Effects of storage time, temperature and modified atmosphere on sensory quality and health related compounds in fresh-cut swede and turnip

Effekter av lagringstid, -temperatur og modifisert atmosfære på sensorisk kvalitet og helserelaterte innholdsstoffer i ferdigkuttet kålrot og nepe

Philosophiae Doctor (PhD) Thesis

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Ås (2015)

Thesis number 2015:9
ISSN 1894-6402
ISBN 978-82-575-1266-8

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Acknowledgements

This thesis is a part of the requirements for the PhD degree at Department of Plant Sciences, Norwegian University of Life Sciences (NMBU). The work was carried out at Nofima AS, Ås, as a part of the project "Improved quality of Norwegian fruits, potatoes and vegetables after long- and short-term storage" (Project Nr. 199409, Research Council of Norway). The research was funded by Foundation for Research Levy on Agricultural Products and the Agricultural Agreement Research Fund, together with the Norwegian food industry partners Gartnerhallen AL, Bama Gruppen AS, Findus Norge AS, FellesJuice AS, HOFF SA, Graminor AS, NordGrønt, Norgesgrønt, Maarud AS and KiMs Norge AS.

Supervisors have been Associate Professor Anne-Berit Wold at NMBU, and Dr. Anders Leuvén and Dr. Gunnar B. Bengtsson at Nofima. I am grateful to my supervisors for their scientific guidance and encouragement, from planning of experiments, through the writing process and to the final stages of this PhD journey. I would also like to thank the project leader, Dr. Arne Hermansen, and project secretary, Dr. Eldrid Lein Molteberg, and the rest of the project group at Bioforsk and NMBU for their support during these years.

The perfect working conditions at Nofima are highly appreciated and I want to thank research director Helga Næs and The Packaging Group for the good atmosphere. A special thanks to Hanne Larsen for interesting and supporting discussions regarding MAP and vegetables. I am very grateful to the sensory department: Josefine Skaret, Mats Carlehøg, Kristine S. Myhrer and the sensory panel, and Marit Rødbotn for her enthusiasm when I asked if I could use the sensory panel for my experiments. Thanks to Per Lea for statistical guidance, and the people in the Food and Health Group, especially Berit Karoline Martinsen for helping me with equipment. I want to thank Mona Ringstad, Silje Johansen, Hanne Zobel and Elin-Merete Nicolaisen for excellent technical assistance in the lab, Aud Espedal for skilful packaging assistance, and also Trygve Helgerud for helping me with sugar analyses (and coffee breaks).

Thank you to all former and present PhD students at Nofima and NMBU, who I had the pleasure of getting to know. A special thanks to my two office mates: Jib, for introducing the scientific and social parts of the PhD, and Dimitrios, for good advice and encouragement. I would like to thank Vegard Segtnan and Thomas Eie for encouraging me to start this PhD.

Grazie a Paola e Natalino per l'uso del vostro ufficio. To my parents and my sister: thank you for your support and care.

I dedicate this thesis to my wife Clara, which I love and admire so much. You are right, "nothing is impossible until it is done".

Ås, January 2015
Haakon S. Helland

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Abstract

Introducing new fresh-cut vegetable products onto the market may increase vegetable consumption. Usually the availability of Norwegian grown vegetables for fresh-cut production is limited by a short growing season. However, root vegetables such as swede and turnip are available for a longer period of the year. Both vegetables are sources of vitamin C and glucosinolates, which are important due to their potential health benefits and may influence taste and flavour attributes. Fresh-cut vegetables undergo physiological changes after peeling and cutting, which could influence sensory quality and the content of beneficial compounds. These changes can be influenced by storage parameters, including temperature and modified atmosphere packaging. Therefore, the main purpose of this thesis is to study the effect of storage time, temperature and modified atmosphere on the sensory quality and vitamin C, glucosinolate and sugar content of fresh-cut swede and turnip.

Packaging atmosphere was modified by using different combinations of product weight, packaging films and perforations. Packages were stored for 5 and 10 days at 5 ºC and 10 ºC. Both passive and active modified atmospheres were used. In addition, storage temperatures of -2 ºC, 0 ºC, 5 ºC and 10 ºC for 10 days were tested, including one sample stored at -2 ºC for 5 days followed by 5 days at 10 ºC. Packaging films made of biaxially oriented polypropylene (BOPP) and polylactic acid (PLA) were also tested. Quantitative descriptive sensory analysis using a trained sensory panel was used to evaluate appearance, odour, taste and flavour, and texture attributes in fresh-cut swede and turnip. Chemical analyses were used to determine the content of individual glucosinolates, sugars, and vitamin C.

The results show that storage time and temperature influenced intensities of odour, taste and flavour attributes more than storage in different modified atmospheres. Prolonged storage time and higher temperature gave lower intensities of attributes such as sour odour, sour flavour, green odour and green flavour. Intensity of cloying odour and cloying flavour increased with longer storage time and higher temperature for both vegetables, although results for swede were not significant for all experiments. Sulphurous odour and pungent odour in turnip decreased with longer storage time and higher temperature, while in swede they increased with higher temperature. Swede and turnip were susceptible to discolouration after cutting, and in both cases an uneven colour increased with length of storage and higher temperature. In contrast to swede, a change in hue for turnip was seen in all experiments, and seemed to be temperature dependent. This indicates that the mechanisms resulting in a change of appearance were different for the two vegetables. Modified atmosphere had an effect on the appearance for both vegetables, although no differences between passive and active modified atmospheres were found.

Vitamin C content was neither affected by time, temperature nor modified atmosphere.
Increased storage time resulted in a higher content of total glucosinolates in swede, but there was no relationship between temperature and glucosinolate content in swede. For turnip, no significant effects of storage time or temperature on total glucosinolate content were observed. Total aliphatic glucosinolate content in fresh-cut swede increased with storage time, while total aliphatic glucosinolate content in turnip decreased in response to longer storage time and higher storage temperature. Longer storage time and higher temperature also led to a higher total indolic glucosinolate content in both swede and turnip. Furthermore, the content of glucobrassicin and 4-methoxyglucobrassicin increased in both swede and turnip as an effect of prolonged storage and higher temperature. Prolonged storage time and higher temperature resulted in a lower content of total sugar in swede and turnip. When temperature was the only experimental parameter, total sugar content of swede was not significantly affected. Longer storage time reduced sucrose content in both swede and turnip, while lower temperature resulted in higher sucrose content in turnip. For both swede and turnip, storage at -2 ^{0}C resulted in a higher sucrose content compared with storage at 0 ^{0}C.

Packaging materials and methods studied had less influence on sensory attributes and chemical compounds, than storage time and temperature. Nevertheless, modified atmosphere had an effect on appearance of both vegetables, although no differences between passive and active modified atmospheres were found. However, packaging material containing PLA gave higher weight loss in both vegetables, but had no effect on texture attributes.

In conclusion, this thesis may be regard as a contribution in understanding how quality of fresh-cut vegetables change before reaching the consumer.

Sammendrag

Nye produkter med ferdigkuttede grønnsaker kan være med å gi et økt forbruk av grønnsaker. Bruk av norskdyrkede grønnsaker til produksjon av ferske ferdigkuttede grønnsakprodukter er begrenset på grunn av den korte vekstsesongen. Lagringsdyktige rotgrønnsaker, som kålrot og nepe vil derimot være tilgjengelig for en lengre periode av året. Rotgrønnsaker som kålrot og nepe, er gode kilder til helserelaterte innholdsstoffer som vitamin C og glukosinolater, som også kan påvirke smaken. Skrelling og kutting kan forårsake fysiologiske endringer i grønnsakene som igjen kan gi opphav til endringer i sensorisk kvalitet og viktige innholdsstoffer. Lagringsparametrer, som temperatur og modifisert atmosfære, kan påvirke i hvilken grad disse endringene finner sted. Målet med dette arbeidet er å studere effekt av lagringstid, -temperatur og modifisert atmosfære på sensorisk kvalitet og innhold av vitamin C, glukosinolater og sukker i ferdigkuttet kålrot og nepe.

Modifisert atmosfære i pakkene ble dannet ved å bruke ulike kombinasjoner av produktvekt, filmtype og antall perforeringer i filmen. Pakkene ble lagret i 5 og 10 dager ved 5 ^{o}C og 10 ^{o}C, og både passiv og aktiv modifisert atmosfære ble brukt. I tillegg ble lagring ved -2 ^{0}C, 0 ^{0}C, 5 ^{0}C og10 ^{0}C i 10 dager testet, samt en prøve som ble lagret ved -2 ^{o}C i 5 dager etterfulgt av 5 dager ved 10 ^{0}C. To embalasjematerialer bestående av biaxialt orientert polypropylene (BOPP) eller polymelkesyre (PLA) ble også testet. Beskrivende sensoriske analyser ble utført av et trent sensorisk panel som bedømte intensiteten av sensoriske egenskaper knyttet til utseende, lukt, smak og tekstur hos ferdigkuttet kålrot og nepe. Kjemiske analyser ble utført for å bestemme innholdet av individuelle glukosinolater, sukker, og vitamin C.

Resultatene viser at lagringstid og -temperatur påvirket intensiteten av lukt- og smaksegenskaper mer enn de ulike modifiserte atmosfærene som ble testet. Lengre lagringstid og høyere temperatur resulterte i lavere intensitet av egenskaper som syrlig lukt, syrlig smak, grønn lukt og grønn smak. Intensiteten av emmen lukt og emmen smak økte med lagringstiden og høyere temperatur, for begge grønnsakene. Intensiteten av svovellukt og stikkende lukt i nepe ble redusert ved lengre lagringstid og høyere temperatur, mens i kålrot økte disse egenskapene ved høyere temperatur. Kålrot og nepe endret utseende etter kutting, og for begge grønnsakene ble det observert en mer ujevn farge ved lengre lagringstid og høyere temperatur. Fargetone for nepe ble endret i alle eksperimentene, til forskjell fra kålrot, og denne endringen ble påvirket av temperaturen. Dette indikerer at mekanismene som gir opphav til endring i utseende kan være forskjellige for kålrot og nepe. Modifisert atmosfære påvirket utseende hos begge grønnsakene, men det ble ikke observert noen forskjeller mellom passiv og aktiv modifisert atmosfære.

Innholdet av vitamin C var stabilt og ble verken påvirket av lagringstid, -temperatur eller modifisert atmosfære. Lengre lagringstid ga et høyere totalinnhold av glukosinlater i kålrot, men det ikke ble observert noen sammenheng mellom lagringstemperatur og innholdet av glukosinolater. Det ble heller ikke funnet signifikante effekter av lagringstid eller -temperatur på totalinnholdet av glukosinolater i nepe. Totalinnholdet av alifatiske glukosinolater i ferdigkuttet kålrot økte med lagringstiden, mens totalinnholdet av alifatiske glukosinolater i nepe ble redusert. Lengre lagringstid og høyere temperatur ga også høyere totalinnhold av indol glukosinolater i både kålrot og nepe. Innholdet av glucobrassicin og 4-methoxyglucobrassicin økte med økt lagringstid og høyere temperatur for både kålrot og nepe.

Lengre lagringstid og høyere temperatur ga lavere totalinnhold av sukker i kålrot og nepe. Når effekt av temperatur, og ikke tid, ble studert, var totalinnhold av sukker i kålrot ikke påvirket av temperatur. Innholdet av sukrose ble redusert ved lengre lagringstid får både kålrot og nepe, mens lave temperaturer resulterte i et høyere innhold av sukrose i nepe. For både kålrot og nepe ga lagring ved -2 °C høyere innhold av sukrose, sammenlignet med lagring ved 0 °C.

Emballasjematerial og modifisert atmosfære påvirket den sensoriske kvaliteten og innholdsstoffer mindre sammenlignet med lagringstid og -temperatur. Likevel hadde modifisert atmosfære en effekt på uteseende hos begge grønnsakene, men det var ingen forskjell mellom aktiv og passiv modifisert atmosfære. Emballasjematerial bestående av PLA ga et høyere vekttap hos begge grønnsakene, men påvirket ikke grønnsakenes konsistens.

Denne studien bidrar til å forstå hvordan kvaliteten til ferdigkuttede grønnsaker endres under distribusjon og lagring de når forbrukerne.

List of papers

This thesis is based on the following papers referred to in the text by their Roman numerals:

I. **Effect of storage time, temperature and passive modified atmosphere on sensory quality of fresh-cut swede and turnip**
Haakon S. Helland, Anders Leufvén, Gunnar B. Bengtsson, Josefine Skaret, Anne-Berit Wold
Submitted to LWT-Food Science and Technology

II. **Storage of fresh-cut swede and turnip in modified atmosphere: effects on vitamin C, sugars, glucosinolates and sensory attributes**
Haakon S. Helland, Anders Leufvén, Gunnar B. Bengtsson, Josefine Skaret, Per Lea, Anne-Berit Wold
Submitted to Postharvest Biology and Technology

III. **Storage of fresh-cut swede and turnip at different temperatures, including sub-zero temperature: effect on sensory attributes, sugars and glucosinolates**
Haakon S. Helland, Anders Leufvén, Gunnar B. Bengtsson, Marit Kvalvåg Pettersen, Per Lea, Anne-Berit Wold
Submitted to Postharvest Biology and Technology

1. Introduction

1.1 General introduction

Increased consumption of vegetables is highly recommended by organisations and governments worldwide. One measure to make vegetables more readily available and hence increase their consumption is to use them in convenience products (WHO 2005). In fact, the demand for convenience food solutions has led to the development of fresh-cut products, defined by The International Fresh-cut Produce Association (IFPA) as "any fruit or vegetable or combination thereof that has been physically altered from its original form, but remains in a fresh state" (Garret 2002). According to the International Society for Horticultural Science (ISHS), fresh-cut products should be 100% usable products, offering high nutrition, convenience and flavour while maintaining freshness and minimizing waste (ISHS 2012).

Although the availability of ready-to-eat vegetable products is lower in the Norwegian market than other European markets such as United Kingdom and Holland, these types of products have gained interest in Norway (OFG 2014). Consumption of vegetables trimmed, washed or packed, or "value added vegetables" increased by 14%, while "vegetables without any extra added value" increased by 2.1% from 2012 to 2013 in Norway (OFG 2014). The use of Norwegian grown vegetables in fresh-cut products is limited by the short growing season and short storage life. However, root vegetables show good storability and are thus available as a raw material for fresh-cut vegetables for a longer period of time after harvest. Their potential to be used in fresh-cut vegetable products should therefore be studied.

From a plant physiology point of view, exposing vegetables to injuries like peeling and cutting is incompatible with lengthy storage in a distribution chain. Such damage causes physiological responses, leading to faster deterioration and senescence (Toivonen & DeEll 2002), and may also influence sensory attributes and nutritional value (Barrett et al. 2010). However, knowledge of how post-processing handling, in terms of temperature, storage time, packaging and modified atmosphere, affects sensory attributes and nutritional value of products can lead to the development of more favourable storage conditions, and possibly extended shelf-life (Cliffe-Byrnes & O'Beirne 2007). In order for more vegetables to be used as fresh-cut products, an understanding of the sensory changes that occur and the factors that affect these, is needed (Bett 2002). This knowledge is related to the potential shelf life of the product and could be used by the fresh-cut industry to develope new products, improve product quality and solve problems throughout the value chain. This thesis focuses on the root vegetables swede and turnip, which are two typical Norwegian grown vegetables.

