all of which can result in high nutritional quality losses of vegetables. Taste was used to assess doneness of vegetables and was also the reason for the use of salt.

The limitation of this study is that the online self-reporting questionnaires used in this study are not checked for reliability and validity, though they are adapted from the reliable and valid self-reporting questionnaire described by Bongoni et al. (60). Any adapted questionnaire should be validated prior to administration (106).

In summary, the findings of this study are novel and can be used (by food technologists) to optimise cooking, which yields vegetables that meet consumers' sensory preferences, e.g., texture and are higher in nutrients (75). Such information on optimised cooking developed for every consumer cluster identified in this study will assist these consumers to adapt their existing cooking practices. This cluster-specific information can be communicated to consumers in different ways, e.g., through forums, blogs, recipe books or television programmes or cooking classes and by placing pamphlets in the vegetable shops or supermarkets. Cooking programmes at schools could be organised that shall assist in inculcating 'healthy cooking habits' in children.

In order to generalise the consumer clusters found in this study, further research is recommended to cluster and compare consumer behaviour towards vegetables: of same morphology, e.g., potatoes to carrots or cauliflower to broccoli; and of different morphology, e.g., green leafy vegetables.

5. CONCLUSION

A wide variation in domestic processing conditions of broccoli and carrots was found in this study. In agreement with the literature, mainly sensory properties of food (i.e., texture and taste) determined domestic processing of vegetables. Three consumer clusters of consumers are identified: *texture-orientated*, *health-orientated* and *taste-orientated*, with *texture-orientated* consumers being the most prevalent group. Consumer clusters identified in this study give useful information: for food technologists, who can develop vegetable (foods) for specific target groups; and for consumer scientists, to advice consumers in such a way that consumers do not have to trade-off between sensorial properties and health benefits.

6. ACKNOWLEDGEMENT

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Chapter 5

Sensory and health properties of steamed and boiled broccoli

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Bongoni, R., Verkerk, R., Steenbekkers, L.P.A., Dekker, M., Stieger, M. (2014). Evaluation of different cooking conditions on broccoli (*Brassica oleracea* var. *italica*) to improve the nutritional value and consumer acceptance. **Plant Foods for Human Nutrition.**

ABSTRACT

The objective of this study was to gain insight into cooking method that yields broccoli with higher amount of glucosinolates and is liked equally. For this, broccoli was cooked by methods reported to be commonly applied by consumers: boiling with a cold (water) start; boiling with a hot (water) start; and steaming. Firmness, greenness and amount of total glucosinolates in cooked broccoli were instrumentally measured. Sensory evaluation (n=99 by untrained consumers) for liking and sensory attributes intensity rating was performed on broccoli cooked only by steaming and boiling-cold start and at three time points, which resulted in 'high'*,* 'medium'*,* 'low' *firm broccoli samples. At the end of cooking, steaming showed an increase in the amount of total glucosinolates (+ 17 %), while boiling-hot start (- 41 %) and boiling-cold (-50 %) start showed decrease. Sensory evaluation did not show statistically significant differences between steaming and boiling-cold start in* overall liking *at* 'high' *and* 'medium' *firmness; and in the attribute intensity ratings (except for* juiciness *at* 'medium' *firmness, and* flavour *at* 'medium' *and* 'low' *firmness). This study demonstrates that medium firm broccoli showed optimum liking of broccoli and that steaming compared to boiled-cold start showed higher amount of glucosinolates.*

Keywords: Glucosinolates; Firmness; Greenness; Sensory Evaluation; Dutch Consumers; Broccoli.

1. INTRODUCTION

With an increasing awareness among consumers on causes of health disorders like diabetes, cancer and obesity, the significance of vegetable consumption has increased. Vegetables are a rich source of a variety of vitamins and phytochemicals, which act as antioxidants in the human body and protect against various health disorders (42). Broccoli is one of the commonly consumed vegetables in the Netherlands. Broccoli belongs to the *Brassicaceae* family, which are known for their characteristic flavour and health promoting properties. The most typical *Brassicaceae* specific phytochemicals are glucosinolates (GLS). Glucosinolates are a class of organic compounds that contain sulphur and nitrogen and occur as secondary plant metabolites in brassica vegetables such as broccoli, cabbages and Brussels sprouts (12, 107). Isothiocyanates, the biologically active breakdown products of GLS exhibited anti-carcinogenic activity in several *in vitro* and *in vivo* studies (12).

Most vegetables are prepared prior to consumption. Domestic processing brings about a significant change in the health and sensory properties of the prepared vegetable (27, 42). In the last decades, health properties such as nutritional and health-promoting value of vegetables has become equally (if not more) important as sensorial properties such as texture. Health properties, i.e., phytochemicals such as glucosinolates and vitamin C are water-soluble, thermo-labile and susceptible to the vegetable cooking methods and conditions, e.g., amount of water or oil used, the heating temperature-time profile (12, 108). During processing, firmness decreases due to degradation of pectin (109, 110) and colour changes due to degradation of compounds like chlorophyll and carotenes (27). As changes in sensory properties like texture, flavour and colour determine the acceptability of vegetables (111), it is assumed that the expected sensory properties of the prepared vegetable would determine the processing conditions applied by consumers.

The objectives of this study are to examine the influence of cooking methods of broccoli applied by consumers on health and sensory properties; and to gain insight into cooking methods that yield vegetables with a higher amount of phytochemicals and that are liked and rated equally or higher on sensory properties.

Based on the previous research using an online self-reporting questionnaire, boiling and steaming are the most common cooking methods of broccoli applied by consumers (61). Therefore, in this study, we determined the influence of these cooking methods (and time) on texture, colour, glucosinolates, liking and sensory perception of broccoli.

2. MATERIALS AND METHODS

2.1 Setup of the study

Broccoli (*Brassica oleracea* var. *italica*) was cooked by three methods: steaming, boiling with cold start and boiling with hot start. Analytical measurements were carried out to assess instrumental firmness, colour and amount of glucosinolates in broccoli cooked at 6 time points by steaming, boiling-cold start and boiling-hot start (Table 9).

Table 9. Experimental design of the study.

Analyses	Steaming (minutes)	Boiling-cold start (minutes)	Boiling-hot start (minutes)
Firmness **Colour** **Glucosinolate**	0, 2, 4, 7, 13, 17, 22	0, 2, 4.5, 7, 12, 19, 22	0, 1.5, 3, 7, 12, 17, 22
Sensory evaluation **(time required to obtain 'high', 'medium' and 'low' firmness)**	2, 4, 13	4.5, 7, 19	Not conducted

Three time points per cooking method were identified that resulted in broccoli with different instrumental firmness: 'high', 'medium' and 'low' (time points mentioned for 'sensory evaluation' in Table 9) and three more interval time points were included to these time points for the analytical measurements. The time points were chosen to yield different instrumental firmness values between the samples (high, medium and low) cooked by each method, and to yield comparable values of certain 'firmness' between the three cooking methods, i.e., comparable 'high' firmness value between steaming and boiling-cold start broccoli samples. Overall liking and perceived intensity of sensory attributes were determined on high, medium, and low firm broccoli samples cooked only by steaming and boiling-cold start (Table 9) to avoid too many samples for the untrained participants and that these two methods were the most common cooking methods according to a survey conducted (112).

2.2 Broccoli preparation

2.2.1 Standardisation of broccoli

One batch of broccoli per cooking method was purchased (local vegetable shop, Wageningen, the Netherlands) and cooked in triplicate. Standardisation of broccoli was done by selecting florets of diameter 3-4 cm, stalk length 1.5 cm and weighing 9-13 g. For every cooking time point, 200-210 g of the standardised broccoli was cooked.

2.2.2 Steaming

Steaming of broccoli was performed with a domestic steamer (Philips HD9160 steamer). The steamer was filled with 1400 ml cold tap water and switched on. After 2 minutes, 200-210 g broccoli was put into the steamer.

2.2.3 Boiling

Boiling of broccoli was done using an induction plate (ATAG induction hob). For every time point, similar covered stainless-steel pots were used. A vegetable:water ratio of 1:4 was used. For boiling-cold start, the cooking time started when the broccoli together with tap water (25 ^{o}C) was placed on the induction plate. For boiling-hot start method, the cooking time started when the broccoli was added to boiling water (100 ^{o}C).

After cooking by different methods, part of the broccoli sample was immediately frozen with liquid nitrogen, blended to powder and stored at -20 ^{o}C for glucosinolate analysis. The remaining part was used for instrumental firmness and colour analysis.

2.3 Instrumental analysis

2.3.1 Firmness

Firmness of 5-7 standardised broccoli stalks per time point was measured using a texture analyser (Stable Micro Systems) equipped with a Warner-Bratzler V-knife probe. A 50 kg cell load was used to cut every stalk 0.5 cm from the floret to measure the force applied at 40 % strain and test speed 1mm/s (28).

2.3.2 Colour

The colour of the broccoli florets was measured using a ColorFlex meter (Hunter Associates Laboratory, USA). Flowers from 3-5 broccoli florets per time point were placed inverted in the cuvette with the lid closed and measured at two angles. Colour values were documented in a* (greenness), and b* (yellowness) values. Greenness of samples was calculated by -a*/b* values (110).

2.3.3 Glucosinolate analysis

Glucosinolates in broccoli were extracted using hot methanol, which was followed by on-column desulphation and analysis using high pressure liquid chromatography as described by Verkerk et al. (73). The glucosinolates were identified against their known retention time and spectra. Glucotropaeolin (3 mol/l, in water), since is not present in broccoli, was added to all samples as the internal standard.

To facilitate comparison of results from different batches of broccoli used for every cooking method, the relative firmness (F_{rel}) /greenness (G_{rel}) /amount of glucosinolates (GLS_{rel}) are calculated (i.e., values in cooked samples divided by in raw samples).

2.4 Sensory evaluation

2.4.1 Participants

Ninety-nine healthy participants (n = 99), who cook and consume broccoli at least once a week were recruited via an advertisement through email and social networking sites. Seventy-nine participants were aged between 18 and 35 years, ten participants were between 36 and 55 years and the other ten participants were above 55 years. Seventy-one participants were female. 50 % of the participants of this study were students (of Wageningen University) and the other 50 % were non-students from Wageningen area, the Netherlands. All participants were unfamiliar to sensory evaluation of broccoli and were not trained for this study. A financial compensation for participation was given at the end of the study.

2.4.2 Broccoli samples

The standardised broccoli samples, cooked at three time points representing high, medium and low firmness were used for the sensory evaluation (Table 9). Broccoli was cooked in a way to have all the six samples done at the same time to ensure warm serving for sensory evaluation. Each sample was placed in a polystyrene foam cup with a lid (coded with a randomised three digit code) to keep the samples at approximately 50 ^{o}C. The samples were served in random order to the participants.

2.4.3 Attributes

Cox et al. and Poelman et al. used Quantitative Descriptive Analysis to assess the sensory profile of broccoli. Eighteen attributes describing odour, appearance, flavour and texture were used to evaluate brassica vegetables (29, 113, 114). From this list of attributes, six attributes, i.e., firmness, juiciness, greenness, flavour, sweetness and bitterness, which describe the texture, colour, flavour and taste, were selected for this study to compare the sensory evaluation of cooked broccoli. The attribute definitions were translated from English into Dutch. Participants were asked to evaluate the perceived intensity of the given attribute using the provided definitions (Table 10).

The attribute greenness was asked to be rated by visual perception of the broccoli floret; firmness after chewing twice the broccoli stalk; and juiciness, sweetness, and broccoli flavour after tasting the whole sample.

Table 10. Attributes, their definitions and anchors used for the sensory evaluation of cooked broccoli.

Attribute	Definition	Anchors
Greenness	The intensity of the green colour of the broccoli floret.	Low (low in greenness) – High (very green)
Firmness	The force needed to chew the sample between molar teeth after chewing twice.	Low (very soft) – High (very firm)
Juiciness	The amount of juice that is released while chewing.	Low (very little juice) – High (very juicy)
Broccoli flavour	The overall intensity of typical broccoli flavour	Low (very low in typical broccoli flavour) – High (very high in typical broccoli flavour)
Sweetness	Taste sensation of which sugar is typical	Low (very low in sweetness) – High (very sweet)
Bitterness	Taste sensation of which caffeine is typical	Low (very low in bitterness) – High (very bitter)

2.4.4 Design of the sensory study

The sensory session, which approximately took 30 minutes, was conducted in the sensory booths of the department of Human Nutrition, Wageningen University, the Netherlands. All participants were first given oral instructions and were seated in separate sensory booths. The session was divided into two parts in order to serve samples warm (approximately 50 ^{o}C), as broccoli is often eaten warm.

In the first part of the session, participants were given a tray containing six randomly placed coded polystyrene boxes with samples, and were asked to rate the samples for overall liking on a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). In the second part of the session, the participants were served the same six samples, again freshly cooked, and were asked to rate the intensity of the attributes on a 100 mm Visual Analogue Scale that was anchored with 'low intensity' at 0 mm and 'high intensity' at 100 mm. EyeQuestion software was used for filling-in the ratings in both parts of the session. Water and plain crackers were provided to refresh the palate between tasting of the samples.

2.5 Statistical data analysis

IBM SPSS Statistics 19 and MS Excel were used for statistical data analysis. One-way ANOVA was performed to compare the influence of different cooking methods and time on changes in firmness, colour and the amount of GLS, and on overall liking and perceived intensity of attributes. Relative firmness / greenness / glucosinolates / liking / attribute intensity ratings were loaded as dependent variable and cooking time (or the samples for consumer testing) as fixed variable. Tukey post-hoc test was performed at a significance level of $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1 Influence of cooking method and time on firmness of broccoli

Figure 13 shows the relative firmness of broccoli cooked using different methods over times.

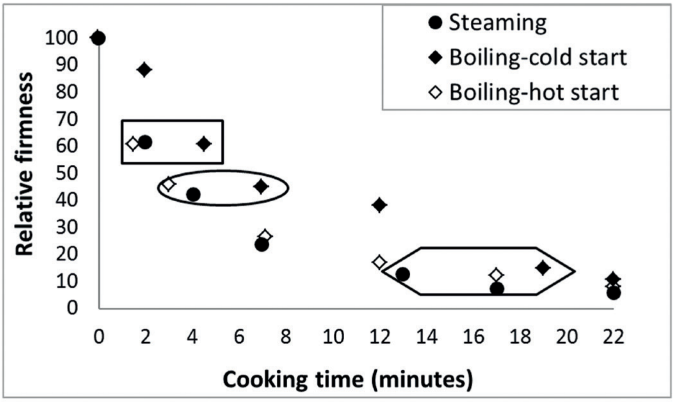

Figure 13. Relative firmness (F/F_{raw}) in broccoli cooked by different methods over time. Sensory evaluation was performed for samples of: ☐ High firmness, ⬭ Medium firmness, ⬡ Low firmness.

For all cooking methods, the relative firmness of the broccoli decreased significantly over time (for values see Appendix 1). This decrease in firmness is in agreement with other studies (33, 109). Thermal processing initially induces expansion of intracellular gases, causing mechanical separation of cells (34). Further heating leads to depolymerisation of pectin by β-eliminative degradation (33), forming a low molecular weight pectic substance which can easily disintegrate, causing the loss of firmness of vegetable tissue (109, 110). Firmness loss of broccoli over time was different between cooking methods. Steaming and boiling-hot start showed a comparable and fast decrease in the firmness of broccoli in comparison to boiling-cold start. The slow rise in the temperature of water during boiling-cold start led to a slower decrease in relative firmness, probably caused by a slower mechanical separation of cells and pectin depolymerisation on heating. The cooking times selected for the sensory study (refer Table 9), gave comparable relative firmness of broccoli (encircled in Figure 13).

3.2 Influence of cooking method and time on greenness of broccoli

The decrease in relative greenness of broccoli cooked over time by different methods is shown in Figure 14.

For all cooking methods, the relative greenness of broccoli decreased over time (for values see Appendix 2). The conversion of chlorophyll to pheophytin and pyropheophytin turns the broccoli from bright green to an olive green colour upon heating (109). The

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observed initial increase in relative greenness followed by a decrease for steaming and boiling-hot start could be a consequence of either changes in the light scattering and surface-reflecting property due to the expulsion of air between cells in the initial stages of heating/blanching or by the conversion of less-coloured precursors of chlorophyll to more visible green colour compounds upon heating (27). Boiling-hot start and steaming compared to boiling-cold start showed higher relative greenness at high and medium firmness. At longer cooking times (low firmness), all three methods resulted in a comparable relative greenness (encircled in Figure 14).

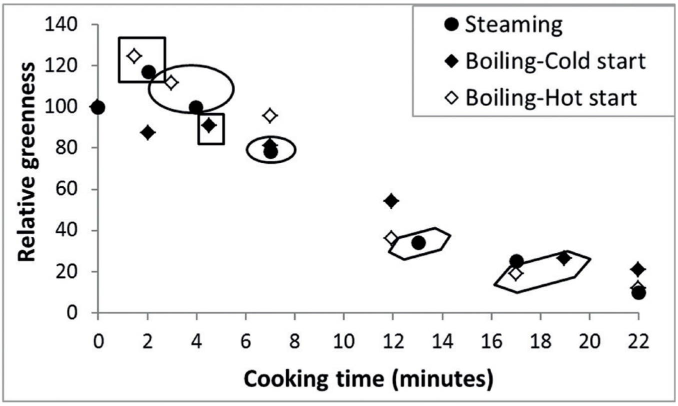

Figure 14. Relative greenness (G/G_{raw}) in broccoli cooked by different methods over time. Sensory evaluation was performed for samples of: ☐ High firmness, ⬭ Medium firmness, ⬡ Low firmness.

3.3 Influence of cooking method and time on the amount of total glucosinolates

Total glucosinolates (GLS) in this study represents the sum of the identified GLS in broccoli: glucoraphanin, glucobrassicin, 4-methoxyglucobrassicin and neoglucobrassicin. In agreement with literature (107), glucoraphanin among the aliphatic GLS, and neoglucobrassicin among the indole GLS, were identified as the predominant GLS in broccoli (data not shown). Figure 15 compares the relative amount of GLS in broccoli cooked by different methods over time.

The total GLS in broccoli cooked by all three methods decreased over time. Glucosinolates being water-soluble are lost in the cooking-water by leaching (12). In addition, heating leads to thermal degradation of GLS and its breakdown products (12). However, steaming is reported to limit the losses of GLS during cooking (42). In this study, steaming showed a GLS decrease (though not statistically significant; $p > 0.05$) of 17 % after a cooking time of 22 minutes. This is substantially a lower loss than boiling-cold start (50 %) ($p < 0.05$) and boiling-hot start (41 %) ($p < 0.05$). Steaming and boiling-hot start (not statistically significant, $p > 0.05$) showed an initial increase in GLS in broccoli, while boiling-cold start showed a decrease in GLS (not statistically significant, $p > 0.05$). This phenomenon has been described before and can partly be explained by a thermally-induced improved extractability of GLS from the matrix of the cooked broccoli (12).

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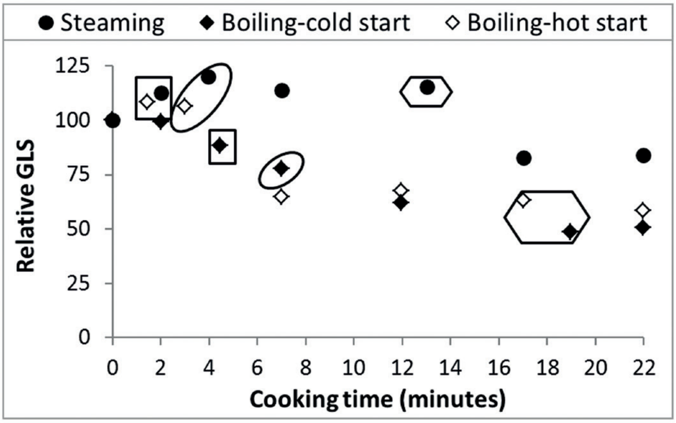

Figure 15. Relative amount of glucosinolates (GLS/GLS_{raw}) in broccoli cooked by different methods over time. Sensory evaluation was performed for samples of: □ High firmness, ⬭ Medium firmness, ⬡ Low firmness.

At all firmness (encircled in Figure 15), steaming followed by boiling-hot start showed highest GLS retention when compared to boiling-cold start. Comparable to the literature (115), we also observed a high standard deviation (3-24 %) in GLS in cooked broccoli (Appendix 3). With these high standard deviations, no statistically significant changes were established in the amount of GLS between fresh (uncooked) broccoli and when cooked by all methods for high and medium firmness. At the low firmness, broccoli boiled with cold and hot start showed significant losses, while steaming still retained GLS (Appendix 3).

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3.4 Influence of cooking method and time on liking and sensory properties of broccoli

3.4.1 Liking

The influence of cooking method and time (varying textures) on the average overall liking of broccoli by consumers is shown in Figure 16.

Texture of broccoli, which was controlled by cooking time, was of significant influence ($F_{1,5} = 28.342$, $p = 0.000$) on the liking of broccoli. Medium firm broccoli, both steamed and boiled, was the most liked. This finding is in agreement with the findings of Poelman & Delahunty (2013), who reported that children liked neither the hard crunchy short cooked vegetables nor the soft mashy vegetables, but liked the vegetables with medium firmness, chewing resistance and cohesiveness.

Significant influence of cooking method on liking at a given texture condition was observed only for low firm broccoli ($p = 0.020$) (Figure 16). For the high and medium firm conditions, cooking method did not significantly influence liking. Steamed vegetables are more flavoursome (Figure 17d), which can lead to higher liking (29).

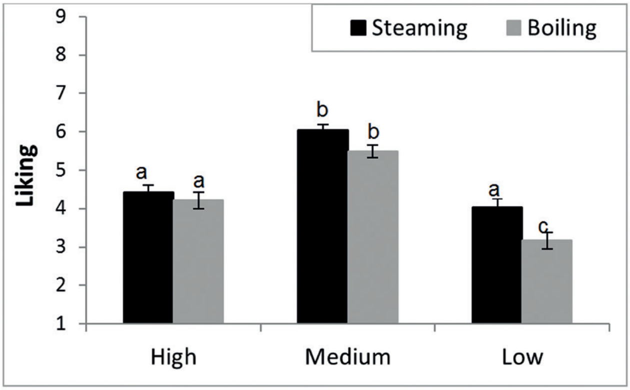

Figure 16. Average (± SEM) overall liking scores for steamed and boiled broccoli cooked for high, medium, low firmness. Liking was assessed by untrained consumers (n = 99) on a 9-point hedonic scale that had anchors dislike extremely = 1, like extremely = 9. Bars with a different letter are significantly different from each other at *p* < 0.05.

3.4.2 Sensory properties

The averaged intensities of all sensory attributes assessed for steamed and boiled broccoli at three textures are presented in Figure 17.

Firmness significantly differed between the three broccolis (high, medium, low firm) and decreased significantly with decreasing firmness. As expected, the firmness of the high firm broccoli was rated the highest, followed by the medium firm broccoli and the low firm samples with the lowest firmness intensity (Figure 17a). Cooking method did not show a significant influence on perceived firmness, which was also confirmed by instrumentally measured firmness (Figure 13) and that cooking times were chosen well so that comparable firmness was obtained between cooking methods.

The *greenness* of the broccoli samples decreased with decreasing firmness, i.e., the softer the broccoli, the lower the perceived intensity of greenness (Figure 17b). Cooking method did not significantly influence the perceived greenness intensity of the florets at each of the three textures.

Juiciness of the broccoli samples increased with decreasing firmness (Figure 17c). Significant differences between the cooking methods were perceived only for the medium firm broccoli.

Broccoli flavour of boiled and steamed broccoli increased from high to medium firm broccoli and decreased from medium to low firm broccoli (Figure 17d). Steamed broccoli was rated significantly higher in flavour for medium and low firm broccoli, i.e., the influence of cooking method on flavour was perceived only at longer cooking times. Steamed vegetables were reported to be more flavoursome than boiled vegetables (29) with steaming refraining the leaching of volatile breakdown products of glucosinolates (116) into the cooking water.

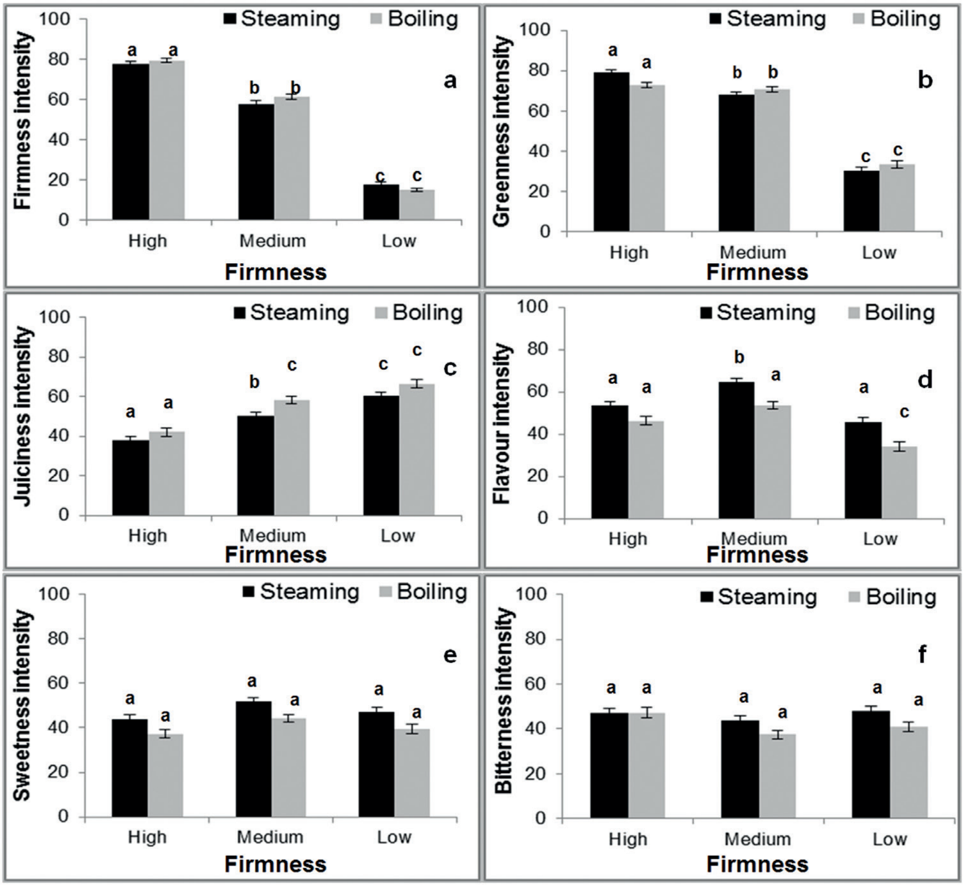

Figure 17. Average (± SEM) intensity ratings for sensory attributes for steamed and boiled broccoli cooked for high, medium and low firmness. All attributes were assessed by untrained consumers (n = 99) on intensity scales ranging from 0 to 100. Bars with different letter are significantly different from each other at $p < 0.05$.

Sweetness of the six broccoli samples did not differ significantly over cooking time (firmness) and method which might be explained by the fact that brassica vegetables are seldom perceived as sweet (113) (Figure 17e). Though not significantly different, steamed broccoli was perceived sweeter at all the firmness over the boiled broccoli.

Bitterness of the broccoli samples also did not differ significantly between cooking methods and textures (Figure 17f). The literature indicates that glucosinolates, i.e., sinigrin, gluconapin and progoitrin are the main contributors of bitterness in brassica vegetables (116). However, these GLS were either not found or were in very low amounts in the broccoli samples. Further, a higher sweetness (induced by sucrose) was reported to mask the bitterness, with a positive influence on 'overall acceptability' of brassica vegetables (116). At medium firmness, the broccoli samples were rated the highest in sweetness and the lowest in bitterness (Figure 17e, 17f).

4. GENERAL DISCUSSION

Whether prepared by steaming or by boiling-cold start, medium firm broccoli was rated higher for liking and significantly different from high and low firm broccoli in intensity of several sensory attributes (Figure 16 and 17). In addition, medium firm broccoli when prepared by steaming retained 23 % higher GLS than when compared by boiling-cold start (Figure 15). However, with no information in the literature on the intake level of GLS from brassica vegetables that can exhibit health benefits on consumption, it can be debatable if consuming a 23 % higher amount of GLS from the steamed (medium firm) broccoli can deliver health benefit.

The findings from this study propose suggestions for consumers on vegetable cooking methods and time that yield vegetables with higher sensory liking and at the same time possess higher values for health promoting compounds. Steamed and cold start-boiled broccoli with a medium firmness is liked more over the high and low firm broccoli. That is, both cooking methods can yield broccoli with the most liked texture (medium firm). Moreover, steaming and boiling with a cold start did not show a significant influence on liking (except at low firmness) and on the perceived intensity for most sensory attributes (except for juiciness at medium firmness, and flavour at medium and low firmness) of broccoli. However, broccoli boiled with a cold start retained on average the lowest and steaming the highest total glucosinolates (though not always statistically significant because of high standard deviations) at all textures and over the range of cooking times.

5. CONCLUSION

When consumers are open for a change in cooking method, steaming would be a better option. For consumers who usually boil broccoli with a cold start (60 %) and a vegetable-water ratio of 1:4 (61) to achieve high or medium firmness, boiling-hot start could be advised as a better cooking method over boiling-cold start. Boiling-hot start takes the shortest time of all three methods to reach these textures and yield in a greener (instrumental analysed) broccoli that retains higher glucosinolates compared to boiling-cold start.

6. ACKNOWLEDGEMENT

We thank Tjachy Hu for her contribution to the data collection.

Chapter 6

Sensory and Health properties of steamed and boiled carrots

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(*submitted for publication*)

ABSTRACT

This study examined the influences of domestic processing conditions applied by consumers on firmness, colour, amount of phytochemicals and liking and sensory attribute intensity ratings of carrots. The aim was to identify a cooking method and time that yields carrots with higher amount of β-carotene while maintaining consumer liking. Instrumentally measured firmness and colour showed comparable degradation trends between cooking methods. While boiling showed a significant decrease in the amount β-carotene after 20 minutes (-19 %), steaming maintained the amount (+40 %). Cooking method did not show a significant effect on liking and intensity ratings for the majority of the sensory attributes. Medium firm carrots were liked the most and low firm carrots the least. This study demonstrates that for optimum liking, carrots should be in the range of medium firmness. This can be obtained through either cooking methods but steamed carrots possess a higher amount of β-carotene and maintains liking.

Keywords: Carrots; β-carotene; Firmness; Colour; Sensory Evaluation; Dutch Households.