1.2 Aim of the thesis

The aim of this thesis is to study how packaging and storage parameters affect sensory attributes and health beneficial compounds in fresh-cut swede and turnip.

The specific objectives are to:

- study effects of passive and active modified atmospheres on sensory attributes and content of vitamin C, sugar and glucosinolates;
- evaluate the impact of storage time and temperature on sensory attributes and content of vitamin C, sugar and glucosinolates;
- compare effects of different packaging materials on sensory attributes and content of sugar and glucosinolates.

2. Background

2.1 Swede and turnip

Vegetables have no botanical definition, but they can be grouped according to the plant organ used as edible produce (Wills et al. 2007). Root vegetables are vegetables where the edible part, in total or to some extent, consists of the root (Stoll & Weichman 1987). Swede, also called Rutabaga, (*Brassica napus* L. *var. napobrassica* Rchb.) and turnip (*Brassica rapa* L. ssp. *rapifera* Metzg.) are root vegetables in the Brassicaceae family (Gowers 2010), swede being a hybrid between turnip and *Brassica oleracea* (Shattuck et al. 1991). The colour of swede flesh is mainly yellow, while turnip flesh is white. Both swede and turnip are good sources of vitamin C, folate, potassium and dietary fibre (Gowers 2010).

In 2013, swede was the second most sold root vegetable in Norway, after carrot, and about 94% of total sales were Norwegian grown (Table 1). In terms of weight, more swede was sold than other important *Brassica* vegetables such as cabbage, broccoli and cauliflower (Table 1). Total production of swede was 13 371 Mg in 2013, while production of turnip was lower than swede, 573 Mg (SSB 2014).

Table 1 Vegetable sales from wholesalers in 2013.

Vegetable[1]	Norwegian (Mg)	Imported (Mg)	Total (Mg)	Kg pr. capita
Carrot	32 685	7 497	40 182	7.88
Swede	11 335	734	12 069	2.37
Cabbage	10 229	1 359	11 588	2.27
Broccoli	3 152	7 602	10 754	2.11
Cauliflower	4 559	5 809	10 368	2.03

[1] Obtained from OFG (2014).

2.2 Chemical compounds

2.2.1 Glucosinolates

Brassica vegetables have gained attention due to their glucosinolate content (Björkman et al. 2011). Compared with other natural plant products, glucosinolates are a small group of compounds, limited to species of the order Brassicales, included *Brassica* crops (Grubb & Abel 2006). Glucosinolate composition and concentration depend on a plant's genetic background, environmental conditions and physiological factors (Verkerk et al. 2009).

Glucosinolates are nitrogen and sulphur containing compounds, and consist of thioglucoside with a cyano group and a sulphate group as shown in Fig. 1 (Jahangir et al. 2009). Glucosinolates are divided into three groups; aliphatic, aromatic and indolic glucosinolates, depending on which amino acid the glucosinolates are derived from.

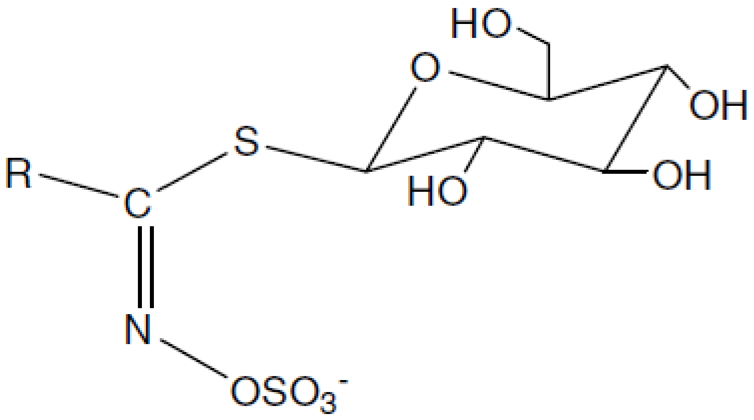


Fig. 1. General structure of glucosinolates (Jahangir et al. 2009).

When plant cells are ruptured, glucosinolates are mixed with the enzyme myrosinase, and glucosinolates are hydrolysed. Degradation products from this hydrolysis, such as thiocyanates, nitriles and isothiocyanates, have gained interest due to their possible health benefits, for example in cancer prevention (Björkman et al. 2011; Cartea & Velasco 2008; Mithen et al. 2000). These products could also contribute to the sensory attributes of *Brassica* vegetables, which have been described as pungent, bitter, radish-like, having a strong aroma or sulphur aroma (Fenwick et al. 1982).

2.2.2 Vitamin C

Brassica vegetables are important providers of vitamin C to the human diet. The content varies among species and cultivars, as well as with growing conditions and postharvest treatments (Domínguez-Perles et al. 2014).

Vitamin C belongs to the group of water-soluble vitamins, and occurs naturally in vegetables. The term vitamin C is used for all compounds with a similar biological activity to L-Ascorbic acid (AA) (Lee & Kader 2000). The oxidised form of L-ascorbic acid is L-dehydroascorbic acid (DHA) and both forms contribute to vitamin C activity (Gregory 1996). However, uptake of AA in the small intestine is more efficient than DHA uptake (Domínguez-Perles et al. 2014). Vitamin C content degrades during post-harvest treatments, from the field to the consumer, and different post-harvest treatments may influence this degradation (Domínguez-Perles et al. 2014).

2.2.3 Carbohydrates

The most commonly found free sugars in plants are the monosaccharides, glucose and fructose, and the disaccharides, sucrose and maltose (Halford et al. 2011). These carbohydrates are energy sources for humans, but also have other functions in the body. Vegetables are a source of dietary fibre, which passes undigested through the body (Hounsome et al. 2008).

Glucose, fructose and sucrose may influence the sweet taste in vegetables (Beaulieu & Baldwin 2002) and the sugar content can mask bitterness, such as in carrot (Kreutzmann et al. 2008). Increased sugar content due to low temperature storage has also been shown to give a sweeter taste in parsnips (Shattuck et al. 1989). Generally, vegetables contain more glucose and fructose than sucrose (Haard & Chism 1996), which is also observed in the case of swede and turnip (Gowers 2010).

2.3 Sensory attributes

Characteristics of foods as perceived by human senses are measured by sensory evaluation methods. Sensory perception is based on information from sight, taste, smell and touch and the interpretation of these senses in the human brain. Various methods are used for sensory analysis, depending on the objective of the study. Food products are described in a quantitative way, using sensory descriptive analysis, and normative methods are used to describe products in relation to their specifications. Both are objective methods where a trained sensory panel is used. Subjective methods where consumer tests are conducted are used instead for describing liking, acceptance or preference of a product (Martens 1999; Martens & Baardseth 1986).

Changes in sensory attributes of fresh-cut vegetables are important because they are related to the shelf-life of products. Descriptive sensory analysis is often the preferred method to measure these changes (Bett 2002). The number of descriptive attributes can vary between products, and their definitions are developed by a trained sensory panel (Barrett et al. 2010).

Appearance attributes of fresh-cut vegetables include colour, influenced by the presence of different pigments such as chlorophylls and carotenoids, and enzymatic and non-enzymatic reactions might cause developments of brown, grey or black spots on the surface (Barrett et al. 2010), often expressed as reduced colour evenness (Meilgaard et al. 1991).

Volatile compounds inhaled through the nose are responsible for odours. Taste is divided into four primary tastes (sweet, sour, salty and bitter), and flavour is a combination of the sensation of taste, odour and feeling (Meilgaard et al. 1991). Green, sweet, sour, bitter and astringent are taste and flavour characteristics often used to describe vegetable. In general, vegetables have a low-intensity of sweet taste, and are generally not considered as sweet, however carrots and sweet potatoes are exceptions (Bett 2002).

Texture attributes are used for solid food, and are related to the sense in the muscles of the jaw when chewing (Meilgaard et al. 1991). Texture can be defined in terms of hardness, but could also be related to moisture attributes measured by nerves on the surface of the tongue (Meilgaard et al. 1991). Some important texture attributes regarding fresh-cut vegetables are crispiness, hardness and juiciness (Bett 2002).

Descriptive sensory analyses of swede are scarce. Sweetness, crispiness, juiciness, fruitiness and bitterness are sensory attributes found to discriminate between different swede cultivars grown under different environmental factors (Fjeldsenden et al. 1981). No descriptive sensory analyses of turnip has been found in the literature, although sensory terms such as sharp and mild have been used in an evaluation of turnip flavour (Antonious et al. 1996).

2.4 Influence of minimal processing, packaging and storage on chemical compounds and sensory attributes of fresh-cut vegetables

2.4.1 Processing

Processing of fresh-cut vegetables may involve operations like trimming, coring, peeling, cutting, washing, centrifugation (or other water removing techniques) and packaging before storage and transport to food service outlets and retail markets (Barrett et al. 2010; Cantwell & Suslow 2002; Varoquaux & Mazollier 2002). Peeling and cutting increase the perishability of vegetables, while processing techniques, such as heat treatment, freezing or drying stabilize and improve the products storability. In contrast to heat treated, frozen and dried vegetables, fresh-cut vegetables are still respiring after processing and may therefore undergo physiological changes more rapidly (Brecht et al. 2008; Cantwell & Suslow 2002; Garcia & Barret 2002; Toivonen & DeEll 2002; Watada et al. 1996). The potential shelf life of fresh-cut vegetable products is related to the physiological effects of wounding caused by the processing (Toivonen & DeEll 2002). These physiological changes can lead to limitations in shelf life due to microbial spoilage, shrivelling, discolouration, and changes in flavour, odour and texture (Garcia & Barret 2002).

Glucosinolates

When *Brassica* vegetables are cut, tissues are damaged and glucosinolates are enzymatically hydrolysed by myrosinase (Verkerk et al. 2009). The effects of the cutting depend on its degree (de Vos & Blijleven 1988). Hydrolysis of glucosinolates in chopped or sliced cabbage was limited, while thorough mechanical homogenization (pulping) of cabbage resulted in a high degree of glucosinolate degradation (Verkerk et al. 2001). Fine cutting (5mm cubes or squares) reduced glucosinolate content in broccoli, Brussel sprouts, cauliflower and green cabbage by up to 75% when kept for 6 hours at ambient temperature (Song & Thornalley 2007). In the same study, coarse cutting resulted in a lower reduction in glucosinolate content (< 10%) in broccoli, Brussels sprouts, cauliflower and green cabbage. After cutting broccoli and cabbage, the content of aliphatic glucosinolates was significantly reduced, while the indolic glucosinolate content increased (Verkerk et al. 2001).

BACKGROUND

Vitamin C

Water-soluble vitamins are susceptible to postharvest degradation in vegetables (Brecht et al. 2008). Vitamin C content in carrot disks decreased during 8 days of storage, and manual peeling of the carrots retained vitamin C better than abrasion peeling (Kenny & O'Beirne 2010). Sharpness of cutting equipment may also affect vitamin C content, as vitamin C loss was lower in lettuce cut with a sharp knife compared with cutting with a dull knife (Barry-Ryan & O'Beirne 1999). Degree of cutting may also affect vitamin C content, as ascorbic acid content decreased in shredded radish, while ascorbic acid content in sliced and whole radish was preserved (del Aguila et al. 2006).

Carbohydrates

The physiological stress due to processing could increase respiration rate of vegetables and thus increase the consumption of sugars (Nei et al. 2006). Zhu et al. (2001) showed that consumption of O_2 and production of CO_2 by fresh-cut swede increased with the degree of cutting. Although respiration might increase use of sugars, the total sugar concentration will depend on the balance between sugar synthesis and consumption (Escalona et al. 2003).

Sensory attributes

Sensory attributes of fresh-cut vegetables can change during storage because of physiological changes caused by peeling and cutting (Toivonen & DeEll 2002). Studies on how processing steps affects the sensory properties of swede and turnip are scarce. Discolouration of both swede and turnip after peeling and cutting has been observed, and hand peeling resulted in less shrivelling than abrasion peeling (Alexander & Francis 1964a; Alexander & Francis 1964b). Hand peeling has also been reported to give better sensory quality in carrots, compared with fine and coarse abrasion peeling (Barry-Ryan & O'Beirne 2000). Manual rather than mechanical peeling and slicing for carrot discs has been recommended (Clife-Byrnes et al. 2007), probably due to less cellular damage (Barry-Ryan & O'Beirne 1998). Mechanical stress, due to shaking and washing processes has been found to increase bitterness in whole carrots (Seljåsen et al. 2004; Seljåsen et al. 2001). Peeling and cutting may change sensory attributes in fresh-cut vegetables. Odour and flavour changes could be due to the formation or loss of volatiles (Forney 2008), as described for cut onions, in which volatiles were formed by cell damage (Järvenpää et al. 1998). Moreover, loss of carrot aroma was higher for carrot slices cut with a machine than those cut with a razor blade (Barry-Ryan & O'Beirne 1998).

Cutting may lead to changes in appearance due to enzymatic browning on the cut surface. This results from the accumulation of brown or black coloured melanin due to the reaction between polyphenol oxidases with polyphenols and oxygen (Toivonen & Brummell 2008). Increased whiteness in carrots, also called white blush, is probably due to the drying of damaged cell walls and an accumulation of lignified material (Toivonen & Brummell 2008).
Changes in the texture of fresh-cut vegetables are related to senescence and water loss, among other factors (Toivonen & Brummell 2008).

2.4.2 Modified atmosphere packaging

Modified atmosphere packaging (MAP) is packaging that is designed to change the atmosphere surrounding food products from normal air, by active or passive processes. The initial atmosphere inside packages is either air in the case of passive MAP, or the air is flushed out and replaced with a chosen gas mixture in active MAP (Al-Ati & Hotchkiss 2002). O_2 and CO_2 molecules take part in metabolic processes in plants and the permeability of the packaging material to O_2 and CO_2 will, in combination with the respiration rate of the vegetable, generate a modified atmosphere during storage (Zhang et al. 2011; Beaudry 1999). Respiration rates vary with vegetable commodities and factors such as temperature, atmosphere composition, processing, post-processing handling and storage (Zhuang et al. 2011a). Controlling the gas flow into packages can be achieved by either gas exchange through a continuous film or through holes in the film (perforations). The reduction in O_2 concentration and increase of CO_2 concentration due to respiration create gradients so that O_2 will diffuse into and CO_2 out of the package (Beaudry 2000; Robertson 1993). The amount of O_2 entering the package could be different from the amount of CO_2 escaping from the package, depending on the CO_2/O_2 permselectivity of the packaging film (Al-Ati & Hotchkiss 2002). If the package is perforated, the gas exchange will primarily occur through the perforations, and the amount of O_2 entering the package will equal the amount CO_2 leaving the package (Beaudry 2000). These perforations can vary in size and shape which will influence the gas transmission rate (Larsen & Liland 2013).

Beneficial effects of MAP are reduced water loss, reduced respiration, inhibition of tissue browning, reduced microbial growth and delayed ripening (Zhuang et al. 2011b; Gorny 2003). The potential effects of a modified atmosphere on a specific fruit or vegetable product must be considered on an individual basis, as different produce may require different atmospheres in the package (Toivonen & DeEll 2002). A modified atmosphere might maintain an acceptable product quality, but it can also have negative effects on the quality, and cause development of off-flavours and off-odours (Zhuang et al. 2011b).

Glucosinolates

Studies regarding glucosinolate content in fresh-cut vegetables are scarce. Low O_2 and high CO_2 content in the package atmosphere preserved indole and aliphatic glucosinolates in mini cauliflower (Schreiner et al. 2006). In contrast, an atmosphere with higher O_2 and lower CO_2 content preserved aliphatic and indolic glucosinolates in mini broccoli (Schreiner et al. 2006). Thus the glucosinolate response to modified atmospheres may be commodity dependent. No effect of packaging atmosphere was observed for aliphatic glucosinolate content of fresh-cut cauliflower and broccoli or indolic glucosinolate content in fresh-cut broccoli, but indolic glucosinolate content in fresh-cut cauliflower increased in response to low O_2 or high CO_2 concentration (Schreiner et al. 2007). An increase in the content of the indolic glucosinolates 4-methosxuglucobrassicin in response to low O_2 atmosphere has been found in whole broccoli (Hansen et al. 1995). Packaging may also prevent loss in glucosinolate content by preventing tissue dehydration (Jia et al. 2009).

Vitamin-C

Proper packaging is important to preserve vitamins in fresh-cut vegetables (Gil & Kader 2008). Broccoli florets packed in modified atmospheres lost 15% of vitamin-C content. In comparison, non-packaged samples showed a decrease of 31% (Barth et al. 1993). Degradation of ascorbic acid in Galega kale was slowed down during storage in a low O_2 atmosphere at 20 °C (Fonseca et al. 2005). Simoes et al. (2009) did not report any effect of two modified atmospheres of 10% O_2 + 10% CO_2 and 2% O_2 + 15–25% CO_2 on vitamin-C levels in carrot sticks. Thus, the effect of modified atmosphere could depend on the commodity and the tested atmospheres. An important property of packaging is the prevention of dehydration in order to reduce degradation of Vitamin C (Bengtsson & Hagen 2008).

Carbohydrates

Glucose, fructose and sucrose content in diced kohlrabi stored in bags with and without a modified atmosphere, decreased after 14 days of storage, but the modified atmospheres preserved sucrose content better (Escalona et al. 2003). In contrast, no effect of modified atmosphere on sugar content in kohlrabi sticks was found (Escalona et al. 2007). A decrease in total sugar content of shredded cabbage has been related to increased respiration rate (Nei et al. 2006), suggesting that an effect of modified atmosphere could be due to altered respiration rate.

Sensory attributes

Packed cut swede can develop off-odours as a response to low O_2 concentration within the package, but at the same time low O_2 concentration might slow down the discolouration process (Alexander & Francis 1964a). An O_2 level of 15% in the package has been suggested for fresh-cut swede in order to avoid anaerobic respiration (Alexander & Francis 1964a). Recent research on fresh-cut swede in MAP is scarce. Storage of fresh-cut swedes with an atmosphere of 5% O_2 and 5% CO_2 has been suggested (Gorny 2003). Vacuum packed, peeled and diced turnip developed off-flavours more quickly, than samples packed in perforated and non-perforated bags, probably as a reaction to a low O_2 atmosphere or a high CO_2 atmosphere inside the package (Alexander & Francis 1964a). However, samples in vacuumed bags and non-perforated bags did not develop discolouration as quickly as the samples stored in perforated bags. This indicates that turnip could be packed in a low O_2 atmosphere to avoid discolouration, but there is a risk of off-flavours in the product when O_2 is too low or CO_2 is too high (Alexander & Francis 1964a).

2.4.3 Storage time and temperature

Storage time for fresh-cut vegetables is related to the distribution chain, from producer to consumer. Even though low temperature is one of the most important parameters in preserving food products, temperature during the distribution may vary. A study by Nunes et al. (2009) has shown that the surface temperature of fresh-cut vegetables ranged from 6.8 °C - 8.1 °C. Retail display temperatures varied from -0.7 °C – 16.4 °C, depending on the position in the retail display. Storing vegetables at temperatures as low as possible without freezing has been suggested (Guo et al. 2008). In fact, garlic cloves were stored at -6 °C for one week and damage due to freezing was not observed (James et al. 2009).

Glucosinolates

Total glucosinolate content did not change in whole peeled turnip during 4 weeks of storage (Shattuck et al. 1991b). Higher glucosinolate content has been reported for whole turnip stored at 4 °C compared with 22 °C (Aires et al. 2012). Storage at 0 °C gave a lower content of total glucosinolates than storage at 10 °C after 8 weeks (Shattuck et al. 1991a).

Vitamin C

Vitamin C content of peeled whole turnip was not affected during storage at 0 °C (Shattuck et al. 1991b), and vitamin C content in fresh-cut swede was not affected during storage for 8 days at 2.5 °C (Rydenheim 2008). Studies regarding effect of storage at higher temperatures on vitamin C content in swede and turnip has not been found.

Sugar

No differences in sugar content of whole swedes were found between storage at 0 °C and 10 °C (Shattuck et al. 1991a). Glucose and fructose content decreased in peeled whole stored turnip during 4 weeks of storage, while fructose content increased. Escalona (2003) found that glucose, fructose and sucrose in fresh-cut kohlrabi decreased with storage time, and suggested this could be due to respiration during storage.

Sensory

Storage temperatures have been shown to affect odour and flavour attributes in whole carrots, and intensity scores of ethanol flavour, earthy flavour, bitterness and aftertaste where higher for carrots stored at 10 °C or 20 °C compared with carrots stored at 2 °C. However, acidic taste decreased as a response to higher temperatures (Seljåsen et al. 2004). The colour of green bean stored at either 25 °C or 8 °C changed compared with storage at 0 °C (Guo et al. 2008).

3. Materials and methods

3.1 Plant material

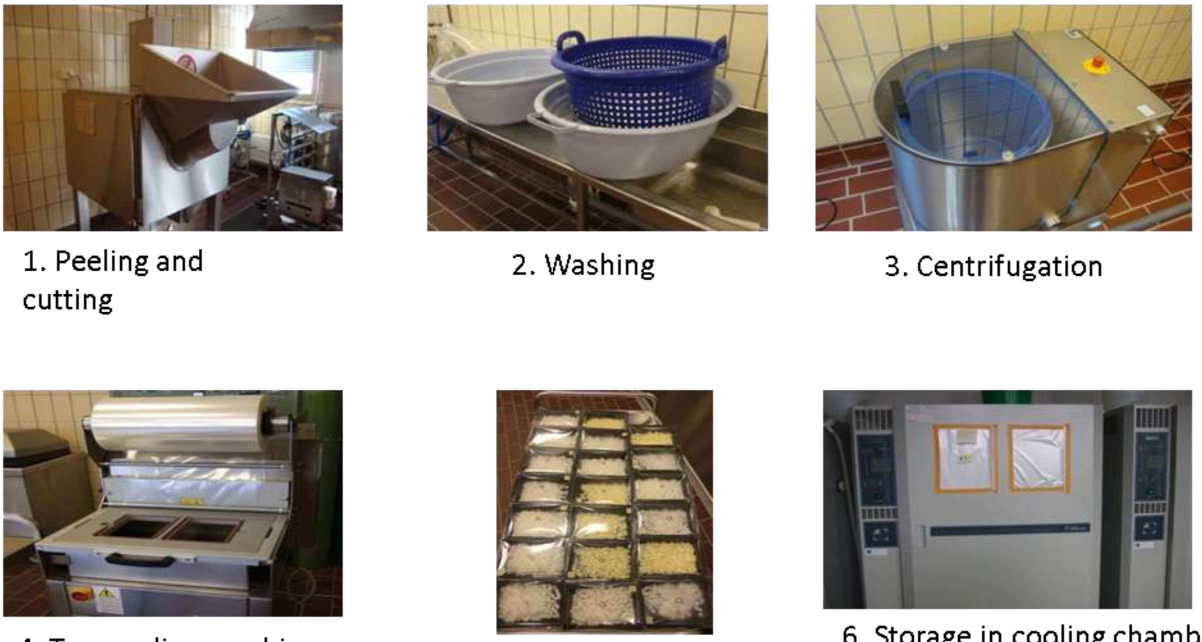
Swede (*Brassica napus* L. var. *napobrassica* Reichenb. cv. Vigod) and turnip (*Brassica rapa* var. *rapifera* L. cv. Solanepe) were produced by growers in the Oslofjord-area and south western part of Norway, respectively. Vegetables from the growing season 2011, 2012 and 2013 were used in Paper I, Paper II and Paper III, respectively. The vegetables were produced by the same growers in all years. The vegetables were harvested in September-October and stored whole in perforated plastic bags at 0-1 °C until experiments were conducted in November-December. In Paper I the vegetables were stored until February the following year.

3.2 Processing, packaging and storage

The vegetables were hand peeled, cut in vegetable dice (10 mm) using a cutting machine, washed and centrifuged according to the methods described in Papers I-II-III (Fig. 2).

Passive modified atmosphere packaging (passive MAP) and active modified atmosphere (active MAP) were created as described in Papers I-II. Pouches of biaxial oriented polypropylene (BOPP) and material containing polylactic acid (PLA) were made as described in Paper III.

In paper I and II, storage temperatures were 5 and 10 °C, and samples were stored for 5 and 10 days. In paper III, storage temperatures of -2, 0, 5 and 10 °C were used, and all samples were stored for 10 days. In addition, the effect of storing for 5 days at -2 °C followed by 5 days at 5 °C was tested.



1. Peeling and cutting

2. Washing

3. Centrifugation

4. Tray sealing maching

5. Selected weight and perforations

6. Storage in cooling chambers

Figure 2. Equipment used in the experiments.

3.3 Sensory analysis

Quantitative descriptive analysis of sensory attributes was conducted using a trained sensory panel. The assessors were selected, trained, and the analysis was performed according to ISO standards. The assessors agreed on sensory attributes to describe raw swede and turnip during a training session (Paper I-II-III).

3.4 Vitamin C

Vitamin C content was determined as the amount of L-ascorbic acid (AA) and L-dehydroascorbic acid (DHA) according to the method described by Steindal et al. (2013). Content of DHA was determined by analysing AA in a separate chromatographic sample after reducing the DHA present in the sample to AA. The amount of DHA was then determined by subtracting reduced AA from total AA. The reported vitamin C content is the sum of AA and DHA content. Vitamin C analysis was conducted as described in Paper II.

3.5 Glucosinolates

Identification and quantification of glucosinolates in swede and turnip were performed according to ISO 9167-1:1992(E) with modifications (Paper II-III).

3.6 Sugars and other quality related parameters

The amount of glucose, fructose and sucrose in swede and turnip was determined according to Elmore et al. (2007) with modifications as described in Paper II-III. Dry matter (DM) content and weight loss were determined as described in Paper III.

3.7 Freezing point

The cooling curve method was used to obtain the freezing point of swede and turnip dice (Rahman et al. 2002), and was conducted as described in Paper III. By using the cooling, or freezing curve, the equilibrium freezing point (EFP) and ice crystallization temperature (ICT) could be evaluated.

3.8 Statistical analysis

Analysis of variance (ANOVA), using general linear model (GLM), was used to study the effects of storage parameters. Principal component analysis (PCA) was used to get an overview of variations between the samples and the variables responsible for this variation. Partial least squares regression (PLSR) was used to study relationships between chemical measurements and sensory attributes.

4. Results and discussion

4.1 Effects of modified atmospheres, storage time, temperature and packaging material

4.1.1 Sensory attributes

Modified atmospheres were found to influence odour, taste and flavours of swede and turnip to a low degree (Paper I-II). This is in accordance with Alasalvar et al. (2005), who did not find differences in odours between shredded carrot stored in packages with modified atmospheres (5% O_2 and 5% CO_2, and 95% O_2 and 5% CO_2) and carrots stored in normal atmosphere (air) at 5 ^{o}C for 13 days. The observed effects of modified atmospheres on fresh-cut swede and turnip indicate that anaerobic conditions did not occur using the chosen atmospheres (Paper I and II). However, modified atmospheres have been shown to influence the sensory quality of carrot discs more than storage temperature (8 ^{0}C and 4 ^{0}C) (Cliffe-Byrnes & O'Beirne 2007). In fact, studies regarding sensory quality of carrots and modified atmospheres have shown that too low a O_2 concentration results in off-odours from anaerobic respiration (Cliffe-Byrnes & O'Beirne 2007; Cliffe-Byrnes & O' Beirne 2005; Seljåsen et al. 2004; Barry-Ryan et al. 2000).

Intensity of sour odour, sour flavour, green odour, and green flavour decreased in both vegetables as an effect of storage time (Paper I-II) and temperature (Paper I-II-III). Sour flavour and green flavour are attributes found in different vegetables (Bett 2002). Intensity of cloying odour increased with longer storage time (Paper I-II) and higher temperature (Paper I-III) for both vegetables, however the effects were not significant for swede in Paper II and III. Intensity of cloying flavour increased in swede and turnip as an effect of prolonged storage time and higher temperature (Paper I). This was also observed in Paper II, but was not significant for swede. In Paper III, intensity of cloying flavour in turnip increased significantly with increasing temperature. Fresh-cut vegetables are living, hence physiological processes continue during storage and flavour changes could be due to diffusion or metabolism of compounds (Forney 2008).

Sulphurous and pungent are characteristic flavours of *Brassica* vegetables, and could originate from glucosinolate breakdown products (Cartea & Velasco 2008). In swede, sulphurous flavour was not affected by storage parameters (Paper I-II-III), while pungent flavour increased due to higher storage temperature (Paper I). In turnip, sulphurous flavour decreased due to increased temperature (Paper I-II), while pungent flavour was not affected by storage parameters (Paper I-II-III). Sulphurous and pungent odours in turnip decreased with longer storage times (Paper I-II) and higher temperature (Paper I-II-III). For swede, sulphurous and pungent odours increased with higher temperatures (Paper III). Flavours are sensed in the moment of chewing, while odours could originate from volatile compounds formed during processing. Evaporation of volatiles during storage might explain the decrease in odour intensity, while an increase in odour intensity could indicate formation of volatile compounds. Differences between *Brassica* vegetables in the formation of volatiles in response to storage conditions have previously been found (Forney & Jordan 1999).

The storage parameters did not influence sweet or bitter tastes in swede and turnip in Papers I and II. However, the intensity of sweet taste in turnip was reduced by increased storage temperature (Paper III). Intensity of sweet taste in swede and turnip were related to total sugar and sucrose content (Paper II-III), and Paper II showed that bitterness in both swede and turnip were correlated to total indolic glucosinolates, 4-methoxyglucobrassicin and glucobrassicin. However, in Paper III the correlation between bitterness and glucosinolates was weaker for swede. In turnip, the bitter taste was correlated to 4-hydroxyglucobrassicin, progoitrin, total indolic glucosinolates, glucobrassicin and 4-methoxyglucobrassicin. Total glucosinolates content, neoglucobrassicin and glucobrassicin content have been found to correlate with bitterness in cabbage (Beck et al. 2014). A negative correlation between sweet and bitter tastes was observed for both swede and turnip (Paper II-III), and this has also been shown for cabbage (Beck et al. 2014) and cooked cauliflower (Engel et al. 2002). Schonhof et al. (2004) suggested that perception of sweetness decreased due to increased bitterness in cauliflower and broccoli, and van Doorn et al. (1998) discussed whether sweetness in Brussels sprouts is a result of non-bitterness. The variation in sweet and bitter tastes could therefore be due to either an increase or reduction in bitter or sweet compounds, or a combination.

The mechanisms behind flavour changes in fresh-cut vegetables are not fully understood, and several interactions, including chemical compounds and human perception are probably involved (Forney 2008). However, of the environmental factors during storage, time and temperature have a considerable influence on odour and flavour changes.