6

1. INTRODUCTION

There is a growing awareness among consumers on the role of vegetables in maintaining and improving their health status (117). Cohort studies indicate that high consumption of vegetables reduces the risk of occurrence of chronic degenerative diseases like cancers and cardiovascular diseases (7). Different classes of vegetables provide a varied array of nutrients and phytochemicals, which exhibit various health protective properties. Carrots are one of the widely consumed vegetables in the Netherlands (118) and are known for their rich supply of the phytochemical β-carotene, which exhibits anti-oxidant and pro-vitamin A activity on consumption (7, 41, 119, 120). Carrots contribute to up to 50 % of the β-carotene intake in most of the European countries and Northern America (121). Although sometimes eaten raw, carrots are often boiled, steamed or stir-fried prior to consumption (122). Processed vegetables are considered to be lower in nutritional values as most nutrients and phytochemicals are sensitive to processing conditions (123) such as the amount of water used, cooking time-temperature, method of cooking, size of the vegetable (12, 124). In this respect, thermal processing of carrots may affect the carotene amounts; the long chain conjugated double-bond structure of β-carotene makes it susceptible to degradation due to heat, oxygen, light and acid. Thus, β-carotene undergoes degradation and isomerisation during industrial processing, reducing its anti-oxidant and pro-vitamin A activity (125, 126). These changes are, however, not perceptible by consumers. In addition to the influence on nutritional values, domestic processing significantly alters sensory properties of vegetables (10, 42). Consumers use changes in sensory properties during cooking to value the vegetables. Processing conditions influences the texture (127) and colour (128) and also influence liking and acceptance of vegetables to a great extent (7, 129). When comparing different methods of cooking, participants preferred steamed carrots over boiled or microwaved (in Zip 'n' Steam bags) carrots, for better flavour and overall acceptability (29). Dutch children and young adults preferred boiled and steamed carrots over stir-fried, microwaved or mashed carrots, mainly because of the texture and colour (74).

In the last decades, health properties of vegetables are gaining equal (if not more) importance as the sensory properties (1) such as texture of cooked vegetables. Consumers are demanding for vegetables that are healthy and still meet their sensory preferences. Therefore, the objective of this study is to examine the influence of cooking methods of carrots applied by Dutch households on sensory and health properties to gain insights into cooking methods that yield carrots with a higher amount of carotenes and comparable (or higher) liking .

Based on previous research using an online self-reporting questionnaire, boiling and steaming were identified as the most common cooking methods applied by Dutch households (122). Texture was mainly used to decide the doneness of carrots (122).

Therefore, this study determined the influences of these cooking methods (and time) on instrumentally measured firmness, colour and amount of β-carotenes; and overall liking and sensory perception of carrots.

2. MATERIALS AND METHODS

2.1 Setup of the study

Carrots were cooked by steaming and boiling using a cold start. Firmness, colour and amount of carotene in steamed and boiled carrots were analysed at six time points (Table 11). Three time points per cooking method were identified that resulted in carrots with different instrumental firmness: 'high, 'medium' and 'low' (the time points mentioned for 'sensory evaluation' in Table 11). These time points were chosen to yield different instrumental firmness values between the samples (high, medium and low) cooked by a single method. In addition these time points yield comparable values for the given 'firmness' between cooking methods. For example, a comparable 'high' firmness value between steamed and boiled carrots samples. Overall liking and perceived intensity of sensory attributes were determined on high, medium, and low firm cooked carrots (Table 11).

Table 11. Experimental Design of the study.

Analyses	Steaming (minutes)	Boiling (minutes)
Firmness **Colour** **β-carotene amount**	0, 2, 4, 7, 16, 20	0, 5, 9, 15, 20, 25
Sensory evaluation **(time required to obtain 'high', 'medium' and 'low' firmness)**	4, 7, 16	5, 9, 20

2.2 Preparation of carrots

2.2.1 Standardisation of carrots

One batch of carrots per cooking method was purchased (local vegetable shop, Wageningen, the Netherlands) and cooked in triplicate. Standardisation of carrots was done by selecting carrots with a diameter of 2-3 cm and length of 16-20 cm. These carrots were washed, peeled and trimmed at the shoot and tip of roots. For every cooking time point, 200-210 gram of the standardised carrots was cooked.

2.2.2 Steaming

Steaming of carrots was performed with domestic steamers (Philips HD9160 steamer). The steamer was filled with 1400 ml cold tap water and switched on. After 2 minutes, 200-210 g of carrots were put into the steamer and cooked as per Table 11.

2.2.3 Boiling

Boiling of carrots was done using an induction plate (ATAG induction hob). For every time point, similar covered stainless-steel pots were used. A vegetable-water ratio of 1:4 was used and a cold start was applied, i.e., cooking time started when the carrots along with tap water (25 ^{o}C) were put on the induction plate.

After boiling or steaming, part of the cooked carrots was immediately frozen with liquid nitrogen, blended to powder and stored at -20 ^{o}C for carotene analysis. Another part was used for instrumental firmness and colour analysis.

2.3 Instrumental analysis

2.3.1 Firmness

Firmness (N/cm^2) of 3 to 5 standardised carrot pieces per time point was measured using a texture analyser (Stable Micro Systems) equipped with a Warner-Bratzler V-knife probe. A 50 kg cell load was used to cut every carrot piece at 1 cm from its top to measure the force applied at 40 % strain and test speed 1 mm/s (130). The relative firmness (F_{rel}) was expressed as the firmness of the cooked carrots (F) divided by the firmness of the raw carrots (F_{raw}).

2.3.2 Colour

Three to five carrots (the same sample after texture analysis) were blended into a homogenous paste. This paste was divided into 3 parts and each part was placed into the cuvette of ColorFlex meter (Hunter Associates Laboratory, USA), with the lid closed and measured at two angles for a* (red) and b* (yellow) values. Colour of the samples was calculated by a*/b* values to express the colour changes in redness and yellowness. The relative colour (C_{rel}) is expressed as the colour of the cooked carrots (C) divided by the colour of the raw carrots (C_{raw}).

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2.3.3 Carotene analysis

A sample of 2 g powdered carrot, 6 ml water and 10 ml hexane was turraxed, flushed with nitrogen and centrifuged (Thermo Scientific, Germany) for 5 min at 1600 g and supernatant was collected. 0.1 % butylated hydroxyl toluene in ethanol was used as the antioxidant. The pellet was re-extracted twice with 10 ml Tetra Hydro Furan (THF), turraxed, flushed with nitrogen and centrifuged to collect supernatant. The combined supernatant was concentrated by vacuum evaporation (Buchi, Switzerland) at 270 millibar, 40 ^{o}C under nitrogen flush, dissolved in 50:50 THF: Eluent mix, filtered with 0.45 µm membrane and analysed with HPLC (Dionex Softron GmbH, Germany) using

Vydac RP C18 column at a flow rate 1 ml/min. Eluent of 92.5 % Methanol, 7.5 % THF and 0.1 % triethylamine was used to facilitate the elution of carotenes which were identified against their known retention time and spectra. The amount of β-carotene was calculated using the calibration curve (131). The relative amount of β-carotene (BC_{rel}) is expressed as measured β-carotene in cooked carrots (BC) divided by β-carotene in the raw carrots (BC_{raw}).

2.4 Sensory evaluation

2.4.1 Participants

Healthy Dutch participants (n = 100), who cooked and consume carrots at least once a month were recruited via an advertisement through email and social networking site. Seventy-four participants were aged between 18 and 35 years, twenty-six participants were aged above 36 years. Seventy-one participants were female. The participants were not representative for the Dutch population since 50 % of the participants of this study were students (Wageningen University) and the other 50 % were non-students from Wageningen area, the Netherlands. All participants were unfamiliar with sensory evaluation of carrots and were not trained for this study. A financial compensation for participation was given at the end of the study.

2.4.2 Samples

The standardised carrot samples were cut into 4 cm long pieces and were cooked at three time points representing high, medium and low firmness (Table 11). Carrots were cooked in such a way that all six samples were done at the same time to ensure warm servings for the sensory evaluation. Each sample was placed in a polystyrene foam cup with a lid (coded with a randomised three digit code) to keep the samples at approximately 50 ^{o}C. The samples were served in random order to the participants.

2.4.3 Attributes

Donadini et al. and Zeinstra et al. used Quantitative Descriptive Analysis to assess the sensory profile of carrots and evaluated the carrots using fifteen attributes describing appearance, texture and taste (29, 74, 132) . From this list of attributes, five attributes that describe texture, colour, flavour, and taste were selected for this study to assess the sensory properties of cooked carrots (Table 12). The definitions were translated into Dutch. During the sensory session, the participants were first given a tray containing six randomly placed coded polystyrene boxes with samples, and were asked to rate the samples for overall liking on a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). Later, the participants were served freshly cooked six samples and asked to evaluate the perceived intensity of the given attribute on a 100 mm visual analogue scale anchored with "low intensity" at 0 mm and "high intensity" at 100 mm. The attribute 'orange colour' was asked to be rated by visual perception of the carrot piece; 'firmness' after chewing the carrot piece twice; and 'juiciness', 'sweetness', and 'carrot flavour' after swallowing the sample.

Table 12. Attributes and their definitions used for sensory evaluation steamed and boiled carrots.

Attribute	Definition	Anchor
Orange colour	The colour of the carrot from light orange/yellow to dark orange.	Low (very light orange) – High (very dark orange)
Firmness	The force needed to chew the sample between molar teeth, after two times chewing.	Low (very soft) – High (very hard)
Juiciness	The amount of juice that is released while chewing.	Low (very little juice) – High (very juicy)
Carrot flavour	The overall intensity of typical carrot flavour.	Low (very low in typical carrot flavour) – High (very high in typical carrot flavour)
Sweetness	Taste sensation of which sugar is typical.	Low (very low in sweetness) – High (very sweet)

2.4.4 Design of the sensory study

The sensory session, which approximately took 30 minutes, was conducted in the sensory booths of the division of Human Nutrition, Wageningen University, the Netherlands. All participants were first given oral instructions and were seated in separate sensory booths. The session was divided into two parts in order to serve samples warm (approximately 50 ^{o}C). Overall liking of the six carrot samples was assessed in the first part of the session. Perceived intensity of the sensory attributes was assessed in the second part. EyeQuestion software was used for filling-in the ratings in both parts of the session. Water and plain crackers were provided to refresh the palate between tasting of samples as reported in the literature (29, 74).

2.5 Statistical data analysis

IBM SPSS Statistics 19 and MS Excel were used for the statistical data analysis. One-way ANOVA was performed to compare the influences of different cooking methods and times on changes in firmness, colour, amount of carotenes and overall liking and perceived intensity of attributes. Relative firmness/colour/carotene and ratings for liking and attribute intensity were loaded as dependent variable and the cooking time (samples for sensory evaluation) as fixed variable. Tukey post-hoc tests were performed and a significance level of $p < 0.05$ was used.

3. RESULTS AND DISCUSSION

3.1 Influence of cooking method and time on the firmness of carrots

Figure 18 shows the relative firmness (F/F_{raw}) of carrots cooked by steaming and boiling over time.

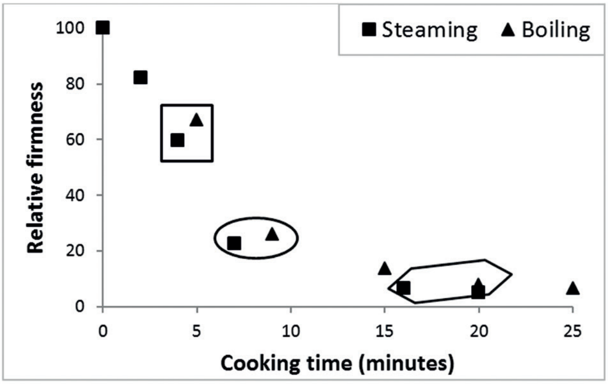

Figure 18. Relative firmness (F/F_{raw}) of steamed and boiled carrots over time. Sensory evaluation was performed for samples of: □ High firmness, ⬭ Medium firmness, ⬡ Low firmness.

Both steaming and boiling showed a statistically significant decrease in the firmness of carrots over time (Figure 18; for values see Appendix 4). Heating is reported to degrade the texture of vegetables by a β-eliminative degradation reaction, which leads to pectin depolymerisation and cell disintegration (33, 34, 127). From the current findings, it is evident that cooking time rather than cooking method influenced the firmness of carrots. As was expected from the design of the study, steaming and boiling resulted in comparable firmness of carrots at the given textures points (encircled in Figure 18 and refer Appendix 4).

3.2 Influence of cooking method and time on the colour of carrots

Figure 19 depicts the relative colour (C/C_{raw}) of steamed and boiled carrots over cooking time.

The decrease in relative colour of steamed and boiled carrots over cooking time was statistically significant (Figure 19; Appendix 5). The α- and β-carotenes are reported to be responsible for the red-orange colour of carrots (133). Isomerisation of carotenes from *trans*- to *cis*- forms (30, 128) and their thermal degradation during processing (134) is reported to have changed the colour of carrot chips (128) and juice (135) to more yellow. Steaming compared to boiling is reported to show lower leaching losses of carotenes into the cooking water (136). Therefore, steamed carrots are expected to be more red (a*) and less yellow (b*), i.e., with higher a*/b* values, than boiled carrots. However, in this study, the boiled carrots showed slightly higher a*/b* values than the steamed carrots with comparable firmness, though statistically significantly different only at high firmness ('encircled' in Figure 19, Appendix 5).

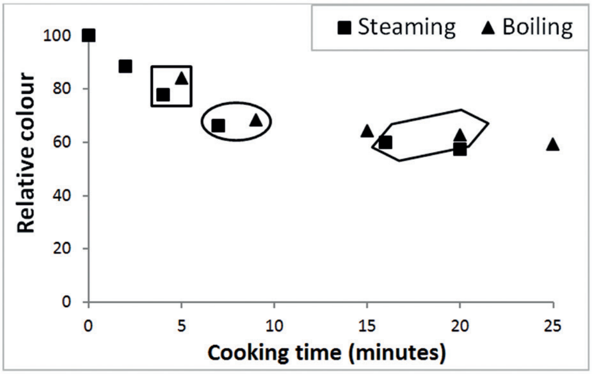

Figure 19. Relative colour (C/C_{raw}) of steamed and boiled carrots over time. Sensory evaluation was performed for samples of: □ High firmness, ⬭ Medium firmness, ⬡ Low firmness.

3.3 Influence of cooking method and time on the amount of β-carotene

Figure 20 shows the relative amount of β-carotene (BC/BC_{raw}) in steamed and boiled carrots over time.

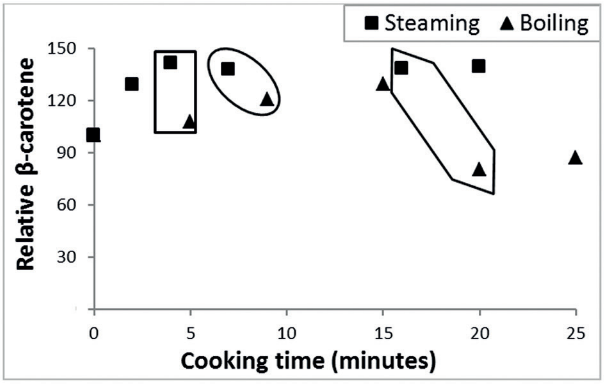

Figure 20. Relative amount of β-carotene (BC/BC_{raw}) in steamed and boiled carrots over time. Sensory evaluation was performed for samples of: □ High firmness, ⬭ Medium firmness, ⬡ Low firmness.