Paper I, II and III showed that swede and turnip were susceptible to discolouration after cutting. This has also been found in other studies (Alexander & Francis 1964a; Alexander &

Francis 1964b). In both vegetables, uneven colour increased with longer storage times (Paper I-II) and higher temperatures (Paper I-II-III). The colour of turnip changed, as indicated by an increase in hue (Paper I-II-III), and this was due to higher temperatures (Paper I-II-III). An increase in hue of swede due to higher temperature was only observed in Paper I. This indicates that the mechanisms resulting in a change of appearance are different for swede and turnip. The change in appearance could be due to oxidation by polyphenol oxidase, which causes the development of brown or black pigments resulting from the formation of melanin (Toivonen & Brummell 2008). Dehydration of the cut surface can also lead to changes in appearance (Barry-Ryan & O'Beirne 1998), probably due to drying of broken cells after peeling and cutting (Lamikanra 2002). Dehydration of the surface and lignin formation can provoke a phenomenon called “white blush” on carrots (Toivonen & Brummell 2008). Stored swede samples got higher whiteness scores, compared with control sample (Paper II-III). This is in accordance with Rydenheim (2008), who observed an increase in white colour on the surface of fresh-cut swede after 5 days of storage. This whiteness was reduced when swede slices where dipped in water without centrifugation before packaging and storage. In addition, formation of a lignin layer was found on the cut surfaces of swede, and was enhanced by exposure to ethylene (Rhodes et al. 1981). The observed discolouration may negatively influence consumer liking of fresh-cut swede and turnip. Discolouration of Jerusalem artichoke and beetroot influenced consumer appropriateness and was considered undesirable (Bach 2012).

Modified atmosphere had an effect on the appearance of fresh-cut swede and turnip (Paper I-II). Lower O_2 or higher CO_2 concentrations gave higher scores for colour evenness in swede (Paper I) and turnip (Paper I-II). For both vegetables, there were no significant differences between the effects of active and passive modified atmospheres (Paper II). The effects of modified atmosphere on appearance could be due to lower O_2 concentration slowing the discolouration process (Beaudry 1999). However, the O_2 concentrations used in Paper I and II were probably not low enough to prevent discolouration. For cut lettuce an O_2 concentration < 1% when stored at temperatures between 5 ^{0}C and 10 ^{0}C has been found to prevent discolouration (Smyth et al. 1998).

In Paper III, packaging in BOPP bags gave a higher score for colour evenness for swede than PLA. This could be related to an increased drying of the cut surface caused by PLA, due to moisture absorbing properties of PLA (Pettersen et al. 2011). No significant effects of packaging material on appearance attributes were observed for turnip.

Most of the texture attributes for swede were not influenced by the experimental parameters (Paper I-II-III). However, in turnip, fibrousness increased as an effect of longer storage time (Paper I) and higher temperature (Paper I-II), while crispiness and juiciness decreased with higher storage temperature (Paper III). These texture changes in turnip could be due to weight loss (Paper III), even if similar weight loss was observed for swede (Paper III). This indicates that fresh-cut turnip is more prone to texture changes than fresh-cut swede during storage. The observed changes in texture could influence commercial use. In fact, high sensory scores for crispiness and juiciness in raw beetroot have been related to consumer appropriateness (Bach 2012). No effects of packaging materials were seen on texture attributes of either swede or turnip. However, packaging using PLA gave a significantly higher weight loss than using BOPP, for both vegetables (Paper III).

The stored samples were different from unstored control samples regarding sensory attributes (Paper I-II-III). This has also been shown for broccoli stored in MAP versus unstored broccoli (Jacobsson et al. 2004; Gillies et al. 1997). This indicates that none of the experimental parameters used totally prevented changes in sensory attributes during storage. The sensory panel is trained to describe sensory attributes objectively, without evaluating consumers' liking. Whether a change in intensity of a sensory attribute is positive or negative for consumers could depend on whether the attribute is expected for the relevant vegetable (Bach 2012). Thus, changes during storage could influence consumer perception if it is assumed that fresh-cut vegetables are equal to freshly prepared vegetables.

4.1.2 Vitamin C

In Paper II, vitamin C content was not affected by time, temperature or modified atmosphere. This is in agreement with previous studies that reported no changes in vitamin C content for swede cut in slices and sticks, stored at 2.5 °C for 8 days (Rydenheim 2008). This shows that the vitamin C content of fresh-cut swede and turnip is stable during storage. Vitamin C content in whole swede and turnip has also been reported to be stable during storage (Shattuck et al.1991b; Watada 1987). The preservation of vitamin C could be due to the prevention of dehydration during storage (Bengtsson and Hagen 2008).

A lower content of vitamin C in swede and turnip was reported in Paper II compared with other studies (see Paper II). The explanation could be that the studied vegetables were cut in small dice (Paper I-II-III), and as previously shown, different processing methods can affect vitamin C levels in cut vegetables (Kenny and O'Beirne 2010; Barry-Ryan and O'Beirne 1999). Vegetable variety, experimental procedures and analytical methods may also explain differences between studies (Domínguez-Perles et al. 2014).

4.1.3 Glucosinolates

Total glucosinolate content of swede increased with storage time (Paper II), but was not influenced by storage temperatures (Paper II-III). However storing first at -2 ºC for 5 days followed by storage at 5 ºC gave a lower total glucosinolates content, compared with storage at 5 ºC for 10 days (Paper III). For turnip, no significant differences in total glucosinolate content were observed between different storage times (Paper II) or temperatures (Paper II-III). These results indicate that total glucosinolate content of fresh-cut swede and turnip are stable. The stability of glucosinolates in vegetables after cutting may vary (Song & Thornalley 2007; Verkerk et al. 2001). Since the hydrolysis of glucosinolates is more likely to occur at the surface of the cut vegetable (Verkerk et al. 2001), stability after cutting has been related to the coarseness of the cutting (Song & Thornalley 2007). Even though total glucosinolate content does not change, content of individual glucosinolates may change (Verkerk et al. 2001).

Total aliphatic glucosinolate content of fresh-cut swede increased with storage time (Paper II), while total aliphatic glucosinolates in turnip decreased as a response to increasing storage time (Paper II) and storage temperature (Paper II-III). Longer storage time (Paper II) and higher temperature (Paper II-III) gave a higher total indolic glucosinolate content in both swede and turnip. An increase in indolic glucosinolates after cutting has also been observed in white cabbage, while no change in indolic glucosinolates was observed for red cabbage (Verkerk et al. 2001). Moreover, the content of glucobrassicin and 4-methoxyglucobrassicin increased in both swede and turnip as an effect of prolonged storage (Paper II) and higher temperature (Paper II-III). This is in accordance with results reported for cut white cabbage and broccoli, where content of 4-methoxyglucobrassicin increased (Verkerk et al. 2001). An increase in indolic glucosinolates in swede has been explained as a response to stress (Birch et al. 1992), which could explain its increase in fresh-cut swede and turnip after peeling and cutting.

A modified atmosphere with lower O_2 and higher CO_2 gave lower total indolic glucosinolate content in both swede and turnip, although there was no significant difference between active and passive modified atmospheres for turnip (Paper II). However, for both vegetables an active modified atmosphere with 5% O_2 gave lower glucobrassicin content (Paper II). Thus the observed increase in indolic glucosinolates due to increased storage time and storage temperature seemed to be diminished by a lower O_2 or higher CO_2 atmosphere, and could be a response to lower respiration rate. Others have found that a modified atmosphere of 1% O_2 and 21% CO_2 preserved content of total indolic glucosinolate in mini cauliflower, but not in mini broccoli (Schreiner et al. 2006). In a similar study, total indolic glucosinolates increased in cauliflower stored in a modified atmosphere of 1% O_2 and 21^{o} CO_2 (Schreiner et al. 2007), thus the effect of modified atmosphere on glucosinolate content seems to vary between commodities.

4.1.4 Sugar

Prolonged storage time and higher temperatures led to a lower total sugar content of swede and turnip (Paper II). This is in accordance with findings for whole turnip, where a decrease in total sugar content was observed after two weeks of storage at 0 ^{0}C (Shattuck et al. 1991b). However, the results are in contrast to those reported for whole swede, where total sugar content was not affected by temperature during storage (Shattuck et al. 1991a). Nonetheless, in Paper III, where temperature was the only experimental parameter tested, total sugar content of swede was not significantly affected by temperature. Total sugar content in fresh-cut turnip was affected by storage temperature, and storage at either -2 ^{0}C or 0 ^{0}C gave significantly higher total sugar content than in samples stored at higher temperatures (Paper III). In shredded cabbage, total sugar content decreased with increasing storage temperature, and was related to an increase in respiration rate (Nei et al. 2006). Respiration could also be the explanation for changes in total sugar content in fresh-cut swede and turnip. There were indications that a modified atmosphere with lower O_2 and higher CO_2 concentration resulted in a higher total sugar content although there was no significant difference between passive and active modified atmospheres on total sugar content of either vegetable (Paper II).

RESULTS AND DISCUSSION

Longer storage time reduced sucrose content in both swede and turnip, while higher temperatures gave a lower sucrose content in turnip (Paper II). A temperature effect on sucrose content in turnip was also observed in Paper III, where a higher sucrose content was observed for turnip stored at -2 ^{0}C or 0 ^{0}C compared with 5 ^{0}C or 10 ^{0}C. For both swede and turnip, storage at -2 ^{0}C resulted in a higher sucrose content compared with 0 ^{0}C (Paper III). An increase in sucrose content in whole turnip roots stored at 0 ^{0}C for two weeks has been observed previously, and was suggested to be due to starch hydrolysis and sucrose formation from fructose and glucose (Shattuck et al 1991b). Increased sucrose content has also been observed for parsnip after 7 and 14 days of storage, and the increase was highest in parsnips stored at 0 ^{0}C, compared with storage at 10 ^{0}C (Shattuck et al. 1989).

Glucose levels in swede were only affected by modified atmosphere, while fructose was affected by temperature and modified atmosphere in Paper II. In Paper III there was an effect of temperature on glucose and fructose content in swede, but no observed relationship between temperature and glucose or fructose. The lower glucose and fructose content in turnip after storage at 10 ^{0}C (Paper II) and 10 ^{0}C or 5 ^{0}C (Paper III), could be due to increased respiration as a response to higher temperature. Fructose and glucose are used in metabolic processes which could lead to a decrease in these sugars, and at the same time glucose and fructose content might increase due to cleavage of sucrose (Escalona 2003).

5. Main conclusions

This thesis has shown that the sensory quality of fresh-cut swede and turnip change during storage. This change was influenced by storage temperature and storage time, rather than modified atmosphere. Nevertheless, modified atmosphere had an effect on the appearance of both vegetables, although no differences between passive and active modified atmospheres were found.

Increased storage time gave higher total glucosinolate content in swede, but no relationship between temperature and total glucosinolate content in swede was observed. For turnip, storage time and temperature did not influence total glucosinolate content. However, total indolic glucosinolates increased in response to prolonged storage time and higher temperature in both vegetables. Moreover, the content of glucobrassicin and 4-methoxyglucobrassicin increased in both swede and turnip as a result of prolonged storage and higher temperature.
Vitamin C content was not affected by time, temperature or modified atmosphere, in either swede or turnip.

Prolonged storage time and higher temperature resulted in a lower content of total sugar in swede and turnip. When temperature was the only experimental parameter tested, total sugar content of swede was not significantly affected by temperature. Storage at -2 ° gave the highest sucrose content in both swede and turnip.
Packaging material containing PLA gave higher weight loss in both vegetables, but had no effect on texture attributes.

This thesis contributes to an improvement in understanding and knowledge of how storage parameters affect sensory quality and health benefitting compounds in fresh-cut swede and turnip. In general, fresh-cut swede and turnip are good sources of compounds beneficial to health and have high nutritional value, but changes in sensory attributes might influence their commercial use. Lower storage temperatures slowed the changes in sensory quality, especially for turnip, and storage at sub-zero temperatures could be beneficial for fresh-cut swede and turnip.

6. Future perspectives

It would be interesting to study further the possibilities and limitations of storing fresh-cut vegetables at sub-zero temperatures. This could include finding minimum temperatures before freezing. This knowledge could be used for developing new distribution and packaging solutions. Moreover, low temperature storage could also be investigated as a possible method to enhance sweetness in root vegetables before further processing.

In future studies of fresh-cut vegetables, consumer studies should be related to changes in sensory attributes, to understand how changes in sensory quality changes influence consumer acceptance. A better understanding of the underlying mechanisms leading to changes in sensory quality could contribute to development of tailor-made storage and packaging solutions.

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Papers I-III

Paper I

Effect of storage time, temperature and passive modified atmosphere on sensory quality of fresh-cut swede and turnip

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ABSTRACT

Fresh-cut swede and turnip were packed and stored for 5 and 10 days at 5 and 10 ^{0}C. Three passive modified atmosphere developments were obtained at each temperature by different combinations of product weights and package permeabilities (film and perforations). A trained sensory panel described odours, taste and flavour, appearance and texture attributes at the end of storage. The experiment was conducted in November and repeated in February with the same, long-term stored raw materials.

Storage time and temperature affected appearance, odour, taste and flavour, whereas passive modified atmospheres had an effect on appearance. Odour attributes in fresh-cut swede and turnip changed most during the 5 first days of storage, while changes in flavour and appearance showed continuous change during storage. Texture attributes changed less during storage. Green and sour odour and flavour decreased, while cloying odour and flavour increased during storage. Both vegetables developed a discolouration. The changes in sensory quality in both November and February experiment were similar.

1. Introduction

Fresh-cut vegetables are easier to prepare for the consumer as they are peeled, cut and washed, and could therefore increase the vegetable consumption. Swede (*Brassica napus* L. var. *napobrassica* Rchb.) and turnip (*Brassica rapa* L. ssp. *rapifera* Metzg.) are root vegetables which are interesting to use in healthy convenience food products (Olsson and Gustavsson, 2009). Norwegian grown vegetables are available for a limited period, due to a short growing season, which reduces the use of Norwegian grown vegetables in the fresh-cut production. However, swede, and turnip show good capability of long-term storage (Stoll and Weichman, 1987, Suzuki and Cutcliffe, 1981) and has a potential to be used in fresh-cut products during the winter season.

When developing new fresh-cut vegetable products it is important to understand how storage and packaging parameters affect different quality aspect of the vegetables after processing. Processing and packaging may influence sensory attributes in fresh produce during storage, and thereby influence the commercial use (Beaulieu and Baldwin, 2002). Few studies are available regarding sensory quality of fresh-cut swede and turnip. Off-odours and discolouration have been found to limit shelf-life of peeled, diced and packed swede and turnip (Alexander and Francis, 1964b, Alexander and Francis, 1964c). To improve the quality of fresh-cut vegetables, it is important to understand sensory changes (Bett, 2002). Methods used to preserve the quality of fresh-cut produce are storage temperature and modified atmosphere packaging (MAP), (Barrett *et al.*, 2010).

MAP is used to lower respiration rate in packed produce, and reduce discolouration in some fresh-cut commodities, like lettuce. Care should be taken when packing respiring products, since to low O_2 concentration could reduce sensory quality (Seljåsen *et al.*, 2004). A low O_2 concentration in packages might induce anaerobic respiration, as shown for shredded carrots (Barry-Ryan and O'beirne, 2000). The gas concentrations inside packages with modified atmosphere (MA) are a result of the produce respiration rate and permeability of the packaging material (Jacxsens *et al.*, 1999). MAP studies have been done using different commercially available films in combination with temperatures to create different atmosphere developments surrounding the packed produce (Barry-Ryan *et al.,* 2000). Another approach is to create different MAs by varying the product weight (Beaudry *et al.*, 1992), packaging film and perforations at selected temperatures (Vallejo and Beaudry, 2010).

The aim of this work was to 1) create different passive modified atmospheres by manipulating film permeabilities, product weight and temperature, and 2) investigate the effect of passive modified atmosphere and temperature during short-term storage on sensory quality of cut swede and turnip, and 3) to repeat the experiment after vegetables have been stored for a longer period.

2. Material and methods

2.1 Plant material

Swede (*Brassica napus L. var. napobrassica Rchb.* cv. Vigod) and turnip (*Brassica rapa L. ssp. rapifera Metzg.,* cv. Solanepe) were provided from local growers in the Oslofjord-area and south western part of Norway, respectively. Turnip was transported to Ås in a refrigerated truck holding 4 ^{0}C. Swedes were harvested in September and turnips in October, and approximately 100 kg of both vegetables were harvested. The vegetables were stored in perforated plastic bags at 0-1 ^{0}C. The first experiment was carried out in November and repeated three months later, in February, using the same plant material.

2.2 Minimal processing

After washing in cold tap water, swede and turnip were peeled by hand using a sharp stainless steel knife, or a potato peeler (Victorinox, Ibach-Schwyz, Switzerland), respectively. Any discolouration was removed. The roots were washed again and cut into 10 mm cubes, using a dicing machine (Eillert Bl1000A; Machinefabriek Eillert B.V., Ulft, The Netherlands). The dice were first washed in cold tap water, and then in tap water mixed with crushed ice, to cool the vegetables before packaging. After washing the cut vegetables were spin dried in a vegetable centrifuge for 30 seconds at 1000 rpm (Eillert, Machinefabriek Eillert B.V., Ulft, The Netherlands).

2.3 Packaging and atmosphere selection

Diced vegetables were packaged in 1100 ml high density polyethylene (HDPE) trays (Promens Kristiansand, Norway). A film consisting of ethylene vinyl alcohol (EVOH) as the barrier layer (Wipak, Nastola, Finland), and a polyethylene film (52LD) with four laser perforations (Amcor Flexible, Ledbury, UK) were sealed to the trays, using a Polimoon 511VG tray sealing machine (Promens Kristiansand, Norway).To obtain different package permeabilities, the EVOH film was perforated with 1, 2, 3 and 4 perforation(s) using a 0.22 mm acupuncture needle. Three perforations of the 52LD film were covered with a rubber septum to obtain only one perforation in this film (Larsen and Liland, 2013). The latter film was included since laser perforations have a lower gas transmission rate than the acupuncture holes (Larsen and Liland, 2013). Samples of 50, 100, 150 and 200g of the diced vegetables were packed using all package permeabilities, and stored at 5 and 10 ^{0}C. This created a range of passive atmosphere developments, as previously described by Beaudry *et al.* (1992), Gong and Corey (1994) and Vallejo and Beaudry (2010). O_2 and CO_2 concentrations inside the packages were measured twice a day for 10 days using a CheckMateII O_2/CO_2 -analyser (PBI-Dansensor, Ringsted, Denmark). The atmosphere sample was collected through a rubber septum placed on the film using a needle connected to the gas analyser. Three modified atmosphere (MA) levels at each temperature, without severe fermentation odours, were chosen for the main experiment for swede and turnip (figure 1). The following combination of film type, number of perforations and product weight (g) were used for swede stored at 5 ^{0}C: MA-1 (EVOH-2-150), MA-2 (EVOH-1-150) and MA-3 (52LD-1-200), and at 10 ^{0}C: MA-1 (EVOH-2-100), MA-2 (EVOH-2-150) and MA-3 (52LD-1-150). The following combinations were used to create modified atmospheres for turnip stored at 5 ^{0}C: MA-1 (EVOH-2-100), MA-2 (EVOH-2-200) and MA-3 (EVOH-1-200), and at 10 ^{0}C: MA-1 (EVOH-3-100), MA-2 (EVOH-3-150) and MA-3 (EVOH-1-100).

2.4 Preparing of samples for sensory analysis

For all samples, the same batch of each vegetable was used. To evaluate samples stored for 5 and 10 days at the same time, processing and packaging was done 5 and 10 days before the sensory evaluation, respectively. On the day of sensory analysis, the dice from the five packages of each of the 12 treatments were mixed, and a control sample was prepared in the same way as the stored samples.

2.5 Sensory analysis

Quantitative descriptive analysis was performed according to ISO 13299:2003(E) by a trained 10 person sensory panel employed exclusively to work as assessors at Nofima (Ås, Norway).

The assessors were selected and trained according to ISO 8586-1:1993(E), and the analysis was performed in a room with standardized light and separate booths according to ISO 8589:2007(E). Before the analysis, the sensory panel was calibrated, using the control sample and a stored sample. The assessors agreed on attributes to describe taste, odour, flavour, appearance and texture (table 1) during a training session prior to the analysis. One tablespoon (25g) of room temperate vegetables from each treatment and control sample were served in plastic trays with lids and a three digit code. Each sample was served twice. The panelists recorded their results at individual speed on a 15 cm non-structured continuous scale with the left side of the scale corresponding to the lowest intensity and the right side corresponding to the highest intensity. The electronic data registration system (Eye Question, v. 3.8.6, Logic 8, The Nederland) transformed the responses into numbers between 1 (low intensity) and 9 (high intensity). Due to the number of samples, the sensory evaluation had to be performed during two days. Which samples to be analysed on which day were randomly chosen.

2.6 Statistical analysis

The experiments were performed as a full factorial design with the factors storage time, temperature and modified atmosphere. Analysis of variance (ANOVA) was run to evaluate the effect of storage time, temperature and modified atmosphere, were the effect of assessor was set as random. Tukey`s HSD test was used for multiple comparisons. The November and February experiment were analysed as two separate experiments. Statistical analysis was carried out using a general linear model (Proc GLM) in SAS 9.4 (SAS Institute, Inc., Cary, NC, USA), and statistical significant level was set to $p = 0.05$. Principal component analysis (PCA) was performed using The Unscrambler Version 10.1 (CAMO Software AS, Oslo, Norway).

3. Results and discussion

3.1 Atmosphere developments

The headspace gas composition obtained during storage from experiment in November are shown in figure 1. The atmosphere developments in February showed a similar trend, but lower O_2 end concentrations could indicate a change in respiration rate after long-term storage (result not shown). For both swede and turnip, MA-1 gave the highest level of O_2 at both 5 and 10 ^{0}C after 5 and 10 days. MA-2 combinations gave the mid-level of O_2 concentrations, while packaging combinations used to create MA-3 resulted in the lowest level of O_2 concentration. The corresponding CO_2 levels showed that packaging combinations for MA-1 gave lowest CO_2 level, while MA-2 and MA-3 gave mid-level and highest CO_2 concentrations, respectively. Turnip developed steady state level after 2-3 days, while O_2 level for swede continued to decrease during the storage period.

3.2 PCA overview of samples and attributes

83% and 79% of the variation between swede samples, in the November and February experiment respectively is explained by principal component (PC) 1 (fig. 2). For turnip, PC1 explained 91% and 90% for the November and February experiment, respectively. Thus the variance between the samples is mainly explained by PC1, both for swede and turnip (Næs *et al.*, 2010). Along PC1, for both vegetables, samples are distributed with the control sample to the most right, and then samples stored for 5 days at 5 ^{0}C appear, while samples stored for 10 days at 10 ^{0}C were located to the most left. Samples stored for 5 days at 10 ^{0}C, and samples stored for 10 days at 5 ^{0}C were grouped in the middle. Thus PC1 explain the difference in sensory attributes caused by storage time and temperature, and also differencebetween the unstored control sampleand the stored samples. PC2 explained 10 and 9% of the variance between swede samples (November and February, respectively), and 4 and 6% of the variation between turnip samples in November and February, respectively. Since the control sample is located in the upper part of the score plot, PC2 explained some of the variation in sensory attributes between the control sample and the stored samples, which indicates that the sensory attributes also changed during the five first days of storage.

Samples exposed to the same storage time and temperature are located close to each other, and show that modified atmosphere had less effect on the sensory attributes compared to time and temperature. The loading plots for swede (fig. 2b and d) and turnip (fig. 3b and d) show how much each sensory attribute contribute to the variance between the samples. Appearance, odour and taste attributes contributed to the variation, since these attributes span the plot. However, texture attributes are located more in the middle, which indicate less difference in texture between the samples. Sour odour, green odour, sour flavour and green flavour, colour intensity, colour evenness and whiteness are located on the right side of the plot. Together with cloying odour and cloying flavour, cellar flavour and cellar odour on the left side in the plot, these are attributes contributing most to the variation in the samples explained by PC1. The odour attributes located more in the upper part of the loading plot might cause a variation explained by PC2. Whiteness is located in the lower part of the plot, meaning that some difference in whiteness between the samples could be explained by PC2.

3.3 Effect of storage time, temperature and passive modified atmosphere

3.3.1 Odour

Storage time and temperature had significant effect on sour odour and green odour in swede (table 2) and turnip (table 3) in both experiments, and the intensity of these attributes decreased due to longer storage time and higher temperature. In addition, earthy odour, sulphurous odour and pungent odour in turnip decreased as a consequence of higher temperature and longer storage time (table 3). Longer storage time and higher temperature also caused an increase in the intensity of cloying odour and cellar odour in both vegetables Sulphurous odour, metallic odour, and earthy odour in swede were affected by storage time or temperature, but this was not consistent between the two experiments (table 2). Modification of atmosphere had an effect on sulphurous odour and metallic odour in turnip (table 3), but this was only significant in February. No significant effects of the chosen atmosphere levels were observed on swede odours. Pungent odour in swede was not significantly affected by any of the experimental factors.

Odour attributes could originate from aroma compounds naturally occurring within the plant tissue, or secondary compounds formed as a result of cell damage due to peeling and cutting (Beaulieu and Baldwin, 2002). During the first days of storage, these volatile compounds might evaporate from the surface, which could explain the reduced intensity of some odour attributes. Similar results has been found for carrot discs, where reduced aroma was observed between day 1 and day 6, and samples stored at 8 ^{0}C lost more aroma compared to storage at 4 ^{0}C. (Cliffe-Byrnes and O'beirne, 2007). Loss of carrot aroma in carrot slices after 5 days of storage at 8 ^{0}C has also been described (Barry-Ryan and O'beirne, 1998).

3.3.2 Taste and flavour

Intensity of sour flavour and green flavour decreased in swede (table 4) and turnip (table 5) during storage, as an effect of longer storage time and higher temperature. The results also show that MA influenced sour taste in swede in February, but this effect was not significant in November. Earthy flavour in swede decreased, as an effect of longer storage time and higher temperature. Intensity of sweetness decreased in turnip with longer storage time and higher temperature, while a significant reduction of sweetness in swede was only observed in the November experiment

There was an increase of cloying flavour and cellar flavour during storage in both swede (table 4) and turnip (table 5). This increase was affected by longer storage time and higher temperature. Bitter taste in swede increased during storage, and was affected by time, while effect of temperature and MA was only significant in November (table 4). Increase of bitter taste in turnip was only affected by temperature in November (table 5). Longer storage time and higher temperature increased the intensity of pungent flavour in swede, but the effect was only significant in February (table 4). MA-1 gave a more pungent flavour in swede, but this effect was only significant in November (table 4). Pungent flavour in turnip was not significantly affected by the storage conditions. Time, temperature and MA showed no significant effect on sulphurous flavour in swede (table 4). Storage at 10 ^{0}C gave a decrease in intensity of sulphurous flavour in turnip. Metallic flavour in swede was not affected by storage time, temperature or MA (data not shown). In turnip, a change in the intensity of metallic flavour was observed in November, where MA-1 gave a higher intensity, than MA-3 (table 5). Astringency in swede increased when comparing 5 ^{0}C and 10 ^{0}C, but this was only significant in November (table 4). No significant effects on astringency in turnip were observed (data not shown). 10 days of storage increased the intensity of after taste in swede, compared with 5 days, in November and February. Modified atmosphere also affected the after taste of swede, and samples in packages with MA-1 had higher intensity of aftertaste than MA-3. This was seen in both experiments (table 4). Intensity of after taste in turnip increased as an effect of higher temperature, but was only significant in February (table 5).

Changes in the intensity of flavour and taste attributes of swede and turnip were mainly related to storage time and temperature. The cut vegetables lost intensity of sour flavour, green flavour and cellar flavour during 10 days of storage. Green flavour and sour flavour are attributes used to describe the flavour of several vegetables (Bett, 2002). Green flavour (Seljåsen *et al.*, 2004, Kreutzmann *et al.*, 2007) and acidic taste (Seljåsen *et al.*, 2001, Seljåsen *et al.*, 2004) has been described in carrot. Seljåsen *et al.* (2004) found that carrots stored at 10 ^{0}C lost intensity of acidic taste, compared to carrots stored at 2 ^{0}C for 10 days, and acidic taste in carrot decreased due to mechanical stress (Seljåsen *et al.*, 2001).

In the present experiments, there were few significant effects of modified atmospheres on flavour and taste attributes. A modified atmosphere with low O_2 concentration affected sensory attributes in carrots, probably due to initiation of a fermentation process (Seljåsen *et al.*, 2004). This could indicate that fermentation process was initiated for all atmospheres, or the increase of cloying flavour in this experiment is due to other mechanisms during storage.. Reduction in some taste and flavour attributes and increase in others could influence consumers perception of a product containing fresh-cut swede and turnip.

3.3.3 Appearance

Colour evenness decreased during storage for swede (table 6) and turnip (table 7), as a result of longer storage time and higher temperature. This decrease could be related to discolouration due to development of spots on the cut surface. Discolouration of swede has previously been described (Alexander and Francis, 1964b, Cumming and Stark, 1977), and discolouration of peeled and cut turnip has also been observed (Alexander and Francis, 1964c). There was also an effect of MA on colour evenness, as dice in packages that developed MA-3 were more even in colour than dice in packages that developed MA-1, for both swede and turnip. Thus, a lower O_2 concentration seemed to reduce the discolouration, which has also been observed in other studies of cut swede and turnip (Alexander and Francis, 1964b; Alexander and Francis, 1964c). Lower O_2 concentration is known to prevent or delay discolouration in other fresh-cut produce (Smyth *et al.*, 1998). For swede, the increase in hue, affected by longer storage time and higher temperature were only significant in the November experiment, while hue in turnip increased with increasing storage time and temperature in both experiments. Colour intensity of swede decreased as a result of longer storage time and higher temperature, while in turnip colour intensity increased as an effect of increasing storage time and temperature. The observed results for hue and colour intensity indicates different mechanisms behind the observed discolouration for swede and turnip. In addition, MA showed no significant effect on colour intensity of swede, while turnip packed in packages developing MA-1 in November were more intensive in colour, which could strengthen this assumption. Swede samples stored at 5 ^{0}C were whiter than samples stored at 10 ^{0}C, and samples stored for 5 days were whiter than samples stored for 10 days. Dice in packages developing MA-3 were whiter than swede dice in packages with MA-1. For turnip, storage time and temperature also affected whiteness. Increase in time and temperature, decreased the whiteness in turnip. MA-1 gave a lower whiteness score than MA-2 and MA-3 (table 6), but the difference was not significant.