Both steaming and boiling showed an initial increase in the relative amount of β-carotene, up to 142 % by steaming for 4 minutes and up to 130 % by boiling for 15 minutes. β-carotene in carrots are stored in the carotene-chromoplast-protein complex (137). Heating releases the bound β-carotene, increasing its extractability by 28-88 % in cooked carrots (138). Leaching of the soluble solids into the cooking water was also shown as a major factor responsible for the initial increase of β-carotenes during processing carrots (139, 140). Upon further heating, the 'free' carotenes are susceptible to heat and oxygen and degrade or isomerise into cis-forms (141), which exhibit lower antioxidant and pro-vitamin A activity. In addition, the carotene-chromoplast-protein complex is slightly water-soluble (137, 141).

After 20 minutes of cooking, steaming resulted in an increase in β-carotene (+40 %) compared to the raw (uncooked) carrots, while boiling resulted in a decrease (-19 %). These findings are in agreement with the literature, where boiling for 30 minutes resulted in decrease of β-carotene by 40 %, while steaming showed an increase +39 % (43, 51, 138). Absence of water in steaming may have reduced the leaching losses of carotenes. There were substantial differences in amount of β-carotene in the carrot samples cooked by different methods over time in this study. However statistical significances could not always be established, especially for steaming. Steaming showed higher relative standard deviations (between 0 and 19 %), in comparison to 0 to 11 % for boiling (Appendix 6). Findings of several studies also showed high standard deviations of up to 21 % (137, 142). Only boiling for low firmness (longer time) showed a significant decrease in β-carotene in carrots ('encircled' in Figure 20).

3.4 Influence of cooking method and time on liking and sensory properties of carrots

3.4.1 Liking

The average liking of steamed and boiled carrots cooked for different time periods (resulting in three instrumental firmness: high, medium and low) is presented in Figure 21.

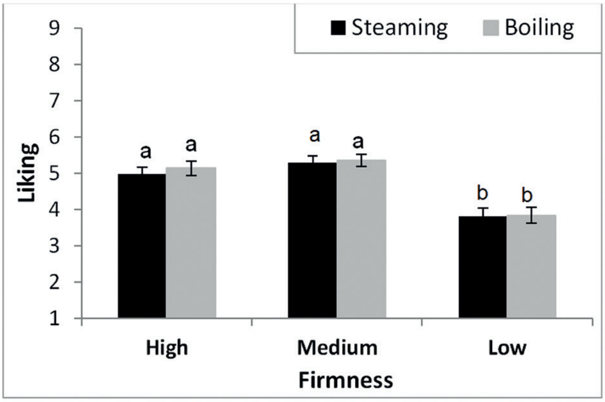

Figure 21. Average (± SEM) liking scores for steamed and boiled carrots cooked for high, medium, low firmness. Liking was assessed by untrained consumers (n = 100) on a 9-point hedonic scale that had anchors 'dislike extremely' = 1, 'like extremely' = 9. Bars with different letters are significantly different from each other at $p < 0.05$.

Texture, which was controlled by cooking time, significantly influenced the liking of carrots ($F_{1,5} = 13.175$, $p = 0.000$). Carrots with a low firmness are significantly less liked than carrots with a medium or high firmness. High and medium firm carrots did not differ significantly in liking. The cooking method did not significantly influence the liking of carrots.

3.4.2 Sensory properties

The average perceived intensities of the sensory properties assessed for steamed and boiled carrots at three levels of firmness are presented in Figure 22.

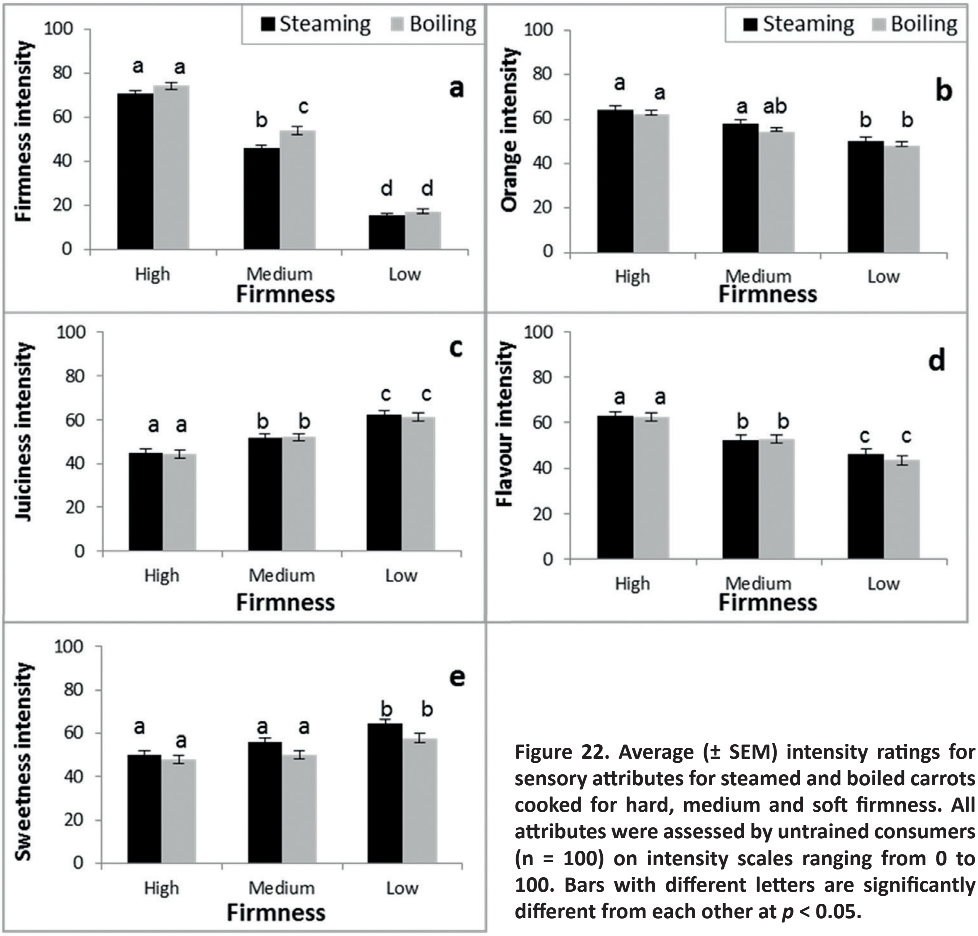

Figure 22. Average (± SEM) intensity ratings for sensory attributes for steamed and boiled carrots cooked for hard, medium and soft firmness. All attributes were assessed by untrained consumers (n = 100) on intensity scales ranging from 0 to 100. Bars with different letters are significantly different from each other at $p < 0.05$.

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Firmness significantly differed between the three carrot samples (high, medium and low firm) and decreased with increasing cooking time (Figure 22a). As was expected, the firmness of the high firm carrots was rated the highest, followed by the medium and low firm carrots. Except at medium firmness, cooking method did not show a statistically significant influence on the perceived firmness of carrots.

Orange colour of carrots decreased slightly with decreasing firmness (increasing cooking time) (Figure 22b), though not statistically significant. Cooking method did not significantly influence the perceived orange colour of carrots at all three firmness levels.

Juiciness of the carrots significantly increased with decreasing firmness (Figure 22c). Cooking method did not show a significant influence on the perceived juiciness of carrots.

Carrot flavour (Figure 22d) significantly decreased with increasing cooking time (decreasing firmness). Heating involves the breaking of cells causing release of flavour molecules (101) such as reducing sugars, amino acids, terpenes which produce the characteristic aroma and flavour of carrots (143). Steamed vegetables are considered to be more flavoursome because of no leaching of flavour compounds into the cooking water. However, in this study cooking method did not show a significant influence on the perceived carrot flavour.

Sweetness increased with decreasing firmness (Figure 22e), though statistically significant only at low firmness. This increase in sweetness indicates the possible release of (bound) sugars under heat treatment (101).

4. GENERAL DISCUSSION

Whether steamed or boiled, *high* and *medium* firm carrots were liked the most and *low* firm carrots were liked the least. The cooking method (steaming and boiling) did not significantly affect the liking of carrots when compared at similar instrumental firmness. The cooking method (steaming and boiling) also did not significantly influence the sensory properties except for perceived firmness which varied between the medium firm carrots. Steamed carrots in comparison to boiled carrots retained a higher amount of β-carotenes at all firmness. One of the factors that determines the health benefits exhibited by phytochemicals like β-carotene is the intake amount, since the intake amount will determine the amount of bioavailable β-carotenes from carrots (144).

Besides a rich source of β-carotene, carrots contain many other health-promoting phytochemicals like polyphenols, folates, vitamin B and polyacetylenes (falcarinol) (145-147). However, many of these compounds are water-soluble and can leach into the cooking water during boiling. These losses can be prevented to a large extent by steaming carrots.

5. CONCLUSIONS

Cooking method did not significantly influence liking and sensory properties (firmness, orange colour, juiciness, sweetness, flavour intensity) of carrots except for perceived firmness of medium firm carrots. Medium firm carrots were significantly more liked than low firm carrots. Perceived firmness, orange colour, carrot flavour decreased with decreasing instrumental firmness i.e. increasing cooking time, while perceived juiciness and sweetness increased. This study demonstrates that for optimum liking of carrots, firmness should be in the range of medium firmness, which can be obtained by either boiling or steaming. However, steamed carrots possess a higher amount of β-carotene .

6. ACKNOWLEDGEMENT

We thank Selma Willems for her contribution in data collection.

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Chapter 7

General discussion

1. INTRODUCTION

Nowadays consumers demand food products with properties that meet their sensory preferences but are also healthy. Designing such products is always a challenge for food technologists as domestic food processing may significantly alter not just the sensory properties but also the health properties. Though domestic processing of vegetables is not always detrimental for the health property, several phytochemicals and (micro) nutrients are sensitive to processing and may thus degrade. To study and optimise processing conditions that yield vegetable products meeting consumers' sensory preferences, for example, firmness, and have a higher amount of phytochemicals, is hard to achieve by a single scientific discipline because information on (i) consumer behaviour and sensory preferences towards cooked vegetables through consumer science studies, and (ii) influences of this behaviour on sensory and health properties of cooked vegetables through food technological studies must be known and integrated with each other. Therefore, in this thesis, *Consumer-Orientated Food Technology* was presented as an approach to achieve food technological solutions (domestic process optimisation) that are consumer-orientated.

The objective of this thesis was to gain insight into consumer behaviour and motives towards cooking of vegetables and to optimise the domestic vegetable processing conditions applied by consumers resulting in an equal liking and higher amount of nutrients or phytochemicals. This discussion commences with a summary of the main findings and uses these findings to optimise domestic processing of vegetables. This is followed by methodological considerations on the study design and discussion and interpretation of the findings. The general discussion concludes with some future prospects and implications of the results.

2. MAIN FINDINGS

The interdisciplinary *Consumer-Orientated Food Technology* (COFT) research approach developed in this thesis **(Chapter 2)** proposed to use mathematical modelling to integrate information (i) on consumer behaviour and motives, (ii) on behaviour translated into influences on sensory and health properties, and (iii) on sensory evaluation of vegetables processed at different conditions. The COFT approach aims to redefine the 'current' vegetable product into a 'new' product that aligns with consumers' sensory preferences but possesses higher amount of phytochemicals. The COFT approach was illustrated using broccoli as a case study in **Chapter 2**, where changes in the amount of glucosinolates and in texture (firmness) were modelled using 'assumed' conditions to show the effect of optimisation of domestic vegetables processing. This COFT approach will only be effective when the domestic processing conditions applied by consumers and their consequences on sensory and health properties are known.

Therefore, an appropriate research method to collect such information is needed, given the lack of information on consumer behaviour towards domestic processing of vegetables.

In **Chapter 3**, three research methods were evaluated: in-home observations, observations using cameras in a model-kitchen and a self-reporting questionnaire. All three methods were found to be reliable (test-retest, inter-observer and parallel-form reliability) and valid (face, content and concurrent validity) in collecting information on domestic processing of broccoli by consumers (n = 25). Participants were shown to be consistent in the majority of the domestic processing conditions applied towards broccoli when measured on different days and using different research methods. However, a wide inter-individual variation in behaviour towards domestic broccoli processing was observed. A large sample size is thus necessary to capture the many possible variations in domestic processing of vegetables. Therefore, the self-reporting questionnaire was concluded to be the most practical method to collect information on the domestic processing of vegetables.

In **Chapter 4**, the above self-reporting questionnaire was adapted (i) to an online self-reporting questionnaire, in order to reach a large and varied sample of Dutch households, and (ii) into two separate questionnaires, in order to collect information on domestic processing of broccoli and carrots. The majority of the participating Dutch households (70 %) boiled both vegetables using a cold-start and a high water level. Mainly texture was used as the way to decide doneness of the cooked vegetables. When cluster analysis was performed using information on several aspects of domestic processing of both vegetables, consumers were categorised into: *texture-orientated*, *health-orientated* and *taste-orientated* groups. The *texture-orientated* group was the predominant group representing 56-59 % of the study sample. About 20-30 % of the respondents represented the *health-orientated* group of the study sample and these consumers used both health and sensory properties in determining domestic processing of vegetables. The *taste-orientated* group counted for 8-26 % of the study sample depending on the type of vegetable. Demographic details like household composition, gender and educational background did not show a statistically significant influence on clustering consumers.

Various aspects of domestic processing conditions are anticipated to cause a variation in texture, colour and sensory properties (overall liking and attribute intensity rating) and in the amount of phytochemicals in cooked vegetables. Influence on these quality attributes of boiling vegetables at a high water level and using a hot or cold start was compared to steaming (i.e., indirect (no) use of water as opposed to a high water level for boiling): broccoli in **Chapter 5** and carrots in **Chapter 6**. Since mainly texture was reported to determine the doneness, texture of vegetables during processing was controlled by cooking to specific time points that yielded high, medium and low firm vegetables when cooked by either method.

In line with the design of the study, steaming, boiling-cold start and boiling-hot start yielded vegetables with comparable firmness values at all three texture (time) points, when cooked by either methods for the pre-determined times. At high firmness, the relative firmness (firmness of cooked samples compared to raw) of the vegetables was about 60 % for broccoli and carrots. At medium firmness, the relative firmness was 40 % for broccoli and 20 % for carrots. At low firmness, the relative firmness was around 8 % for both vegetables.

Colour change followed different trends between the two studied vegetables. In case of broccoli, the greenness first increased followed by a decrease. This trend was more apparent for steaming and boiling-hot start and less apparent for boiling-cold start. However, after certain time, all cooking methods resulted in comparable colour losses in broccoli. In case of cooked carrots, orange-red colour only decreased with time and this trend was comparable for steaming and boiling-cold start.

In general, glucosinolates in broccoli, when compared to β-carotenes in carrots, were more sensitive to domestic processing, especially when broccoli was boiled with a cold start. Boiling-hot start and steaming showed a comparable amount of glucosinolates in broccoli at high and medium firmness and this amount was higher than boiling-cold start at these firmness. At low firmness, steaming did not show any losses in glucosinolates, while boiling-hot start showed substantial losses, though these amounts were slightly higher than when boiled with a cold start. β-carotene in high and medium firm carrots showed an increase when either steamed or boiled with a cold start. At low firmness, in contrast to boiling-cold start, steaming did not show carotene degradation.

Sensory evaluation of steamed and boiled (with cold start) broccoli and carrots showed that medium firm vegetables were most liked and the low firm vegetables were least liked, indicating that for optimal liking, the texture of vegetables should be in the range of medium firmness, especially for this study sample.

3. OPTIMISING DOMESTIC PROCESSING CONDITIONS OF VEGETABLES

As evident from this thesis, quality attributes like firmness, colour, and amount of phytochemicals change significantly over the applied domestic processing conditions. These changes in quality attributes can be expressed in terms of mathematical models. Mathematical models consist of a set of equations that predict the changes in output variables like amount of vitamins, colour and firmness for the given input variables like time and temperature (47). In a mechanistic model, the equations describe the essential sub-processes that affect dynamic changes in a relevant quality attribute as a function of various processing conditions. In this thesis, consumer behaviour towards vegetables, i.e., the domestic vegetable processing conditions, are translated into technological aspects such as time, temperature and vegetable-water ratio (V:W) applied during cooking. This behaviour can be incorporated as input variables to predict the changes in the output variables represented by sensory and health properties. Further, these models can be used to optimise domestic processing conditions for sensory and health properties of the vegetable.

An illustration of model predictions and optimisation of domestic processing of broccoli for firmness and amount of glucosinolates is shown in this thesis.

3.1 Mathematical model for firmness

The loss of firmness during cooking of broccoli can be described by a fractional conversion model (28, 142) as shown in equation 1:

$$\frac{\mathrm{d}\left(F_t - F_\infty\right)}{\mathrm{d}t} = -k_t \cdot (F_t - F_\infty) \qquad \text{(Equation 1)}$$

In equation 1, F_t is the firmness (N/cm^2) at time t (min), is the residual firmness after infinite treatment (N/cm^2), and k_t is the rate constant of loss in firmness (1/min).

3.2 Mathematical model for glucosinolates

Degradation of glucosinolates can be explained by various mechanisms occurring at different stages of cooking: cell lysis and leaching of glucosinolates, myrosinase inactivation and thermal degradation and enzymatic degradation of glucosinolates are among the main mechanisms involved, which are described in detail and translated into mathematical equations in the literature (24, 38). Inactivation of myrosinase occurs quickly during boiling and is therefore ignored in this thesis. Cell lysis, leaching and thermal degradation of glucosinolates in the intact vegetable cell, in the lysed cell and in the cooking water (after leaching) are studied here. The parameters to describe these changes are k_L, $k_{d,V}$, $k_{d,w}$ respectively (see reference 28 and 38 for details on the equations). The equations use these parameters together with information on the temperature-time profile and the vegetable/water ratio to predict the amount of glucosinolates (GLS) in broccoli. In all the above equations, reaction rate constants (k_t, k_d, k_L) depend on temperature according to Arrhenius' law.

Parameter estimations for the rate constants were done using Athena Visual WorkBench (www.athenavisual.com) and are presented in Table 13 and 14 for degradation of firmness and glucosinolates, respectively. The available data from this thesis were not sufficient to allow accurate estimation of the activation energies. Therefore, the activation energy values were assumed from other studies (4).

Table 13. Parameter estimates for loss of firmness in broccoli during cooking.

Parameters	Estimates
k_t	0.3 min^{-1}
E_a	63200 J/mol
F_e	1 N/cm^2

Table 14. Parameter estimates of glucosinolate degradation in broccoli during cooking.

Parameters	Estimates
k_L	0.04 min^{-1}
k_{dv}	0.01 min^{-1}
k_{dw}	0.02 min^{-1}
E_{a_kL}	50000 J/mol
E_{a_kdv}	100000 J/mol
E_{a_kdw}	100000 J/mol

3.3 Optimising domestic processing of broccoli

Steaming did not show any substantial losses in glucosinolates (GLS) at high, medium and low firmness. Therefore, the optimisation of domestic processing of broccoli focusses only on the boiling process. Boiling with a cold start and a high vegetable-water (V:W) ratio (1:4) is the most commonly applied domestic processing condition identified in this thesis and also describes the prevalent texture-orientated group of consumers in the study sample.

Using the above mentioned mathematical equations that describe various mechanisms of GLS and firmness degradation, simulations were made that predicted changes in the amount of total GLS and firmness in broccoli when boiled at vegetable-water ratio (V:W) of 1:4, using a cold start (Figure 23a) and a hot start (Figure 23b). Boiling-cold start takes about 4 minutes to reach boiling temperature while boiling-hot start takes about 1.5 minutes for the same.

The model predicts that the relative amount of GLS in boiled broccoli is: about 94 % by cold start and hot start at *high* firmness (~60 % relative firmness); about 81 % in cold start and 86 % by hot start at *medium* firmness (~40 % relative firmness); about 51 % in cold start and 49 % by hot start at *low* firmness (~8 % relative firmness) (Figure 23).

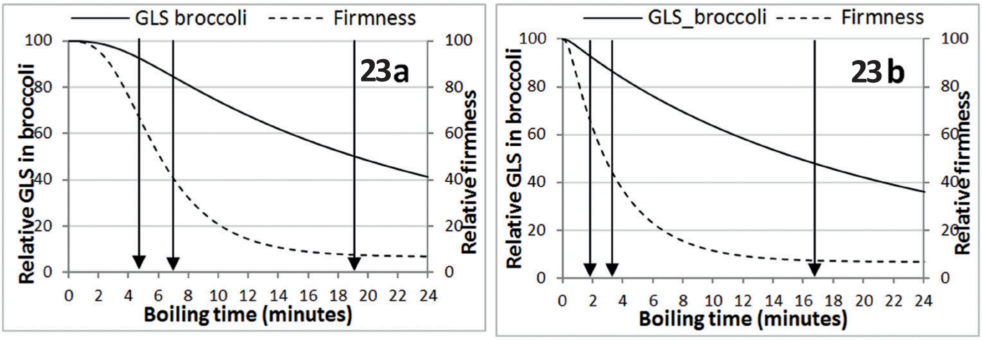

Figure 23. Modelling the changes in relative amount of glucosinolates and relative firmness in broccoli boiled at a high broccoli-water ratio (1:4) with different types of start. 23a represents cold start and 23b represents hot start boiling. Arrows in both figures mark the time points when *high*, *medium* and *low* firmness are reached.

The model simulations (Figure 23) and the data described in Chapter 5 (Figure 15) indicated that boiling did not show a substantial loss in the amount GLS at high and medium firmness. Therefore, optimisation in this thesis is focussed on cooking broccoli for low firmness, i.e., for the consumers who apply a boiling-cold start and cook for a longer time to obtain a soft texture of broccoli. Boiling-cold start was chosen for optimisation as when the type of start for boiling were switched, both methods showed (Chapter 5, Figure 15) and predicted (Figure 23) comparable relative amount of GLS at low firmness. In addition, majority of the respondents of the online-questionnaire study reported to apply a boiling-cold start method for cooking broccoli.

Decreasing cooking time to about 11 minutes is the obvious food technological solution to increase the amount of GLS. In other words, the relative firmness would be ~15 % when cooked for 10 minutes in comparison to ~8 % when cooked for 19 minutes by boiling-cold start. At 15 % relative firmness, the relative amount of GLS is ~70 % in comparison to 50 %. The instrumental firmness measurement values (chapter 5, Figure 13) and the model predictions (Figure 23a) do not show a drastic decrease in texture after about 10 minutes of cooking time. However, according to the sensory study trials conducted to define high, medium, low firmness time points, this ‘no’ difference in instrumentally measured firmness was not perceivable. In this sensory study trial the low firm broccoli was perceived when the broccoli was cooked for 19 minutes, which when measured instrumentally showed ~8 % of relative firmness.

As a result, the cooking temperature and V:W were modified in a way to increase the GLS amount in broccoli cooked for soft texture using a cold start.

Figure 24 is the prediction in the amount of GLS and firmness in broccoli, when the type of start, temperature trajectory and V:W are modified.

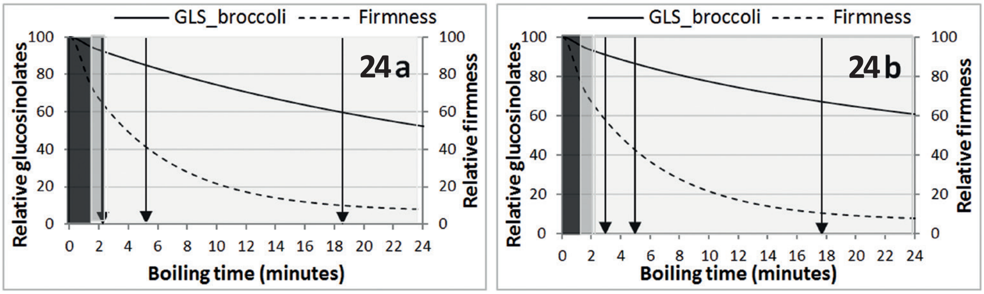

Figure 24. Optimisation of boiling conditions for firmness and glucosinolates in broccoli at different vegetable-water (V:W) ratio. Figure 24a represents a V:W of 1:4; 24b represents a V:W of 1:1 and 'boiling' at 90 ˚C. The colours in the figures indicate the changes in the temperature trajectory for optimising boiling conditions of broccoli.

Temperature increase to 100˚C till 1.5 minutes	Temperature decrease from 100˚C to 90˚C till 2 minutes	Constant temperature at 90˚C from 2 minutes on

In the first place, the cold start was replaced with a hot start, which takes about 1.5 minutes to reach 100 ºC. After this, within a span of 0.5 min, the temperature is gradually decreased to 90 ºC and maintained at this temperature during further 'boiling'. Figure 24a and 24b represent GLS and firmness of broccoli that is boiled at this optimised condition but at V:W of 1:4 and 1:1 respectively. At low firmness, the GLS increased to 60 % (Figure 24a) compared to ~50 % (Figure 23) at the conditions which consumers apply normally. When the V:W was lowered to 1:1, the amount of GLS increased up to 68 %, while still giving a low firm broccoli.

In addition to the above mentioned optimised processing condition, several other modifications were made to compare the increase in the amount of GLS while reaching the desired relative firmness values. Some of these modifications and the corresponding outputs are:

i. The use of a cold start as the consumers normally do, instead of a hot start: On reaching the boiling temperature (about 4 minutes), the temperature trajectory was reduced to 90 ˚C and maintained at this temperature further on. This increased the cooking time, especially for low firmness which needed about 23 minutes to attain ~9 % firmness and gave broccoli with 57 % amount of GLS.

ii. To apply temperatures other than 90 ˚C in the proposed optimisation conditions: Using higher temperature like 95 ˚C did not show an increase in GLS compared to 'usual' cooking conditions reported by consumers. Using lower temperature like 85, 80, 70 ˚C increased the cooking time to reach desired firmness points. The relative amount of GLS increased at low firmness, however, was lower than the proposed 90 ˚C.

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Therefore, the proposed optimisation conditions mentioned in this thesis are optimal in terms of yielding broccoli that is of desired firmness and is higher in amount of GLS.

4. METHODOLOGICAL CONSIDERATIONS

4.1 Choice of research method for domestic processing of broccoli and sample size

The choice of a research method for data collection depends on the behaviour to be measured and the practicality in its use, e.g., involved costs, time needed and information on variation in behaviour. Every research method has its own dis/advantages. In this thesis, in-home observations, observations using cameras in a model-kitchen and a self-reporting questionnaire were evaluated and it was found that all three methods are reliable and valid in collecting information from consumers (n = 25) on domestic processing of broccoli. However, the relative simplicity of broccoli processing and the smaller sample size might be concerns in establishing reliability and validity of the methods. A rather simple and habitual behaviour, i.e., domestic processing of broccoli, was used to evaluate these methods. Larger variation in behaviour might be found when the domestic processing involves multifaceted behaviour like preparation of a whole meal. However, since the focus of this research is only on the domestic processing of one food product, the consistency in behaviour reported in this thesis demonstrates the reliability of the method. The second concern in the evaluation of the research methods used in this study is the external validity, that is, the extent to which the findings can be generalised to a population, which is hard to establish with a relatively small sample size (n = 25). Ideally, a large sample size is desired when comparing research methods. However, increasing the sample size will require more time and a number of researchers for performing several observations and analysing the data.

4.2 Conducting the sensory study

The conventional sensory study to identify optimal liking and attribute intensity ratings for a given product uses a sufficiently large representative sample. In this thesis, the target population was Dutch households of different composition. Due to time constraints and ease of recruitment, mainly Dutch students and employees of Wageningen University were recruited for the sensory study and thus the findings may not be generalised to the Dutch population, though applicable for certain household types.

In this thesis the sensory attributes rated for intensity were not generated by Quantitative Descriptive Analysis (QDA), which is usually performed by a trained sensory panel to identify, quantify and define the sensory attributes of the given product. However, these attributes were picked from the literature which compared sensory evaluation of broccoli and carrot samples cooked at different conditions. These studies generated the attributes by a trained sensory panel through QDA sessions.

4.3 Mathematical modelling

The model simulations described in earlier section (of discussion chapter) were very useful in suggesting the possible changes to be made in the cooking process that will improve the health properties of cooked vegetables (broccoli) and meet desired sensory properties. However, some considerations are to be addressed.

The estimation of activation energy for glucosinolates (GLS) degradation based on the data generated in this thesis was not possible, since no variation in cooking temperature was applied, other than the temperature increase during heating up. Also the accuracy of the other parameters in the model was not very high given the lower number of data points (i.e., 6 time points, analysed 3 times each) for the number of parameters to be estimated (i.e., 7) (47) and high standard deviations in the amount of GLS (Chapter 5, Appendix 3). Broccoli is a natural material and tends to show high standard deviations depending on the batch, growing and postharvest conditions used, along with experimental errors (143). As an illustration and for better estimates and model simulations, estimated activation energy parameters from other studies were used (38). These simulations shown in this thesis therefore serve as an illustration for the approach of optimising domestic processing conditions of broccoli based on consumer behaviour and sensory wishes.

The initial increase in amount of GLS in broccoli that is boiled with a hot start or steamed (shown in chapter 5, Figure 15) is not represented in the model. Some authors attribute this phenomenon of initial increase to an increased extractability of GLS from cooked vegetables (12, 42).

5. DISCUSSION AND INTERPRETATION OF FINDINGS

The sensory and health properties of vegetables are mainly determined by the domestic processing conditions. There is a lack of information describing domestic processing of vegetables and the way consumers decide on doneness of the vegetables. This is the first study to our knowledge that has gathered such information, studied their consequent influence on different quality attributes and attempted to optimise processing conditions of vegetables that meet consumers' sensory preferences and are higher in health properties. An interdisciplinary approach has been used to obtain food technological findings that are consumer-orientated.

When vegetables pass through the food chain, several post-harvest actors modify postharvest conditions to control the physiological changes in vegetables. However, after purchase, when consumers handle the vegetables, several preparation and processing conditions are involved that lead to a significant change in the quality of vegetables at the time of consumption. It was found in another study that every consumer behaves differently even when performing the same household activity (88). Therefore, a great variation in behaviour, i.e., domestic processing of vegetables was expected in this study. In such a case, the research method used should be robust enough not just in terms of reliability and validity to collect such information, but also be practical for use, e.g., in terms of costs, time and ability to reach and capture wide variations.