3.3.4 Texture

Hardness in stored swede (table 6) and turnip (table 7) were not affected by the experimental factors, while crispiness in swede and turnip decreased. For swede, 10 days of storage reduced crispiness compared to samples stored for 5 days, and both longer storage time and higher temperature reduced crispiness in turnip. Juiciness in Swede was not affected by time and temperature. However, juiciness in turnip decreased as an effect of higher temperature in both experiments, and longer storage time in November (table 7). In February, fibrousness increased during storage of swede and was affected by time and temperature. This increase was also seen in November, but there was only an effect of modified atmosphere. Also fibrousness in turnip increased during storage, and this was affected by time and temperature in both experiments (table 7). Firmness of carrots has been reported to decrease as an effect of increase in temperature, and suggested to be a result of cellular breakdown (Barry-Ryan *et al.*, 2000).

4. Conclusion

Sensory attributes of cut swede and turnip were mainly affected by storage time and temperature during 10 days of storage. There were minor effects of passive modified atmosphere on odour, flavour and taste attributes. However, modified atmosphere had an effect on appearance, but the tested atmosphere did not prevent discolouration. Shorter storage time and lower temperature seems to be the most important criteria to prevent changes in sensory quality. However, lower oxygen concentration in combination with active modified atmosphere could be tested to further decrease discolouration. The mechanism leading to flavour changes should be further studied, in order to find strategies to diminish such changes. Sensory attributes in this study were objectively described, but there is reason to believe that the observed changes in sensory quality of fresh-cut swede and turnip could influence the commercial use of these vegetables. Changes in sensory quality in both the November and the February experiment were similar showed that three months of long-term storage did not change the raw materials significantly.

5. Acknowledgements

This research was administered by the Research Council of Norway (Project No. 199409) and funded by the Foundation for Research Levy on Agricultural Products and the Agricultural Agreement Research Fund, together with the Norwegian food industry partners Gartnerhallen SA, Bama Gruppen AS, Findus Norge AS, FellesJuice AS, HOFF SA, Graminor AS, NordGrønt, Norgesgrønt, Maarud AS, KiMs Norge AS. Thanks go to Hanne Larsen for theoretical discussions regarding MAP solutions and Aud Espedal for skilful technical assistance.

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Table 1. Sensory attributes describing fresh-cut swede and turnip.

Attribute	Description
Odour	
Sour	Related to a fresh, balanced odour due to the presence of organic acids
Green	Odour of green (i.e. fresh green grass)
Sulphurous	Odour of sulphur
Metallic	Odour of metal (ferrous sulfate)
Cloying	Unfresh and sickeningly sweet odour
Cellar[1]	Odour of cellar, closed-up odour
Earthy	Odour of fresh soil
Pungent	A pungent, burning odour like radish
Taste and flavour	
Sour	Related to a fresh, balanced flavour due to the presence of organic acids
Green	Flavour of green (i.e. fresh green grass)
Earthy	Flavour of fresh soil
Sweet	Related to the basic taste sweet (sucrose)
Bitter	Related to the basic taste bitter (caffeine)
Cellar	Taste of cellar, closed-up flavour
Pungent	A pungent, burning flavour like radish
Sulphurous	Flavour of sulphur
Metallic	Flavour of metal (ferrous sulfate)
Cloying	Unfresh and sickeningly sweet flavour
Aftertaste	Taste which occurs 30 seconds after elimination of the product
Astringency	Organoleptic attribute of pure substances or mixtures which produces the astringent sensation
Appearance	
Hue (swede)	Surface colour evaluated according to NCS-system 1=G80Y (green/yellow) 9=Y30R (yellow/red)
Hue (turnip)	Surface colour evaluated according to NCS-system 1=Y (yellow) 9=Y30R (yellow/red)
Colour intensity	Surface colour evaluated according to NCS-system
Colour evenness	Uniformity in colour assessed on the entire sample
Whiteness	Surface colour evaluated according to NCS-system
Texture	
Fibrousness	Geometrical textural attribute relating to the perception of the shape and the orientation of particles in a product. Long particles, oriented in the same direction, i.e. celery
Crispiness	Easily breakable
Juiciness	Perception of water after 4-5 chews
Hardness	Mechanical textural attribute relating to the force required to achieve a given deformation or penetration of a product

[1] Cellar odour in turnip was not detected by the sensory panel

Table 2. Effect of storage time, temperature and modified atmosphere (MA) on odour (O) attributes of fresh-cut swede from two experiments conducted in November (Nov) and February (Feb).

	Sour-O		Green-O		Sulphurous-O		Metallic-O		Cloying-O		Earthy-O		Pungent-O		Cellar-O	
	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb
5 Days	2.73	2.28	2.20	1.81	3.06	2.73	2.63	2.69	2.16	2.90	1.83	1.50	2.23	2.05	2.27	2.30
10 Days	2.02	1.73	1.66	1.47	3.50	2.46	2.79	2.73	3.10	4.02	1.68	1.37	2.47	2.03	2.97	2.86
	*	*	*	*	*	n.s	n.s	n.s	**	*	n.s	n.s	n.s	n.s	**	**
5 ^{0}C	2.64	2.29	2.16	1.85	3.26	2.54	2.69	2.55	2.25	2.87	1.89	1.49	2.21	1.93	2.30	2.17
10 ^{0}C	2.10	1.72	1.70	1.43	3.30	2.65	2.73	2.86	3.01	4.05	1.62	1.37	2.50	2.15	2.94	3.00
	*	*	**	n.s	n.s	n.s	n.s	*	*	*	*	n.s	n.s	n.s	*	**
MA-1	2.23	1.94	1.83	1.62	3.27	2.50	2.67	2.76	2.70	3.52	1.77	1.41	2.32	2.13	2.76	2.64
MA-2	2.42	1.99	2.02	1.63	3.28	2.63	2.75	2.70	2.69	3.31	1.70	1.46	2.38	2.09	2.66	2.57
MA-3	2.47	2.08	1.94	1.68	3.30	2.66	2.71	2.66	2.50	3.55	1.80	1.43	2.36	1.88	2.44	2.55
	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s

n.s, not significant $p \geq 0.05$, * $p < 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$

Table 3. Effect of storage time, temperature and modified atmosphere (MA) on odour (O) attributes of fresh-cut turnip from two experiments conducted in November (Nov) and February (Feb).

	Sour-O		Green-O		Sulphurous-O		Metallic-O		Cloying-O		Earthy-O		Pungent-O	
	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb
5 Days	2.72	1.98	2.35	1.61	3.30	2.51	2.64	2.20	2.75	2.51	2.16	1.55	2.86	2.01
10 Days	1.69	1.47	1.53	1.32	2.50	1.96	2.30	1.84	3.80	2.98	1.64	1.20	2.10	1.57
	***	**	***	*	*	**	*	*	**	*	***	*	*	*
5 ^{0}C	2.64	2.15	2.28	1.76	3.09	2.56	2.58	2.15	2.85	2.25	2.17	1.56	2.74	2.06
10 ^{0}C	1.77	1.30	1.60	1.18	2.71	1.91	2.36	1.89	3.71	3.24	1.62	1.19	2.22	1.52
	***	***	***	***	*	*	n.s	n.s	***	**	**	**	***	**
MA-1	2.17	1.60	1.90	1.39	2.71	2.07a	2.38	1.86b	3.17	2.67	1.84	1.32	2.34	1.77
MA-2	2.17	1.80	1.86	1.54	3.01	2.32a	2.48	2.01ab	3.31	2.73	1.85	1.41	2.47	1.90
MA-3	2.28	1.77	2.05	1.47	2.98	2.31a	2.55	2.18a	3.35	2.83	1.99	1.39	2.63	1.70
	n.s	n.s	n.s	n.s	n.s	*	n.s	*	n.s	n.s	n.s	n.s	n.s	n.s

n.s, not significant $p \geq 0.05$, * $p < 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$
For the MA part of the table, values within column followed by different letters are significantly different with Tukey`s test (p=0.05).

Table 4. Effect of storage time, temperature and modified atmosphere (MA) on taste (T) and flavour (F) attributes of fresh-cut swede from two experiments conducted in November (Nov) and February (Feb).

	Sour-F		Sweet-T		Bitter-T		Green-F		Earthy-F		Cellar-F		Pungent-F		Sulphurous-F		Cloying-F		Astringency		After-T	
	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb
5 Days	3.47	2.86	3.71	3.16	4.34	4.56	3.39	2.4	2.77	1.93	2.48	2.25	4.04	3.46	4.15	3.66	2.40	2.91	3.12	3.12	5.09	4.97
10 Days	2.60	2.16	3.46	3.03	5.29	5.09	2.40	1.74	2.10	1.64	3.34	3.22	4.67	3.58	4.43	3.56	3.60	3.83	3.66	3.3	5.59	5.37
	**	***	n.s	n.s	*	**	***	**	*	*	**	**	n.s	n.s	n.s	n.s	**	**	n.s	n.s	n.s	**
5 ^{0}C	3.4	2.93	3.76	3.14	4.6	4.57	3.11	2.39	2.56	2.00	2.67	2.34	4.19	3.21	4.12	3.62	2.58	2.95	3.25	2.98	5.10	4.90
10 ^{0}C	2.67	2.10	3.41	3.05	5.03	5.09	2.68	1.75	2.31	1.58	3.15	3.13	4.52	3.83	4.46	3.59	3.42	3.80	3.53	3.44	5.58	5.44
	***	*	**	n.s	*	n.s	*	*	*	**	*	**	n.s	*	n.s	n.s	*	*	*	n.s	**	**
MA-1	2.94	2.40b	3.52	2.99	4.96	5.29a	2.88	2.01	2.36	1.71	3.12	2.90	4.72a	3.74	4.34	3.60	3.10	3.54	3.53	3.37	5.54a	5.42a
MA-2	3.01	2.79a	3.64	3.16	4.79	4.52b	2.89	2.19	2.42	1.89	2.82	2.58	4.33ab	3.28	4.25	3.73	3.04	3.02	3.43	2.91	5.32ab	4.94b
MA-3	3.15	2.35b	3.60	3.14	4.69	4.68ab	2.92	2.01	2.51	1.77	2.79	2.72	4.01b	3.54	4.27	3.5	2.86	3.56	3.21	3.35	5.16b	5.15ab
	n.s	*	n.s	n.s	n.s	*	n.s	n.s	n.s	n.s	n.s	n.s	*	n.s	n.s	n.s	n.s	*	n.s	*	*	*

n.s, not significant $p \geq 0.05$, * $p < 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$
For the MA part of the table, values within column followed by different letters are significantly different with Tukey`s test (p=0.05).

Table 5. Effect of storage time, temperature and modified atmosphere (MA) on taste (T) and flavour (F) attributes of fresh-cut turnip from two experiments conducted in November (Nov) and February (Feb).

	Sour-F		Sweet-T		Bitter-T		Green-F		Cellar-F		Pungent-F		Sulphurous-F		Metallic-F		Cloying-F		After-T	
Treatment	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb
5 Days	3.20	2.48	3.06	2.50	5.69	5.02	3.59	2.35	2.63	2.48	5.26	3.88	4.38	3.78	3.29	3.14	2.64	2.83	5.78	5.20
10 Days	2.31	1.98	2.72	2.33	5.98	5.19	2.83	1.92	3.14	2.88	5.08	4.07	4.37	3.56	3.18	3.17	3.71	3.47	5.78	5.38
	***	***	**	**	n.s	n.s	*	**	*	**	n.s	n.s	n.s	n.s	n.s	n.s	***	**	n.s	n.s
5 ^{0}C	3.19	2.66	3.01	2.55	5.60	5.02	3.54	2.47	2.61	2.29	5.05	3.87	4.29	3.85	3.25	3.15	2.67	2.63	5.63	5.05
10 ^{0}C	2.33	1.80	2.77	2.27	6.07	5.19	2.87	1.80	3.17	3.07	5.29	4.08	4.45	3.49	3.22	3.16	3.67	3.67	5.92	5.53
	***	**	*	*	*	n.s	**	**	**	***	n.s	n.s	n.s	*	n.s	n.s	***	***	n.s	**
MA-1	2.73	2.14	2.84	2.30	6.00	5.22	3.34	2.15	2.93	2.78	5.16	3.97	4.32	3.63	3.33a	3.03	3.18	3.18	5.83	5.27
MA-2	2.74	2.29	2.84	2.48	5.75	5.02	3.11	2.21	2.91	2.64	5.13	4.09	4.40	3.75	3.25ab	3.21	3.23	3.01	5.83	5.32
MA-3	2.79	2.25	2.99	2.46	5.75	5.08	3.17	2.04	2.83	2.62	5.22	3.86	4.40	3.63	3.13b	3.23	3.11	3.26	5.67	5.28
	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	*	n.s	n.s	n.s	n.s	n.s

n.s, not significant $p \geq 0.05$, * $p < 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$
For the MA part of the table, values within column followed by different letters are significantly different with Tukey`s test (p=0.05).

Table 6. Effect of storage time, temperature and modified atmosphere (MA) on appearance and texture attributes of fresh-cut swede from two experiments conducted in November (Nov) and February (Feb).

	Colour evenness		Hue		Colour intensity		Whiteness		Hardness		Crispiness		Juiciness		Fibrousness	
Treatment	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb
5 Days	5.99	5.34	4.99	5.19	4.44	3.78	6.35	5.99	4.85	4.67	4.79	4.66	4.87	4.90	2.35	2.52
10 Days	3.68	3.40	5.44	5.35	4.08	3.37	5.35	4.84	4.79	4.65	4.47	4.56	5.07	4.75	2.61	2.86
	***	***	**	n.s	**	***	***	***	n.s	n.s	n.s	n.s	n.s	n.s	n.s	**
5 ^{0}C	5.50	5.26	5.10	5.18	4.43	3.70	6.08	5.91	4.85	4.72	4.78	4.76	5.04	4.93	2.39	2.51
10 ^{0}C	4.18	3.48	5.33	5.36	4.09	3.46	5.62	4.92	4.80	4.60	4.47	4.47	4.90	4.72	2.57	2.86
	***	***	*	n.s	*	*	**	***	n.s	n.s	**	*	n.s	n.s	n.s	**
MA-1	4.72b	3.96b	5.30	5.24	4.27	3.48	5.70b	5.12b	4.84	4.78	4.66	4.77	4.97	4.83	2.66a	2.71
MA-2	4.61b	4.56a	5.09	5.23	4.17	3.58	5.81b	5.32b	4.82	4.59	4.53	4.61	4.93	4.93	2.44ab	2.52
MA-3	5.18a	4.59a	5.25	5.34	4.34	3.67	6.05a	5.81a	4.81	4.61	4.70	4.45	5.00	4.72	2.34b	2.84
	**	***	n.s	n.s	n.s	n.s	**	***	n.s	n.s	n.s	n.s	n.s	n.s	*	n.s

n.s, not significant $p \geq 0.05$, * $p < 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$
For the MA part of the table, values within column followed by different letters are significantly different with Tukey`s test ($p=0.05$).

Table 7. Effect of storage time, temperature and modified atmosphere (MA) on appearance and texture attributes of fresh-cut turnip from two experiments conducted in November (Nov) and February (Feb).