5.1 Research methods for consumer behaviour towards vegetables

Consistency in consumer behaviour towards vegetables, i.e., processing broccoli before consumption was checked over time and by three different methods: in-home observations, observations using cameras in a model-kitchen, self-reporting questionnaire. As hypothesised, consumers showed great inter-individual variability for every aspect of vegetable processing. The majority of the consumers were consistent in the behaviour they perform (intra-individual variability) when measured by either methods. Only 'cooking time' showed high intra-individual variability, also when measured by different research methods and can be seen as the least consistent aspect of domestic processing of broccoli. Thus, these selected methods were shown to be interchangeable in terms of data collection on domestic processing of vegetables. The 'social desirability bias' and the 'observer-bias' concerns associated with research methods can be avoided, when the participant is unaware of the aim or focus of the study. In addition, presence of family members, as in the case of model-kitchen observations using cameras in this thesis, might divert or ease the participant while being observed, making the situation more like at home, where family members also might be present during meal preparation. Validation of research methods like observations and self-reporting questionnaires before use is a must. Once the data is collected, it cannot be redone, unlike the repetition of the laboratory experiments for missing data or for sampling errors. In addition, a large sample size should be reached for the information like domestic processing of vegetables, especially when the research outcomes are societally-relevant. Thus, the self-reporting questionnaire, which was evaluated as reliable and valid, was also shown to be practical to use in data collection. However, the questionnaire was adapted in order to use it for other vegetables, i.e., carrots in our second case. Inclusion of the question on peeling of carrots and modification of the question on the size of carrot piece were among the minor adaptions made.

5.2 Factors determining domestic processing of vegetables

With the information on domestic processing of carrots and broccoli, consumer groups were categorised into *texture-orientated*, *taste-orientated*, and *health-orientated* consumers. As hypothesised, sensory properties, mainly the texture assessment during cooking was used to determine doneness of the vegetables. The *texture-orientated* consumers are the prevalent group in our study sample, and they perform various aspects of domestic processing merely as a habit. A behaviour repeatedly and unconsciously done over time turns into a habit (97, 102). The *health-orientated* consumers are conscious of the consequences of domestic processing on nutrients in cooked vegetables. They reported to determine the processing conditions based on sensory and health properties of cooked vegetables.

5.3 Domestic processing defines the quality of vegetables

Given the reported domestic processing conditions applied by consumers and the underlying motives, changes in texture, colour and to some extent the perception of health properties were identified as important properties that determine consumer behaviour towards vegetables.

During domestic processing, firmness of vegetables decreases because of pectin degradation and solubilisation. From a mechanistic point of view, mainly the β-eliminative reaction of pectin is reported to explain the loss in texture (firmness) at higher temperatures (33, 34, 108, 109). Several phytochemicals impart colour to vegetables and fruits (27, 42) and every class of compounds that impart colour behaves differently upon heating. Upon heating the brightness of the colour of broccoli showed an initial increase and then decreased, while the colour of carrots decreased with cooking time. Likewise, the amount of phytochemicals depends greatly on their solubility and thermal stability (35, 42, 46). Glucosinolates in broccoli showed substantial leaching when boiled, while steaming did not show any significant losses. The initial increase in carotenes in carrots was because of their release from the chromoplast-protein matrix upon heating (100, 132). However, on further heating carotenes are shown to decrease due to thermal degradation. More 'harsh' treatments like stir frying or boiling followed by stir frying applied by the *taste-orientated* consumers can result in higher carotene losses in carrots (128, 144). In contrast, literature reported that stir frying does not show a significant loss in glucosinolates in broccoli (52). Different cooking methods and conditions result in vegetable products with varied sensory properties and might thus affect their liking and acceptability (29, 74, 101). When the changes in firmness are controlled, the applied cooking method did not show a significant influence on overall liking and on the majority of the attribute intensity ratings. This once again confirms the hypothesis that mainly sensory attributes like texture determine the domestic processing conditions and the liking of vegetables. Thus, opportunity exists to optimise the processing conditions of vegetables that meet consumer wishes for a certain texture and are higher in nutrients or phytochemicals.

Every individual differs in assessing the quality of cooked vegetables, since some determine the quality by assessing the texture, some by taste and some by colour of the cooked vegetable (8, 88). At least one of these sensory properties or criteria should be satisfied while optimising processing conditions for higher amounts of nutrients or phytochemicals (8).

5.4 Linking consumer science and food technology findings

Texture of vegetables is an important criterion that should be met. When illustrated using simulations (Figure 23), broccoli at low firmness showed a lower amount of glucosinolates. Optimisation of processing conditions was proposed (Figure 24) by modifying the type of start, temperature trajectories and V:W ratio during boiling. Using mathematical modelling as a tool, an increase of up to 20 % of GLS was achieved while broccoli can still be boiled for low firmness. Kitchen appliances like hot plates and stoves can be developed or adapted to control this temperature trajectory, i.e., to reach 100 ^oC in 1.5 minutes, and decrease to 90 ^oC in the next 0.5 minutes and maintain the temperature further on at 90 ^oC till ~18 minutes to get broccoli with low firmness. Such appliances could be very handy for people (e.g. elderly) who prefer soft textured vegetables (145). For consumers who cook for high and medium firmness, extra buttons or switches may be included to the same appliance that stops the cooking process at a certain cooking time (related to the preferred texture). However, consumers have to (learn to) use a hot start while boiling such vegetables. Food industries can also introduce ready-to-eat broccoli (vegetable) products that have such textures and only need warming up before use. Before putting on the market, these products should however be assessed for the influence of storage, packaging and warming-up temperature-time on the health, sensory and the safety aspects of cooked foods (vegetables), and be optimised accordingly.

5.5 Communication strategies of information

The optimised processing conditions of vegetables, illustrated here using amount of glucosinolates and changes in firmness, should be communicated to the consumer. Strategies like placing pamphlets next or attached to these foods in supermarkets; communicating this information through consumer forums; conveying messages to the local and national consumer health organisations; cooking classes; offering samples to taste at supermarkets; or modifying the existing recipes in the recipe books are just a few suggestions. While the satisfied sensory properties might promise an acceptance of information by consumers, this does not necessarily imply a behaviour change as most behaviour is driven by habit, convenience, or associated to cost and time.

6. RECOMMENDATIONS AND IMPLICATIONS FOR FUTURE RESEARCH

In this thesis, consumer behaviour related to cooking of broccoli and carrots and underlying motives in processing these vegetables have been explored. Based on this information, consumers were grouped into texture-, health- and taste-orientated groups for both vegetables separately. It would be insightful to see the intra-individual variability (by comparing the reported behaviour and motives of the same person for both vegetables) in processing broccoli and carrots. Such information will help to generalise the identified consumer clusters regarding vegetable processing conditions to the population.

In addition, the domestic processing of other vegetables that differ morphologically and possess different classes of phytochemicals should also be studied to give a general overview on vegetable processing at domestic level.

The mathematical modelling was used as a tool to optimise domestic processing of broccoli for low firmness. Given the methodological considerations, the optimised processing conditions should be validated by conducting a sensory study with consumers who cook for soft texture of vegetables. The sensory study should ask for overall liking, attribute intensity as well as preference ratings for the given product. Information on intensity along with preference ratings will guide the researcher in understanding the attributes that drive liking of the product, which can be checked using statistical methods like preference mapping and regression models.

The model used to describe and predict changes in texture (firmness) of broccoli (vegetable) in this thesis did not consider the influence of different vegetable-water (V:W) ratios. Predicting firmness at different V:W is a challenge because of the supposed inhomogeneous firmness of broccoli (vegetable) in the pan/pot boiled at different V:W ratios due to the combination of ‘boiling’ for broccoli (vegetable) that is under water, and of ‘steaming’ for broccoli (vegetable) does not have contact with water. A study designed to measure and model the influence of V:W ratio on firmness of vegetable should be conducted.

7. MAIN CONCLUSIONS

The research conducted in this thesis has successfully integrated consumer science and food technology disciplines, which brought a paradigm shift in approaching a given problem. Attempt was made to optimise domestic processing conditions of vegetable, given associated considerations.

This thesis demonstrated that in-home observations or observations using cameras in a model-kitchen or self-reporting questionnaires are reliable and valid research methods for collecting data on vegetable processing at the domestic level. In the view of costs, time and the required sample size, the self-reporting questionnaire was chosen as the most practical method. In general, comparable processing conditions of broccoli and carrots were reported by consumers, though the intra-individual variability in the processing of different vegetables was not assessed. Consumers control processing conditions of vegetables mainly by assessing the changes in sensory (texture) properties (56-59 %), while considerable number of consumers (20-30 %) control the domestic processing conditions for higher health benefits too. Demographic details did not show a significant influence in determining these domestic processing conditions. For optimal liking, the texture of the cooked vegetable should be in the range of medium firmness. At this firmness, the phytochemicals are also substantially higher than at lower firmness. However, for consumers who prefer low firm vegetables, processing conditions were optimised using mathematical modelling to yield a vegetable (broccoli) which is about 18 % higher in amount of glucosinolates and is still soft in texture. With such information, kitchen appliances can be developed or adapted that will assist consumers in cooking 'healthy' and still meet their sensory preference.

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Appendices

Appendix 1. Relative firmness ± SD % of broccoli samples cooked by different methods over time. Highlighted rows indiacte the high, medium, low firm broccoli samples of each cooking method used for sensory study.

Steaming		Boiling-cold start		Boiling-hot start	
Time (minutes)	Relative firmness ± SD %	Time (minutes)	Relative firmness ± SD %	Time (minutes)	Relative firmness ± SD %
0	100.0 ± 0.0[a]	0	100.0 ± 0.0[a]	0	100.0 ± 0.0[a]
2	61.2 ± 10.9[b]	2	88.2 ± 1.6[b]	1.5	60.9 ± 7.4[b]
4	42.0 ± 3.3[c]	4.5	60.8 ± 7.1[c]	3	46.0 ± 1.5[c]
7	24.0 ± 8.4[d]	7	45.3 ± 4.1[d]	7	26.4 ± 9.7[d]
13	13.0 ± 4.8[e]	12	37.9 ± 5.5[d]	12	17.2 ± 25.2[e]
17	7.2 ± 9.7[e]	19	14.8 ± 39.4[e]	17	12.0 ± 8.9[e,f]
22	5.6 ±17.9[e]	22	10.5 ± 19.9[e]	22	7.8 ± 32.1[f]

[*] The values with different superscript letters along each column are signficantly different at $p < 0.05$.

Appendix 2. Relative greenness ± SD % of broccoli sample cooked by different methods over time. Highlighted rows indiacte the high, medium, low firm broccoli samples of each cooking method used for sensory study.

Steaming		Boiling-cold start		Boiling-hot start	
Time (minutes)	Relative greenness ± SD %	Time (minutes)	Relative greenness ± SD %	Time (minutes)	Relative greenness ± SD %
0	100.0 ± 0.0[a]	0	100.0 ± 0.0[a]	0	100.0 ± 0.0[a]
2	116.6 ± 8.8[a]	2	86.9 ±1.1[b]	1.5	124.4 ± 11.1[a]
4	100.0 ± 2.6[a]	4.5	90.9 ± 3.0[b,a]	3	111.5 ± 2.4[a]
7	78.7 ± 5.6[b]	7	81.2 ± 7.7[b]	7	95.2 ± 4.8[a]
13	33.7 ± 29.2[c]	12	53.5 ± 9.7[c]	12	36.2 ± 25.3[b]
17	25.1 ± 10.3[c,d]	19	25.7 ± 13.3[d]	17	19.1 ± 43.7[b]
22	10.1 ± 65.7[d]	22	20.2 ± 37.6[d]	22	12.0 ± 70.2[b]

[*] The values with different superscript letters along each column are signficantly different at $p < 0.05$.

Appendix 3. Relative amount of glucosinolates ± SD % in broccoli samples cooked by different methods over time. Highlighted rows indiacte the high, medium, low firm broccoli samples of each cooking method used for sensory study.

Steaming		Boiling-cold start		Boiling-hot start	
Time (minutes)	Relative GLS amount ± SD %	Time (minutes)	Relative GLS amount ± SD %	Time (minutes)	Relative GLS amount ± SD %
0	100.0 ± 0.0[a]	0	100.0 ± 0.0[a]	0	100.0 ± 0.0[a]
2	112.0 ± 7.3[a]	2	99.0 ± 6.0[a]	1.5	108.3 ± 23.5[a]
4	119.6 ± 4.5[a]	4.5	88.6 ± 19.1[a]	3	105.9 ± 14.2[a]
7	113.7 ± 19.3[a]	7	77.7 ± 6.6[b]	7	64.7 ± 14.1[b]
13	115.9 ± 18.6[a]	12	62.1 ± 3.5[b]	12	67.5 ± 21.8[b]
17	82.9 ± 15.3[a]	19	48.3 ± 1.4[b]	17	62.6 ± 20.3[b]
22	83.4 ± 15.1[a]	22	50.6 ± 14.4[b]	22	58.7 ± 21.2[b]

[*] The values with different superscript letters along each column are signficantly different at $p < 0.05$.

Appendix 4. Relative firmness ± SD% of carrots cooked by steaming and boiling over time. Highlighted rows indicate the high, medium and low firm carrot samples of each cooking method used for sensory study.

Steaming		Boiling	
Cooking time (minutes)	Relative firmness ± SD %	Cooking time (minutes)	Relative firmness ± SD %
0	100.0 ± 0.0[a]	0	100.0 ± 0.0[a]
2	82.3 ± 3.6[b]	5	67.0 ± 6.5[b]
4	59.9 ± 1.9[c]	9	26.0 ± 12.5[c]
7	22.7 ± 15.7[d]	15	13.7 ± 18.1[d]
16	6.6 ± 15.0[e]	20	8.0 ± 12.7[d,e]
20	5.2 ± 5.9[e]	25	6.8 ± 10.4[e]

*The values with different superscript letter along each column are significantly different at $p < 0.05$.

Appendix 5. Relative colour ± SD % of carrots cooked by steaming and boiling over time. Highlighted rows indicate the high, medium and low firm carrot samples of each cooking method used for sensory study.

Steaming		Boiling	
Cooking time (minutes)	Relative colour ± SD %	Cooking time (minutes)	Relative colour ± SD %
0	100.0 ± 0.0[a]	0	100.0 ± 0.0[a]
2	88.3 ± 1.9[b]	5	84.1 ± 1.2[b]
4	77.9 ± 0.8[c]	9	68.3 ± 1.7[c]
7	66.1 ± 3.1[d]	15	64.1 ± 0.9[c,d]
16	59.8 ± 1.5[e]	20	62.8 ± 3.3[d,e]
20	57.3 ± 2.8[e]	25	59.1 ± 4.6[e]

*The values with different superscript letter along each column are significantly different at $p < 0.05$.

Appendix 6. Relative amount of β-carotene ± SD % in carrots cooked by steaming and boiling over time. Highlighted rows indicate the high, medium and low firm carrot samples of each cooking method used for sensory study.

Steaming		Boiling	
Cooking time (minutes)	Relative β-carotene ± SD %	Cooking time (minutes)	Relative β-carotene ± SD %
0	100.0 ± 0.0[a]	0	100.0 ± 0.0[a]
2	129.4 ± 19.5[a]	5	108.1 ± 7.2[a,b]
4	141.8 ± 15.9[a]	9	121.2 ± 1.4[b,c]
7	138.2 ± 13.2[a]	15	129.8 ± 4.9[c]
16	138.7 ± 17.1[a]	20	80.7 ± 10.9[d]
20	139.5 ± 3.0[a]	25	87.4 ± 0.2[d]

*The values with different superscript letter along each column are significantly different at $p < 0.05$.