	Colour evenness		Hue		Colour intensity		Whiteness		Hardness		Crispiness		Juiciness		Fibrousness	
Treatment	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov	Feb
5 Days	6.15	5.68	3.44	3.51	2.44	2.52	6.92	6.76	4.25	3.99	5.49	5.22	5.65	5.32	2.28	2.29
10 Days	4.35	4.35	5.06	4.50	3.14	3.12	5.95	5.92	4.29	4.14	5.24	4.90	5.50	4.99	2.63	2.48
	***	***	***	***	***	***	***	***	n.s	n.s	*	**	n.s	**	*	***
5 ^{0}C	5.92	6.23	3.52	3.11	2.45	2.33	6.90	7.13	4.20	4.05	5.55	5.22	5.72	5.31	2.26	2.27
10 ^{0}C	4.58	3.79	4.97	4.90	3.13	3.32	5.98	5.55	4.34	4.08	5.17	4.90	5.43	5.00	2.66	2.51
	***	***	***	***	***	***	***	***	n.s	n.s	***	**	**	**	**	*
MA-1	5.01b	4.80b	4.34	4.08	2.92a	2.84	6.31a	6.28	4.34	4.12	5.22	4.92b	5.44	5.02	2.63	2.47
MA-2	5.35a	5.20a	4.17	3.89	2.71b	2.75	6.50a	6.43	4.30	3.99	5.42	5.09ab	5.65	5.26	2.43	2.38
MA-3	5.38a	5.03a	4.23	4.04	2.74b	2.87	6.50a	6.31	4.17	4.07	5.44	5.17a	5.64	5.19	2.33	2.31
	***	***	n.s	n.s	**	n.s	*	n.s	n.s	n.s	n.s	*	n.s	n.s	n.s	n.s

n.s, not significant $p \geq 0.05$, * $p < 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$
For the MA part of the table, values within column followed by different letters are significantly different with Tukey`s test (p=0.05).

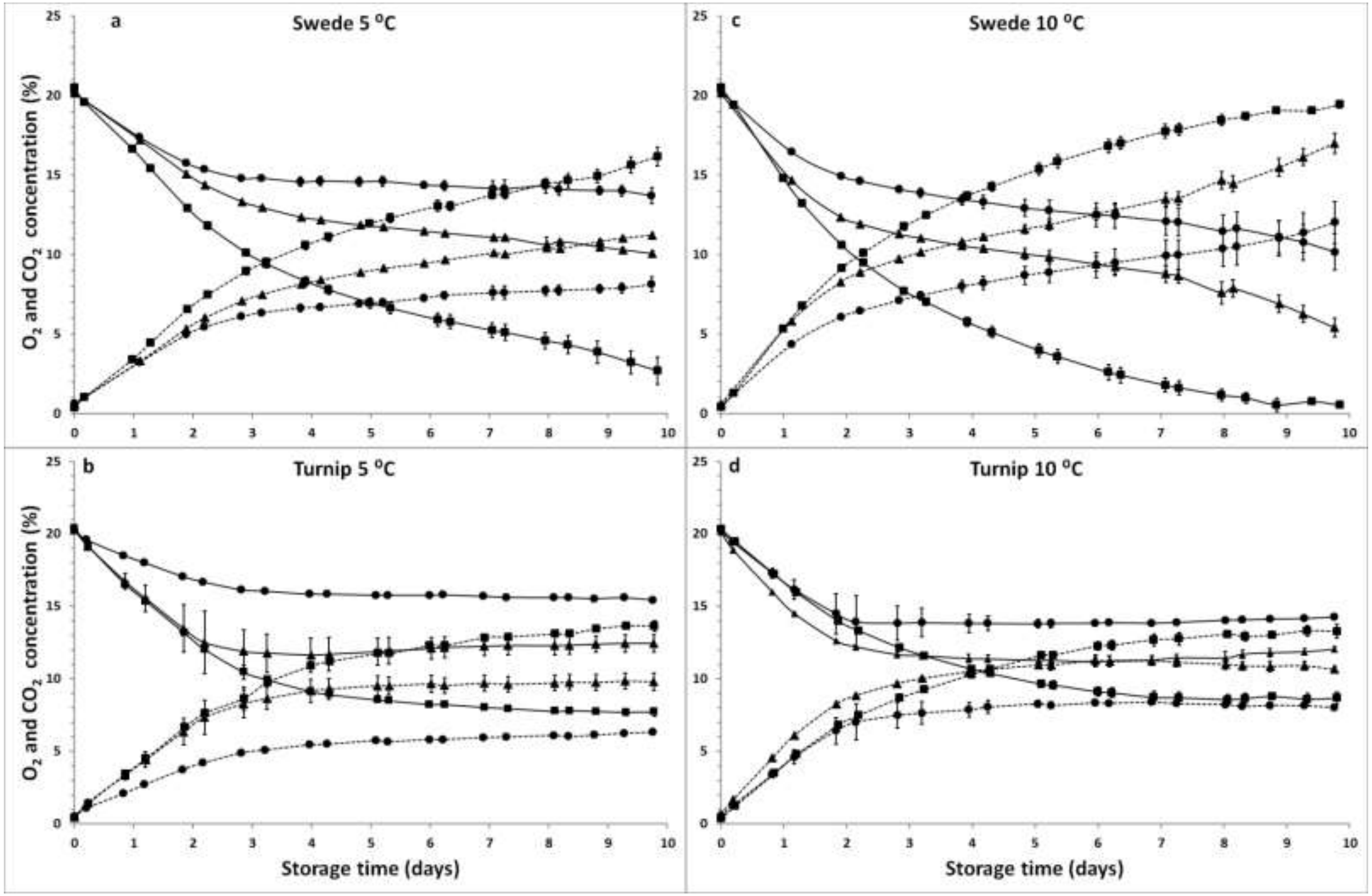

Fig. 1 O_2 (——) and CO_2 (------) concentrations in packages (n=5) of diced swede and turnip in November, stored at 5 ⁰C and 10 ⁰C. Atmosphere developments, MA-1 (●), MA-2 (▲) and MA-3 (■), is a result of film, product weight and perforation(s) at given temperature (see materials and methods).

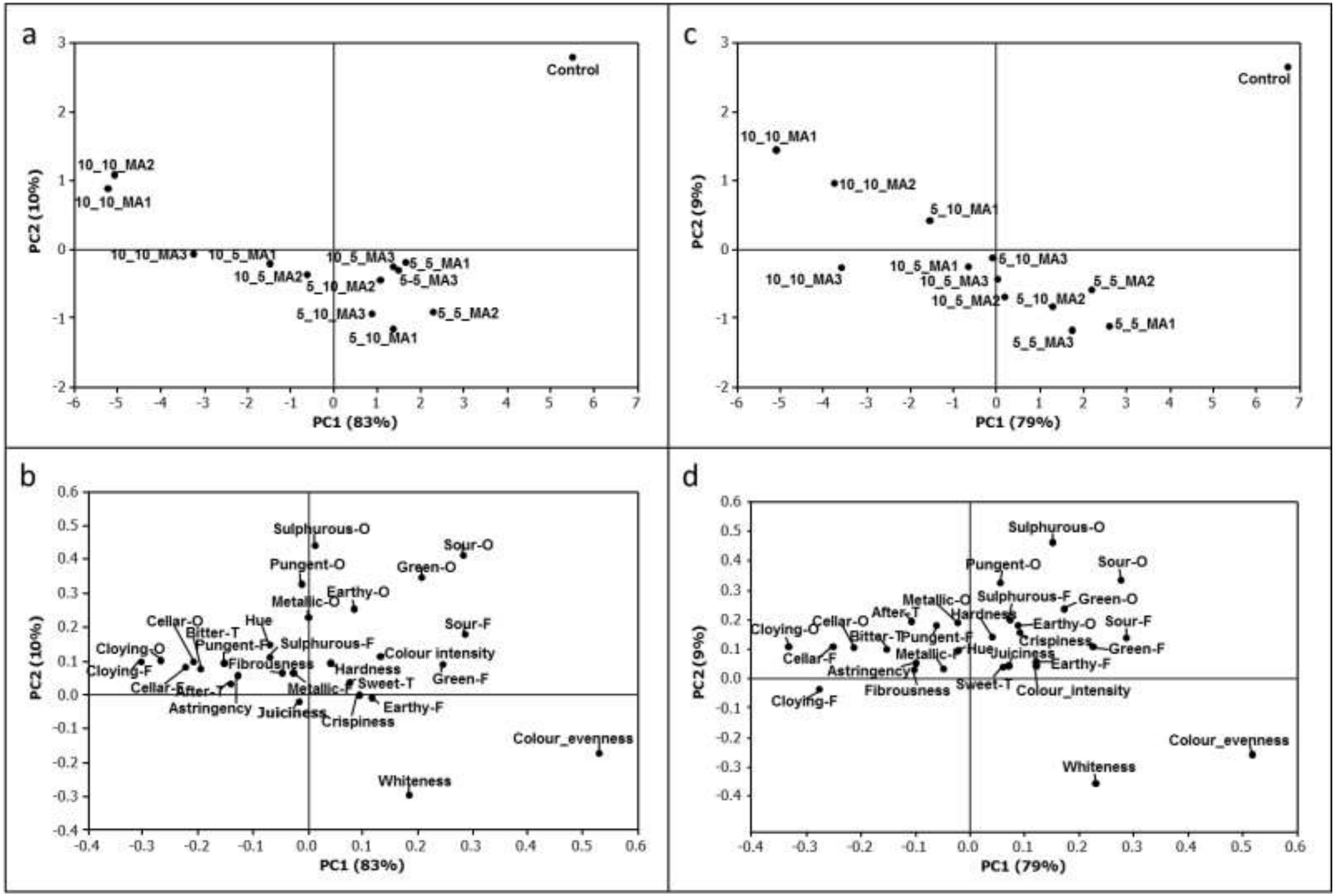

Fig. 2 Results from PCA on sensory data of fresh-cut turnip from experiments in November (left) and February (right). Samples were stored for 5 and 10 days (first number in sample name), 5 ^{0}C and 10 ^{0}C (second number in sample name), and at 3 different modified atmospheres (MA1, MA2 and MA3). Control sample was prepared the same day as the sensory analysis was carried out. The loading plots (b and d) show taste (T), flavour (F), texture and appearance attributes used to describe the different samples in the score plots (a and c).

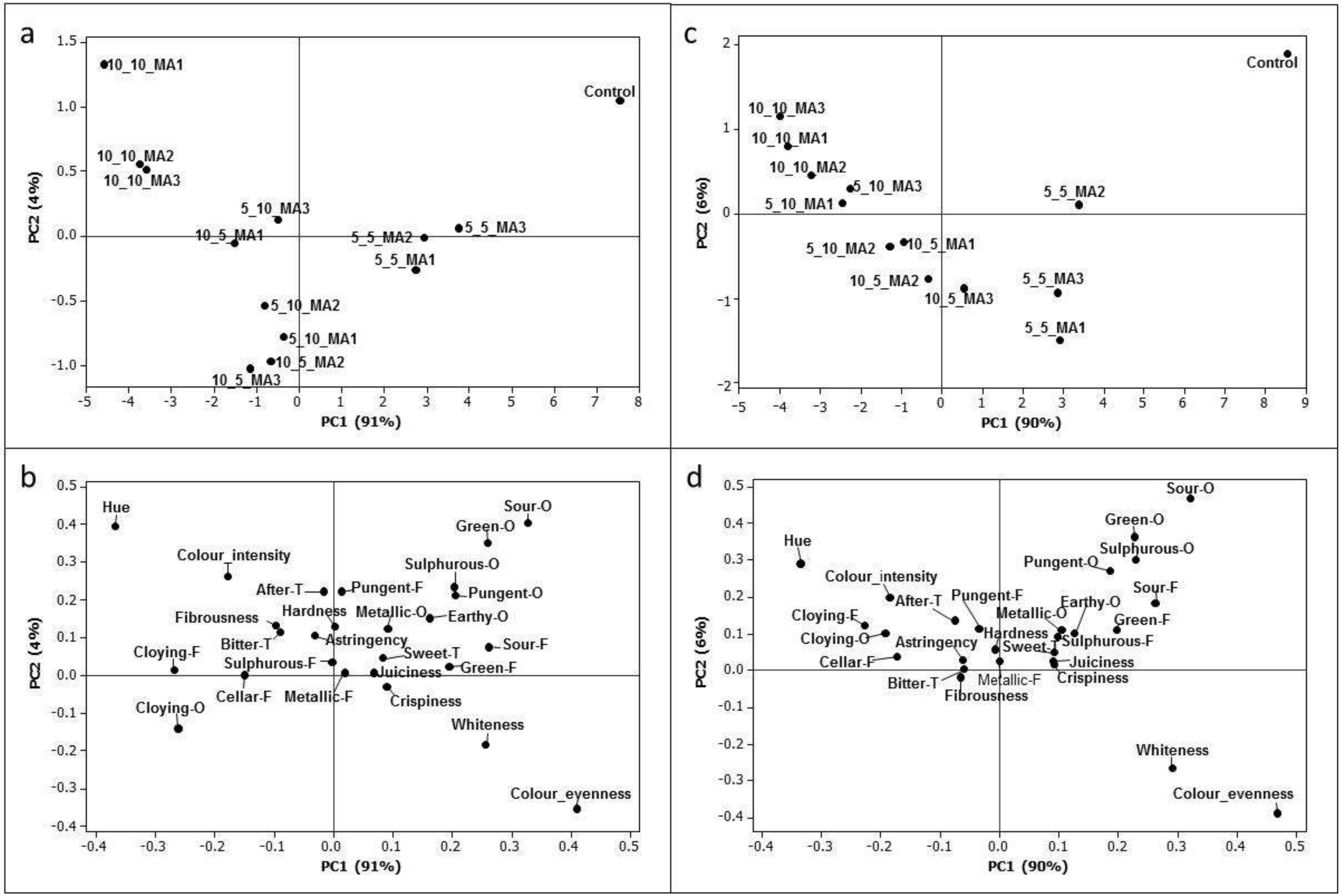

Fig. 3 Results from PCA on sensory data of fresh-cut turnip from experiments in November (left) and February (right). Samples were stored for 5 and 10 days (first number in sample name), 5 ^{0}C and 10 ^{0}C (second number in sample name), and at 3 different modified atmospheres (MA1, MA2 and MA3). Control sample was prepared the same day as the sensory analysis was carried out. The loading plots (b and d) show taste (T), flavour (F), texture and appearance attributes used to describe the different samples in the score plots (a and c).

Paper II

Storage of fresh-cut swede and turnip in modified atmosphere: effects on vitamin C, sugars, glucosinolates and sensory attributes

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Abstract

Fresh-cut swede (*Brassica napus* L. var. *napobrassica* (L.) Rchb.) and turnip (*Brassica rapa* L. ssp. *rapifera* Metzg.) in modified atmosphere packaging (MAP) were stored for 5 or 10 days, at 5 ^{0}C or 10 ^{0}C. Two passive and one active modified atmosphere, with initially 5% O_2 were tested. Vitamin C content was not influenced by the experimental parameters. The content of total sugar decreased during storage for both vegetables, and significant effects of time, temperature and atmosphere were observed for glucose, fructose and sucrose. Total aliphatic and indolic glucosinolates increased in swede during storage, while for turnip total aliphatic glucosinolates decreased and total indolic glucosinolates increased. Atmosphere composition affected glucosinolates, and the response varied between individual glucosinolates. Taste and flavour were more influenced by time and temperature, than by atmosphere in both vegetables. However, modified atmosphere with low O_2 concentration reduced discolouration related changes, especially for turnip. Positive correlation was observed between sugar content and sweet taste for both vegetables. Sweet and bitter tastes were negatively correlated for swede. Low temperature and short storage time were the most important criteria to prevent changes of appearance, odours, taste and flavours, and contents of sugar and glucosinolates of fresh-cut swede and turnip.