Summary

1. BACKGROUND

Food quality can be differentiated into *extrinsic* quality, e.g. referring to production system characteristics, and *intrinsic* quality, directly related to the physical product properties like sensory and health properties. The significance of each aspect of quality differs for every food and at all stages of the food chain. Quality aspects related to vegetables processed at the domestic level are discussed in this thesis, as vegetables are vital components of a balanced diet. Post-purchase processing steps like transportation, storage and domestic processing cumulatively determine the sensorial and health properties of the vegetable at the time of consumption. Therefore, consumer behaviour towards vegetables, i.e., domestic vegetable processing conditions, is central in this thesis.

On the one hand, vegetables processed at the domestic level meet consumers' and their family's sensory preferences towards cooked vegetables. On the other hand, domestic processing (though sometimes beneficial) affects the amount of nutrients and phytochemicals in vegetables. An interdisciplinary *Consumer-Orientated Food Technology* approach is used to optimise domestic processing conditions that will yield vegetables according to consumers' sensory preferences, e.g., a preferred texture, but higher in health property, e.g., amount of phytochemicals.

In this thesis, sensory and health properties of vegetables is studied using broccoli and carrots as an example, since these vegetables are among the commonly consumed vegetables in the Netherlands and differ morphologically and in the type of phytochemicals (glucosinolates in broccoli and β-carotene in carrots).

2. AIM

The objective of this thesis is to gain insights into consumer behaviour towards vegetables and to optimise domestic processing conditions applied by consumers for vegetables which are liked equally but are higher in health property. There is a lack of information on consumer behaviour towards vegetables and the influences of this behaviour on aspects of quality. Therefore this thesis aims to identify a research method that is most reliable, valid and practical, and to collect information on consumer motives and behaviour towards vegetables. This research method can be used to collect information on broccoli and carrot processing conditions applied by Dutch households. Next to this, influences of these processing conditions applied by consumers on the sensory and health properties of broccoli and carrot will be studied. Finally, domestic processing conditions will be optimised to yield vegetables that are liked equally but are higher in healthiness property.

3. RESULTS

The interdisciplinary *Consumer-Orientated Food Technology* (COFT) research approach developed in this thesis **(Chapter 2)** proposed to use mathematical modelling to integrate information (i) on consumer behaviour and underlying motives, (ii) on behaviour translated into influences on sensory and health properties, and (iii) on sensory evaluation of vegetables processed at different conditions. The COFT approach aims to redefine the 'current' vegetable product into a 'new' product that aligns with consumers' sensory preferences but possesses a higher amount of phytochemicals. The COFT approach was illustrated using broccoli as a case study in **Chapter 2**, where changes in the amount of glucosinolates and in texture (firmness) were modelled using 'assumed' conditions to show the effect of optimisation of domestic vegetables processing. This COFT approach will only be effective when the domestic processing conditions applied by consumers and their consequences on sensory and health properties are known. Therefore, an appropriate research method to collect such information is needed, given the lack of information on consumer behaviour towards domestic processing of vegetables.

In **Chapter 3**, three research methods were evaluated: in-home observations, observations using cameras in a model-kitchen and a self-reporting questionnaire. All three methods were found to be reliable (test-retest, inter-observer, intra-observer and parallel-form reliability) and valid (face, content and concurrent validity) in collecting information on domestic processing of broccoli by consumers (n = 25). Participants were shown to be consistent in the majority of the domestic processing conditions applied towards broccoli when measured on different days and using different research methods. However, a wide inter-individual variation in behaviour towards domestic broccoli processing was observed. A large sample size is thus necessary to capture the many possible variations in domestic processing of vegetables. Therefore, the self-reporting questionnaire was concluded to be the most practical method to collect information on the domestic processing of vegetables.

In **Chapter 4**, this self-reporting questionnaire was adapted (i) to an online self-reporting questionnaire, in order to reach a large and varied sample of Dutch households, and (ii) into two separate questionnaires, in order to collect information on domestic processing of broccoli and carrots. The majority of the participating Dutch households (70 %) boiled both vegetables using a cold-start and a high water level. Mainly texture was used as the way to decide doneness of the cooked vegetables. When cluster analysis was performed using information on several aspects of domestic processing of both vegetables, consumers were categorised into: *texture-orientated*, *health-orientated* and *taste-orientated* groups. The *texture-orientated* group was the predominant group representing 56 - 59 % of the study sample. About 20 - 30 % of the respondents represented the *health-orientated* group of the study sample and these consumers used both health and sensory properties in determining domestic processing of vegetables. The *taste-orientated* group counted for 8 - 26 % of the study sample depending on the type of vegetable. Demographic details like household composition, gender and educational background did not show a statistically significant influence on clustering consumers.

Various aspects of domestic processing conditions are taken into account in a comparison between boiling and steaming to obtain a variation in texture, colour and sensory properties (overall liking and attribute intensity rating) and in the amount of phytochemicals in cooked vegetables. Boiling vegetables at a high water level and using a hot or cold start were compared to steaming (i.e., indirect (no) use of water as opposed to a high water level for boiling) to assess the influence of these processing conditions on the above mentioned quality aspects. The results for broccoli are described in **Chapter 5** and for carrots in **Chapter 6**. Since mainly texture was reported to determine the doneness, texture of vegetables during processing was controlled by cooking to specific time points that yielded high, medium and low firm vegetables when cooked by either method.

In line with the design of the study, steaming, boiling-cold start and boiling-hot start yielded vegetables with comparable (instrumentally assessed) firmness values at all three texture (time) points, when cooked by either methods for the pre-determined times. At high firmness, the relative firmness (firmness of cooked samples compared to raw) of the vegetables was about 60 % for broccoli and carrots. At medium firmness, the relative firmness was 40 % for broccoli and 20 % for carrots. At low firmness, the relative firmness was around 8 % for both vegetables.

Colour change followed different trends between the two studied vegetables. In case of broccoli, the greenness first increased followed by a decrease. This trend was more apparent for steaming and boiling-hot start and less apparent for boiling-cold start. However, after a certain time, all cooking methods resulted in comparable colour losses in broccoli. In case of cooked carrots, orange-red colour only decreased with time and this trend was comparable for steaming and boiling-cold start.

In general, glucosinolates in broccoli, when compared to β-carotenes in carrots, were more sensitive to domestic processing, especially when broccoli was boiled with a cold start. Boiling-hot start and steaming resulted in a comparable amount of glucosinolates in broccoli at high and medium firmness and this amount was higher than for broccoli cooked with boiling -cold start at these firmness. At low firmness, steaming did not show any losses in glucosinolates, while boiling-hot start showed substantial losses, though these amounts were slightly higher than when boiled with a cold start. β-carotene in high and medium firm carrots showed an increase when either steamed or boiled with a cold start. At low firmness, in contrast to boiling-cold start, steaming did not show carotene degradation.

Sensory evaluation of steamed and boiled (with cold start) broccoli and carrots showed that for our study sample medium firm vegetables were most liked and that the low firm vegetables were least liked. This indicates that for optimal liking, the texture of vegetables should be in the range of medium firmness.

Steaming broccoli did not show any substantial losses in glucosinolates (GLS) at high, medium and low firmness. Therefore, the optimisation of domestic processing of broccoli focusses only on the boiling process. Boiling with a cold start and a high vegetable-water ratio (1 : 4) is the most commonly applied domestic processing condition identified in this thesis and also describes the prevalent *texture-orientated* group of consumers in the study sample.

Using the mathematical equations that describe various mechanisms of GLS and firmness degradation, simulations were made that predicted changes in the amount of total GLS and firmness in broccoli when boiled at a vegetable-water ratio (V : W) of 1 : 4, using a cold and a hot start.

The model predicts that the relative amount of GLS in boiled broccoli is: about 94 % by cold start and hot start at high firmness (~ 60 % relative firmness); about 81 % in cold start and 86 % by hot start at medium firmness (~ 40 % relative firmness); about 51 % in cold start and 49 % by hot start at low firmness (~ 8 % relative firmness). Optimisation in this thesis is focussed on cooking broccoli for low firmness, i.e., for the consumers who apply a boiling-cold start and cook for a longer time to obtain a soft texture of broccoli.

Decreasing cooking time is an obvious food technological solution to increase the amount of GLS. But this is decrease in cooking time does not yield a broccoli that is perceived as low in firmness by consumers. As a result, the cooking temperature and V : W were modified in a way to increase the GLS amount in broccoli cooked for soft texture. In the first place, the cold start was replaced with a hot start, which takes about 1.5 minutes to reach 100 ^{o}C. After this, within a span of 0.5 min, the temperature is gradually decreased to 90 ^{o}C and maintained at this temperature during further 'boiling'. At low firmness, the GLS retained up to 60 % of the initial value compared to ~ 50 % at the conditions which consumers apply normally. When the V : W was lowered to 1 : 1, the amount of GLS retained was up to 68 %, while still giving a low firm broccoli.

4. CONCLUSIONS

The research conducted in this thesis has successfully integrated consumer science and food technology disciplines, which brought a change in approaching a given problem. With given consideration, the domestic processing was optimised using mathematical modelling.

This thesis demonstrated that in-home observations or observations using cameras in a model-kitchen or self-reporting questionnaires are reliable and valid research

methods for collecting data on vegetable processing at the domestic level. In the view of costs, time and the required sample size, the validated self-reporting questionnaire was chosen as the most practical method. In general, comparable processing conditions for broccoli and carrots were reported by consumers. Consumers control processing conditions of vegetables mainly by assessing the changes in sensory (texture) attributes (56 - 59 %), while a considerable number of consumers (20 - 30 %) control the domestic processing conditions for higher health benefits too. Demographic details did not show a significant influence in determining these domestic processing conditions. For optimal liking, the texture of the cooked vegetable should be in the range of medium firmness. At this firmness, the phytochemicals are also substantially higher than at lower firmness. However, for consumers who prefer low firm vegetables, processing conditions were optimised using mathematical modelling to yield a vegetable (broccoli) which is at least 18 % higher in amount of glucosinolates and is still soft in texture. With such information, kitchen appliances can be developed or adapted that will assist consumers in cooking 'healthy' and still meet their sensory preference.

Samenvatting
(Summary in Dutch)

1. ACHTERGROND/AANLEIDING

Wanneer gesproken wordt over voedselkwaliteit wordt vaak een onderscheid gemaakt tussen extrinsieke kwaliteit, gerelateerd aan bv de productiewijze, en intrinsieke kwaliteit, dat direct gerelateerd is aan fysieke productkenmerken zoals smaak, textuur en gezondheid. De mate van belangrijkheid van elk van de kwaliteitsattributen verschilt voor verschillende producten en voor de verschillende schakels in de productieketen. Kwaliteit van groenten die binnen de huishouding worden bereid is het onderwerp van dit proefschrift. Groenten zijn immers een belangrijke component in een gebalanceerd dieet. Na aankoop van het product ondergaat het verschillende handelingen, zoals transport, opslag en bereiding, die allemaal van invloed kunnen zijn op de uiteindelijke sensorische kwaliteit en gezondheidswaarde op het moment van consumptie. Om die reden staat het consumentengedrag met groenten, en meer specifiek de bereidingswijze van groenten in huishoudens centraal in dit proefschrift.

Wanneer groenten worden bereid moeten ze enerzijds voldoen aan de sensorische wensen en voorkeuren van de bereider en de gezinsleden. Anderzijds beïnvloeden de huishoudelijke bereidingsprocessen – soms positief en soms negatief – de hoeveelheid voedingsstoffen en gezondheidbevorderende stoffen. Een interdisciplinaire benadering, de zgn. 'Consument georiënteerde levensmiddelentechnologie' ofwel COFT (Consumer Orientated Food Technology) is toegepast om de huishoudelijke bereidingsprocessen te optimaliseren, zodat de bereide groenten voldoen aan de sensorische eisen van de consument, bv de gewenste textuur of gaarheid, en tegelijkertijd een hogere gezondheidswaarde hebben, bv een hoger gehalte aan gezondheidbevorderende stoffen.

In dit proefschrift zijn als voorbeeld de sensorische en gezondheidsattributen van broccoli en wortelen bestudeerd, omdat deze groenten regelmatig worden gegeten in Nederland. Verder zijn ze morfologisch verschillend van elkaar en bevatten ze verschillende typen gezondheidbevorderende stoffen (glucosinolaten in broccoli en β-caroteen in wortelen).

2. DOEL VAN HET ONDERZOEK

Het doel van dit onderzoek is inzicht te krijgen in het consumentengedrag bij de bereiding van groenten, om te komen tot een optimalisatie van het bereidingsproces op een zodanige manier dat de bereide groenten gelijk (of beter) gewaardeerd worden door de consument, en tegelijkertijd een hoger gehalte aan gezonde stoffen bevatten. Er is weinig informatie beschikbaar over het consumentengedrag gerelateerd aan de bereiding van groenten en de invloed ervan op de eindkwaliteit van de bereide groenten. In dit proefschrift is derhalve een betrouwbare, valide en praktisch uitvoerbare onderzoeksmethode geïdentificeerd om informatie te verzamelen over het gedrag van consumenten rondom bereiding van groenten en de onderliggende motieven voor dit gedrag. Deze onderzoeksmethode is daarna gebruikt om vast te stellen hoe groenten worden bereid in Nederlandse huishoudens. Daarnaast is de invloed van deze bereidingswijzen op de sensorische attributen en de gezondheidswaarde van broccoli en wortelen bestudeerd. Tot slot zijn de bereidingsprocessen geoptimaliseerd om te bereiken dat bereide groenten gelijk (of beter) worden gewaardeerd als in het gebruikelijke bereidingsproces, en tegelijkertijd een hoger gehalte aan gezondheidbevorderende stoffen bevatten.

3. RESULTATEN

De interdisciplinaire benadering 'Consumer Orientated Food Technology' (COFT), zoals beschreven in Hoofdstuk 2, gebruikt mathematisch modelleren om verschillende bronnen van informatie te integreren: (i) informatie over consumentengedrag en onderliggende motieven voor dat gedrag, (ii) informatie over de invloed van gedrag op sensorische en gezondheidsattibuten en (iii) sensorische evaluatie van groenten die onder verschillende condities zijn bereid. De COFT benadering is bedoeld om de 'huidige' groente om te zetten naar een 'nieuwe' groente die overeenkomt met de sensorische voorkeuren van de consument en tegelijkertijd een hoger gehalte aan gezondheidbevorderende stoffen bevat. Deze COFT benadering is ter illustratie toegepast op broccoli in hoofdstuk 2, waarbij veranderingen in de hoeveelheid glucosinolaten en in textuur (stevigheid) zijn gemodelleerd op basis van 'veronderstelde' bereidingscondities, om op die manier het effect van optimalisatie van groentebereiding te demonstreren. Deze COFT benadering is echter alleen effectief als de huishoudelijke bereidingscondities en de effecten op sensorische en gezondheidsattributen bekend zijn. Dit betekent dat een betrouwbare onderzoeksmethode beschikbaar moet zijn om dergelijke informatie te verzamelen, gegeven het gebrek aan informatie over consumentengedrag rondom de bereiding van groenten in de huishoudelijke context.

In hoofdstuk 3 zijn drie onderzoeksmethoden geëvalueerd: observaties bij consumenten thuis, observaties met camera's in een laboratoriumkeuken en een schriftelijke vragenlijst. De drie methoden bleken betrouwbaar (test-hertest, inter- en intra-observer en 'parallel forms' betrouwbaarheid) en valide (indruks-, inhouds- en criteriumvaliditeit) en geschikt om informatie te verzamelen over huishoudelijke bereiding van broccoli door consumenten (n = 25). De deelnemers waren consistent in de meeste aspecten van bereiding van broccoli, wanneer gemeten op verschillende dagen en met verschillende onderzoeksmethoden. Echter een grote interindividuele variatie in gedrag werd waargenomen. Een grote steekproef is derhalve noodzakelijk om de vele mogelijke variaties in huishoudelijke bereiding van groenten inzichtelijk te maken. Daarom is geconcludeerd dat een gevalideerde schriftelijke vragenlijst de meest praktische methode is om dergelijke informatie te verzamelen.

In hoofdstuk 4 is deze schriftelijke vragenlijst aangepast om te gebruiken (i) in een online vragenlijst, zodat een grote en gevarieerde steekproef van Nederlandse huishoudens bereikt kon worden en (ii) voor het verzamelen van informatie over de bereiding van broccoli en wortelen. De meerderheid van de deelnemende Nederlandse huishoudens (70 %) kookt de twee groenten en past daarbij een koude start en hoog waterniveau toe. Vooral de textuur van de groente wordt beoordeeld om de gaarheid vast te stellen. Op basis van clusteranalyse, toegepast op de verschillende aspecten van bereiding van beide groenten, kunnen consumenten worden ingedeeld in: een textuur-georiënteerde groep, een gezondheid-georiënteerde en een smaak-georiënteerde groep. De textuur-georiënteerde groep is het grootst en omvat 56 - 59 % van de steekproef. Ongeveer 20 - 30 % van de respondenten kunnen worden ingedeeld in de gezondheid-georiënteerde groep. Deze consumenten gebruiken zowel hun ideeën over een gezonde bereidingswijze als sensorische kenmerken van de bereide groente om het bereidingsproces te sturen en te controleren. De smaak-georiënteerde groep omvat 8 - 26 % (voor broccoli resp. wortelen) van de steekproef. Demografische kenmerken zoals huishoudsamenstelling, geslacht en opleidingsniveau hebben geen statistisch significante invloed op de samenstelling van de clusters.

Verschillende aspecten van het huishoudelijk bereidingsproces zijn meegenomen in een vergelijking tussen koken en stomen, waarbij het effect van bereidingswijze op de kwaliteitsattributen textuur, kleur en sensorische kenmerken (mate van lekker zijn en de intensiteit van een aantal kwaliteitsattributen) en in de hoeveelheid gezondheidbevorderende stoffen in bereide groenten zijn vastgesteld. De invloed op deze kwaliteitsaspecten van het koken van groenten met een hoog water niveau, en startend met koud water (‘cold start’) of startend met kokend water (‘hot start’) werd vergeleken met het stomen van groenten (i.e. indirect (of zelfs geen) gebruik van water tegenover koken in een grote hoeveelheid water). De resultaten voor broccoli zijn beschreven in hoofdstuk 5 en die voor wortelen in hoofdstuk 6. Omdat de gaarheid van de groente meestal werd beoordeeld aan de hand van de textuur, werd in dit deel van het onderzoek de textuur tijdens de bereiding gecontroleerd door tot specifieke tijdpunten te koken respectievelijk stomen, om op die manier harde, medium en zachte groenten te verkrijgen.

Overeenkomstig de opzet van het onderzoek resulteerden stomen, koken-‘cold start’ en koken-‘hot start’ tot (drie) specifieke tijdpunten in groenten met een vergelijkbare (instrumenteel gemeten) stevigheid. Voor de ‘harde’ groenten was de relatieve stevigheid (stevigheid van bereide groente vergeleken met die van rauwe groente) ongeveer 60 % voor zowel broccoli als wortels. Voor de ‘medium’ groenten was de relatieve stevigheid 40 % voor broccoli en 20 % voor wortelen. Voor de ‘zachte’ groenten, was de relatieve stevigheid voor beide groenten ongeveer 8 %.

De verandering van de kleur was verschillend voor de twee bestudeerde groenten. De intensiteit van de groene kleur van broccoli werd nam in eerste instantie toe en daarna af. Deze trend was duidelijker waarneembaar bij stomen dan bij koken – ‘hot start’ en minder duidelijk bij koken-‘cold start’. Na een bepaalde tijd, echter, resulteerden alle bereidingsmethoden tot een vergelijkbaar verlies in de intensiteit van de kleur. De oranjerode kleur van de wortelen verminderde met de tijd en deze trend was vergelijkbaar voor stomen en koken-'cold start'.

In het algemeen kan gezegd worden dat de glucosinolaten in broccoli gevoeliger zijn voor de huishoudelijke bereidingsprocessen dan de β-carotenen in wortelen. Dit geldt in het bijzonder voor koken-'cold start'. Koken-'hot start' en stomen resulteerden in een vergelijkbare hoeveelheid glucosinolaten in broccoli van een harde of medium stevigheid en deze hoeveelheid was hoger dan die voor broccoli gekookt met een koude start tot een vergelijkbare stevigheid. Voor de zachte broccoli was er geen verlies van glucosinolaten als deze was gestoomd, terwijl het koken-'hot start' leidde tot aanzienlijke verliezen in hoeveel glucosinolaten. Het gehalte aan β-caroteen in harde en medium wortelen nam toe bij zowel stomen als koken-'cold start'. Bij de zachte wortelen leidde stomen, in tegenstelling tot koken-'cold start', niet tot verlies van β-caroteen.

Sensorische evaluatie van gestoomde en (met koude start) gekookte broccoli en wortelen liet zien dat dat de respondenten een medium stevigheid van de groenten het meest waardeerden. De zachte groente werd het minst gewaardeerd. Dit impliceert dat voor een optimale waardering van groenten deze een medium textuur moeten hebben.

Stomen van broccoli leidde niet tot een substantieel verlies aan glucosinolaten, ongeacht of de textuur hard, medium of zacht was. Daarom werd voor de optimalisatie van het bereidingsproces alleen gekeken naar het koken. Koken-'cold start' in een grote hoeveelheid water in verhouding tot de hoeveelheid groente (ratio 4 : 1) wordt het meest toegepast door de groep respondenten en komt vooral voor in de textuur-georiënteerde groep van consumenten in deze studie, die tegelijkertijd de grootste groep consumenten omvat.

Mathematische vergelijkingen die de verschillende mechanismen van degradatie van glucosinolaten en afname van stevigheid beschrijven zijn gebruikt om te voorspellen hoe de hoeveelheid glucosinolaten en stevigheid van gekookte broccoli veranderen wanneer de broccoli wordt gekookt met een 'cold start' of een 'hot start' en een groente - water ratio van 1 : 4.

Het model voorspelt een relatieve hoeveelheid glucosinolaten in gekookte broccoli van 94 % bij een koude start en hete start voor een hoge stevigheid (~ 60 % relatieve stevigheid); ongeveer 81 % bij een koude start en 86 % ij een hete start voor een medium stevigheid (~ 40 % relatieve stevigheid); en ongeveer 51 % bij een koude start en 49 % bij een warme start voor zachte broccoli (~ 8 % relatieve stevigheid). In dit proefschrift is de optimalisatie van het kookproces van broccoli met een zachte textuur bestudeerd, i.e. voor de consumenten die de broccoli koken-'cold start' en gedurende een langere tijd om een zachte textuur te bereiken.

Een kortere kooktijd is een voor de hand liggende technologische oplossing om de hoeveelheid glucosinolaten te laten toenemen. Maar een verkorting van de kooktijd resulteert niet in broccoli met de gewenste zachte textuur. Daarom worden in de simulatie de bereidingstemperatuur en de verhouding groente : water op een zodanige manier aangepast dat het resulteert in een hoger gehalte aan glucosinolaten bij een gewenste zachte textuur. Om dat te bereiken wordt de 'cold start' vervangen door een 'hot start', waarbij het ongeveer 1.5 minuut duurt voordat 100 ^{o}C is bereikt. Daarna wordt gedurende een halve minuut de temperatuur geleidelijk verlaagd tot 90 ^{o}C en op deze temperatuur gehouden tijdens het verdere 'koken'. Bij het bereiken van de zachte textuur is het gehalte glucosinolaten afgenomen tot 60 % van de initiële waarde in vergelijking tot de afname tot ongeveer 50 % van de initiële waarde in de conditie die de consument gewoonlijk toepast. Wordt de groente : water verhouding aangepast tot 1 : 1 dan neemt het totale gehalte aan glucosinolaten af tot 68 %, terwijl de broccoli dan nog steeds zacht is.

4. CONCLUSIES

In dit proefschrift zijn consumentenwetenschappen en levensmiddelentechnologie succesvol geïntegreerd, resulterend in verandering van de benadering van een probleem. Voor de genoemde situatie is met behulp van mathematisch modelleren het huishoudelijk voedselbereidingsproces geoptimaliseerd.

Dit proefschrift laat zien dat observaties bij consumenten thuis, observaties met camera's in een laboratoriumkeuken en schriftelijke vragenlijsten betrouwbare en valide onderzoeksmethoden zijn om data te verzamelen over het groentebereidingsproces door consumenten. Vanuit het oogpunt van kosten, tijd en de benodigde steekproefomvang kan een gevalideerde schriftelijke vragenlijst worden gezien als de meest praktische methode. In het algemeen worden door de consumenten vergelijkbare bereidingsstappen bij het bereiden van een groente gerapporteerd. Consumenten controleren het bereidingsproces van groente voornamelijk door het vaststellen van de verandering in sensorische (textuur) attributen (56 - 59 %), terwijl een aanzienlijk aantal consumenten (20 - 30 %) de gezondheidswaarde van de groente als motief geeft voor het toegepaste bereidingsproces. Demografische kenmerken blijken geen significante invloed te hebben op de wijze waarop de groente wordt bereid. Voor een optimaal gewaardeerde gekookte groente, moet de textuur 'medium' zijn. Bij deze textuur is de hoeveelheid gezondheidbevorderende stoffen substantieel hoger dan in groente met een zachtere textuur. Echter voor consumenten die groente met een zachtere textuur prefereren zijn de bereidingscondities geoptimaliseerd met behulp van mathematisch modelleren om te bereiken dat de groente (i.e., broccoli) 18 % meer gezondheidbevorderende stoffen bevat bij een gelijke (zachte) textuur. Met dergelijke informatie kan keukenapparatuur ontwikkeld of aangepast worden, die consumenten ondersteunt bij het bereiden van 'gezonde' groente, die ook voldoet aan hun sensorische voorkeuren.

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About the author

Radhika Bongoni was born on 20 August 1986 in Hyderabad, Andhra Pradesh, India. She graduated in BSc Food Science and Nutrition, 2003 – 2007, from Acharya N.G. Ranga Agricultural University, Andhra Pradesh, India and was awarded the 'Best Outgoing Student of the Year 2007' and the 'Dr. Kamaraju Mangasree Memorial Gold Medal'. With financial assistance from NUFFIC Huygens Scholarship Programme, 2007 - 2009, she graduated in MSc Food Technology, specialisation Dairy Technology, from Wageningen University, the Netherlands. Between January 2010 and 2014, Radhika took up PhD studies at Food Quality and Design group (formerly called Product Design and Quality Management) of Wageningen University to investigate the influences of domestic processing on quality of vegetables. Currently, Radhika is a lecturer at the same group. She is granted the 'Academic Excellence Award' to follow International Full-time MBA Programme, September 2014-2015, from TiasNimbas Business School, Tilburg, the Netherlands.

A polyglot and an ardent follower of international politics, Radhika enjoys cooking and travelling as her favourite pastime activities.

List of publications

Publications in peer-reviewed journals

Bongoni, R., Steenbekkers, L. P. A., Verkerk, R., van Boekel, M. A. J. S., Dekker, M. (2013). Studying consumer behaviour related to the quality of food: a case on vegetable preparation affecting sensory and health attributes. *Trends in Food Science & Technology,* 33:139-145.

Bongoni, R., Verkerk, R., Dekker, M., Steenbekkers, L. P. A. (2014). Evaluation of research methods to study domestic food preparation *(accepted)*. *British Food Journal*.

Bongoni, R., Verkerk, R., Dekker, M., Steenbekkers, L. P. A. (2014). Consumer behaviour towards vegetables: a study on domestic processing of broccoli and carrot by Dutch households *(accepted). Journal of Human Nutrition and Dietetics.*

Bongoni, R., Verkerk, R., Steenbekkers, L. P. A., Dekker, M., Stieger, M. (2014). Evaluation of different cooking conditions on broccoli (*Brassica oleracea* var. *italica*) to improve the nutritional value and consumer acceptance (*accepted*). *Plant Foods for Human Nutrition.*

Publications under review

Bongoni, R., Stieger, M., Dekker, M., Steenbekkers, L.P.A., Verkerk, R. Sensory and health properties of steamed and boiled carrots.

Conferences and book of abstracts

Bongoni, R., Steenbekkers, L.P.A., Verkerk, R., Dekker, M. (2010). “Consumer behaviour and healthy vegetables”. *28th International Horticultural Congress*, Lisboa, Portugal **(poster presentation)**

Bongoni, R., Steenbekkers, L.P.A., Verkerk, R., Dekker, M. (2011). “Integrating consumer science with food technology for quality of vegetables after domestic processing”. *Food Denmark PhD Congress*, Copenhagen, Denmark **(oral presentation)**

Bongoni, R., Steenbekkers, L.P.A., Verkerk, R., Dekker, M. (2012). “A study to compare research method for information on vegetables processing practices by Dutch households”. *5th European conference on sensory and consumer research*, Bern, Switzerland **(oral presentation)**

Bongoni, R., Steenbekkers, L.P.A., Verkerk, R., Dekker, M. (2012). “Clustering vegetable processing practices by consumers to estimate the phytochemical content in prepared vegetables”. *5th European conference on sensory and consumer research*, Bern, Switzerland, **(poster presentation)**

Bongoni, R., Steenbekkers, L.P.A., Verkerk, R., Dekker, M. (2013). “Does salt and amount of water for boiling influence the glucosinolate content and colour of broccoli?”. *Euro Food Chem XVII conference*, Istanbul, Turkey **(poster presentation)**

Overview of completed training activities

Courses	Year
Discipline specific courses	
Statistics for life sciences, WIAS graduate school, Wageningen University	2010
Basic statistics, WIAS graduate school, Wageningen University	2011
Applied statistics for food technologists, Product Design and Quality Management group, Wageningen University	2012
International conferences and meetings	
28th International Horticultural Congress, Portugal (poster presentation)	2010
FOOD Denmark PhD Congress, Denmark (oral presentation)	2011
5th European Conference on Sensory and Consumer Research, Switzerland (oral and poster presentations)	2012
EuroFoodChem XVII conference, Turkey (poster presentation)	2013
General courses	
VLAG PhD week	2010
PhD competence assessment, Wageningen Graduate Schools	2010
Project planning and time management, Wageningen Graduate Schools	2010
Techniques of writing and presenting scientific papers, Wageningen Graduate Schools	2011
Advanced course guide to scientific artwork, Wageningen University	2012
Scientific writing, Wageningen University	2012
Mobilising your scientific network, Wageningen Graduate Schools	2012
Philosophy and ethics of food science and technology, Wageningen Graduate Schools	2013
Career orientation, Wageningen Graduate Schools	2013
Optional courses and activities	
Preparing PhD research proposal	2010
PDQ PhD lunch presentations	2010 - 2014
Predictive modelling, MSc. Course, Wageningen University	2010
Organisation and participation in PhD educational trip to the UK	2012

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