Keywords

Swede, Turnip, Fresh-cut, Modified Atmosphere, Packaging, Root Vegetables

1. Introduction

Vegetables are an important part of a healthy diet, and consumption might increase by introducing more vegetables as fresh-cut products (WHO, 2005). Swede (*Brassica napus* L. var. *napobrassica* (L.) Rchb.) and turnip (*Brassica rapa* L. ssp. *rapifera* Metzg.) are root vegetables suggested to be used in convenient food products (Olsson and Gustavsson, 2009). Both are good sources of vitamin C (Baardseth et al., 2010; Shattuck et al., 1991b) as well as glucosinolates (Carlson et al., 1981), which have gained attention due to their possible health beneficial effects (Jahangir et al., 2009).

Physiological changes in vegetables after peeling and cutting can influence both sensory and nutritional quality (Barrett et al., 2010), and understanding how post-cutting handling affects fresh-cut vegetables can help to reduce unwanted changes (Toivonen and DeEll, 2002). Changes in appearance during storage have been found for cut swede and turnip (Alexander and Francis, 1964a, b), and an increased respiration rate as a response to degree of cutting has been observed for swede (Zhu et al., 2001). In addition, change in glucosinolate and sugar contents during storage of whole swede (Shattuck et al., 1991a) and turnip (Shattuck et al., 1991b) has been observed. Moreover, glucosinolates and sugar also influence vegetable flavour (Beaulieu and Baldwin, 2002), and changes in content of these compounds might influence sensory attributes.

Modified atmosphere packaging (MAP), has been used to decrease respiration rate and slow senescence of fresh produce (Al-Ati and Hotchkiss, 2002). Atmospheres achieved using passive MAP are often predetermined for specified values of temperature, produce weight and package permeability (Al-Ati and Hotchkiss, 2002; Beaudry et al., 1992). Typically, the concentration of O_2 is decreased and that of CO_2 increased. When active MAP is used, composition of the initial atmosphere is not air but a predefined atmosphere.

The aim of the present study was to investigate the influence of storage time, temperature and modified atmosphere on sensory attributes and content of individual sugars, glucosinolates and vitamin C in fresh-cut swede and turnip.

2. Materials and methods

2.1 Plant material

Swede (*Brassica napus* L. var. *napobrassica* (L.) Rchb. cv. Vigod) and turnip (*Brassica rapa* L. ssp. *rapifera* Metzg., cv. Solanepe) were provided from local growers in the Oslofjord-area and south western part of Norway, respectively. Turnip was transported to Ås in a refrigerated truck holding 4 ^{0}C. Both vegetables (approximately 100 Kg) were harvested in September and stored in perforated plastic bags at 0-1 ^{0}C.

2.2 Processing

After washing in cold tap water, swede and turnip were peeled by hand using a sharp stainless steel knife, or a potato peeler (Victorinox, Ibach-Schwyz, Switzerland), respectively. For both vegetables 15 Kg of peeled commodity was prepared. The roots were washed again, and cut in 10 mm cubes using a cutting machine (KUJ V, Kronen GmbH, Kehl am Rhein, Germany). The cubes were washed in cold tap water, followed by immersion in tap water mixed with crushed ice for 1 minute, to cool the vegetables before packaging. The vegetables were spin-dried using a vegetable centrifuge for 30 seconds at 1000 rpm (Eillert, Machinefabriek Eillert B. V., Ulft, Netherlands).

2.3 Packaging

2.3.1 Packaging material

Diced vegetables were packaged in 1100 mL high density polyethylene (HDPE) trays (Promens AS, Kristiansand, Norway). A film with ethylene vinyl alcohol (EVOH) as barrier layer (Wipak Oy, Nastola, Finland), or a 40 μm polyethylene film (52LD) with four laser perforations per package (Amcor Flexible, Ledbury, UK) were sealed to the trays, using a Polimoon 511VG tray sealing machine (Promens AS). For active MAP, a mix of 5% O_2 and 95% N_2 (AGA Gas AB, Enköping, Sweden) was flushed into the packages.

2.3.2 Modified atmospheres

To create passive modified atmosphere (MA) during storage, a combination of package permeabilities and product weights were used (Beaudry et al., 1992; Gong and Corey, 1994; Vallejo and Beaudry, 2010). To obtain different package permeabilities, the EVOH film was perforated with 1, 2 or 3 holes using a 0.22 mm acupuncture needle. In addition, a laser perforated film was included, since laser perforations have a lower gas transmission rate than acupuncture holes, due to smaller orifice area (Larsen and Liland, 2013). Three of the perforations of the 52LD laser perforated film were covered with a rubber septum to obtain only one hole (Larsen and Liland, 2013).

The following combinations of film type, number of perforations and product weight (g) were used for swede stored at 5 ^{0}C: **MA-1 (**EVOH- 2-150) and **MA-2** (52LD-2-200), and at 10 ^{0}C: **MA-1** (EVOH-2-100) and **MA-2** (52LD-1-150).

The following combinations were used to create modified atmospheres for turnip stored at 5 ^{0}C: **MA-1** (EVOH-2-100) and **MA-2**: (EVOH-1-200), and at 10 ^{0}C: **MA-1**: (EVOH-3-100) and **MA-2** (EVOH-1-100).

For active MAP (**MA-5%**), the same combinations as for MA-2 at the respective temperatures, were used. Seven packages of every combination were prepared.

2.3.3 O_2 and CO_2 measurements

O_2 and CO_2 concentrations were measured twice a day during storage using a CheckMate-II O_2/CO_2 -analyser (PBI-Dansensor, Ringsted, Denmark). The atmosphere samples were collected through a self-adhesive rubber septum placed on the film.

2.4 Samples for sensory and chemical analyses

For all samples the same batch of each vegetable was used. To evaluate samples stored for 5 and 10 days at the same time, processing and packaging was done 5 and 10 days before the sensory evaluation, respectively. On the day of sensory analysis, the dice from the seven packages of each of the 12 treatments were mixed and 200 g from each treatment were used for chemical analysis and the rest for sensory analysis. On the same day, a control sample was prepared in the same way as the stored samples. Material for chemical analyses from each treatment was split into four portions, frozen in liquid nitrogen and stored at -80 ^{0}C. Frozen material was ground using a Krups 708A food processor and used for vitamin C analysis. For sugar and glucosinolate analyses, the ground, frozen material was freeze dried, and further ground using a Retsch ZM100 mill (Retsch GmbH & Co., Haan, Germany), and stored at -40 ^{o}C in tight containers.

2.5 Vitamin C

Vitamin C was determined by analysing L-ascorbic acid (AA) and L-dehydroascorbic acid (DHA) according to the method described by Steindal et al. (2013), with minor modifications. Five grams of frozen sample were weighed into freeze-cold tubes, and 10 mL of ice-cold 6% metaphosphoric acid with 2 mM EDTA was added before stirring and homogenization, without adding distilled water. Vitamin C content is defined as the sum of the contents of AA and DHA.

2.6 Soluble sugars

Sugars were analysed using an adjusted method described by Elmore et al. (2007). Freeze dried samples (50 mg) were weighed into 15 mL tubes. An internal standard (500 μL, 10 mg L^{-1} trehalose) was added followed by 10 mL 50% (v/v) methanol, before shaking for 15 minutes. After 15 minutes of settling, 1.5 ml of the supernatant was centrifuged (IEC Centra-M2 Centrifuge, Heigar, Oslo, Norway) at 15600 g for 15 min. 50 μL of the supernatant was diluted with 1450 μL 50 % (v/v) methanol and filtered through a 0.22 μm filter (Millex-GV (PVDF), Merck Millipore Ltd., Tullagreen, Ireland). Extracts were analysed with a Thermo Scientific Dionex ICS 5000 ion chromatography system, using Chromeleon software (Thermo Fisher Scientific Inc., Sunnyvale, California). Injection volume was 20 μL, with a gradient program: 50% 200mM NaOH (solvent A) and 50% water, with flow rate of 1 mL min^{-1} for 20 min. The column was washed for 5 min with 500 mM sodium acetate in 100 mM NaOH and re-equilibrated with 50% solvent A for 5 min. External standards of glucose, fructose and sucrose were used for quantification, and values are given in g/100 g dry matter (DM).

2.7 Glucosinolates

Glucosinolates were analysed according to ISO 9167-1:1992(E) with some modifications. Approximately 0.200 g material was mixed with 4.50 mL of preheated (73 ^{0}C) 70% methanol (v/v), and incubated at 73 ^{0}C for 3 min. Glucotropaeolin (100 µl, 1 mg mL^{-1}) was added as internal standard. The samples were left on ice for 10 min before centrifugation at 5346 g (Heraeus Multifuge 4KR, Thermo Scientific, Osterode, Germany) for 15 min at 4 ^{0}C. The pellet was re-suspended with 70% methanol, left on ice for 10 min, and centrifuged. The two supernatants were combined. Thirty mg of glass wool was packed In a 1 mL syringe. After rinsing with 0.5 mL water, 0.5 mL DEAE Sephadex A25 suspension was added, and rinsed (0.5 mL water) before 1 mL of sample was added, and left to drain. One ml of water was added before pH was adjusted by addition of 1 mL of sodium acetate buffer (pH 5). All liquid was drained, and 75 µL sulphatase was added, and left overnight. Desulfated glucosinolates were eluted by adding 1.25 mL water. The eluate was filtered (0.45 µm Millex PVDF filter), and analysed by HPLC-DAD (Agilent HP 1100 Series) on a Spherisorb 5µm ODS2 (4.6 x 250 mm) column (Waters Corporation, Milford, MA, USA). Ultra-pure water (A) and 20% acetonitrile (B) were used as mobile phase. Flow was set to 1.5 mL min^{-1} at 30 ^{0}C, and detection at 227 nm. The injection volume was 30 µL. Gradient programme: 0-1 min, 1% B; 1-21 min, 1-99% B; 21-24 min, 99% B; 24-29 min, 99-1% B; 29-39 min, 1% B. Identification was done by comparing retention time and UV spectra with desulfated standards for progoitrin, glucoraphanin, gluconapin, gluconasturtiin, or tentatively identified by comparing retention time and UV-spectra for glucosinolates in swede, previously identified by mass using LC-MS ion-trap. Quantification of desulfo-glucosinolates was based on response factor, and calculated as µmol g^{-1} DM.

2.8 Sensory analysis

Quantitative descriptive sensory analysis was performed according to ISO 13299:2003(E) by a trained sensory panel of 10 persons at Nofima (Ås, Norway). The assessors were selected and trained according to ISO 8586-1:1993(E), and the analysis was performed according to ISO 8589:1988(E). The sensory panel was calibrated, using the control sample and a sample stored for 10 days at 10 ^{o}C in MA-1. The assessors agreed on sensory attributes to describe raw swede and turnip during a training session (Table 1). Room thermo-stated vegetables (25 g) from each treatment and control sample were served in plastic trays with lids and a three-digit code. Each sample was served twice. The panellists recorded their results at individual speed on a 15 cm non-structured continuous scale. The data registration system (Eye Question, v. 3.8.6, Logic 8, The Nederland) transformed the responses from 0 – 15 cm on the screen to numbers from 1.0 (low intensity) to 9.0 (high intensity). Due to the number of samples, the sensory evaluation had to be performed during two subsequent days. Which samples to be analysed on which day were chosen randomly before the experiment was started.

2.9 Statistical analysis

Analysis of variance (ANOVA) was used on chemical results, using general linear model in R 3.0.3 (R Core Team, 2014). Sensory data were analysed using a general linear model (Proc GLM) in SAS 9.3 (SAS Institute, Inc., Cary, NC, USA). Effect of assessor was set as random and statistical significant level was set to $p = 0.05$. Tukey`s HSD test was used for multiple comparisons. For the relationship between sensory attributes and chemical measurement a partial least square regression (PLSR) was applied (Martens and Martens, 2001), using The Unscrambler X v. 10.2 (CAMO Software AS, Oslo, Norway). For PLSR, sensory (Y) and chemical (X) data were centred and standardised.

Table 1 Sensory attributes describing swede (R) and turnip (T)

Attribute	Description
Odour	
Sour	Related to a fresh, balanced odour due to the presence of organic acids
Green	Odour of green (i.e. fresh green grass)
Sulphurous	Odour of sulphur
Metallic	Odour of metal (ferrous sulfate)
Cloying	Unfresh and sickeningly sweet odour
Cellar[1]	Odour of cellar, closed-up odour
Earthy	Odour of fresh soil
Pungent	A pungent, burning odour like radish
Taste and flavour	
Sour	Related to a fresh, balanced flavour due to the presence of organic acids
Green	Flavour of green (i.e. fresh green grass)
Earthy	Flavour of fresh soil
Sweet	Related to the basic taste sweet (sucrose)
Bitter	Related to the basic taste bitter (caffeine)
Cellar	Flavour of cellar, closed-up flavour
Pungent	A pungent, burning flavour like radish
Sulphurous	Flavour of sulphur
Metallic	Flavour of metal (ferrous sulfate)
Cloying	Unfresh and sickeningly sweet flavour
After taste	Taste which occurs 30 seconds after elimination of the product
Astringency	Organoleptic attribute of pure substances or mixtures which produces the astringent sensation
Appearance	
Hue (swede)	Surface colour evaluated according to NCS-system 1=G80Y (green/yellow) 9=Y30R (yellow/red)
Hue (turnip)	Surface colour evaluated according to NCS-system 1=Y (yellow) 9=Y30R (yellow/red)
Colour intensity	Surface colour evaluated according to NCS-system
Colour evenness	Uniformity in colour assessed on the entire sample
Whiteness	Surface colour evaluated according to NCS-system
Texture	
Fibrousness	Geometrical textural attribute relating to the perception of the shape and the orientation of particles in a product. Long particles, oriented in the same direction, i.e. celery
Crispiness	Easily breakable
Juiciness	Perception of water after 4-5 chews
Hardness	Mechanical textural attribute relating to the force required to achieve a given deformation or penetration of a product

[1] Cellar odour in turnip was not detected by the sensory panel

3. Results and discussion

3.1 Atmosphere development

MA-1 developed the highest O_2 concentration and the lowest CO_2 concentration for both vegetables (Fig. 1). MA-2 and MA-5% reached similar O_2 levels after 10 days of storage. Identical combination of film properties and vegetable amount to obtain MA-2 and MA-5% can explain the similar O_2 concentrations (Fig. 1). For swede, MA-2 developed a higher CO_2 level than MA-5%, while for turnip MA-2 and MA-5% gave similar CO_2 developments. This indicates that the CO_2 production was identical for turnip when either air or 5% O_2 was used as initial atmosphere, while for swede an initial atmosphere of 5% O_2 reduced respiration, as was also found by Zhu et al. (2001).

3.2 Vitamin C

The vitamin C level in swede and turnip was neither affected by storage time, temperature nor modified atmosphere (Table 2). Similar findings for ascorbic acid content of sliced radish have been reported (del Aguila et al., 2006). However, a higher vitamin C content than found in the present study has been reported for swede (Baardseth et al., 2010; Puupponen-Pimiä et al., 2003) and turnip (Azam et al., 2013; Shattuck et al., 1991b). This might be due to various vitamin C contents in different cultivars (Olsson and Gustavsson, 2009) or vitamin C loss during processing (Lee and Kader, 2000).

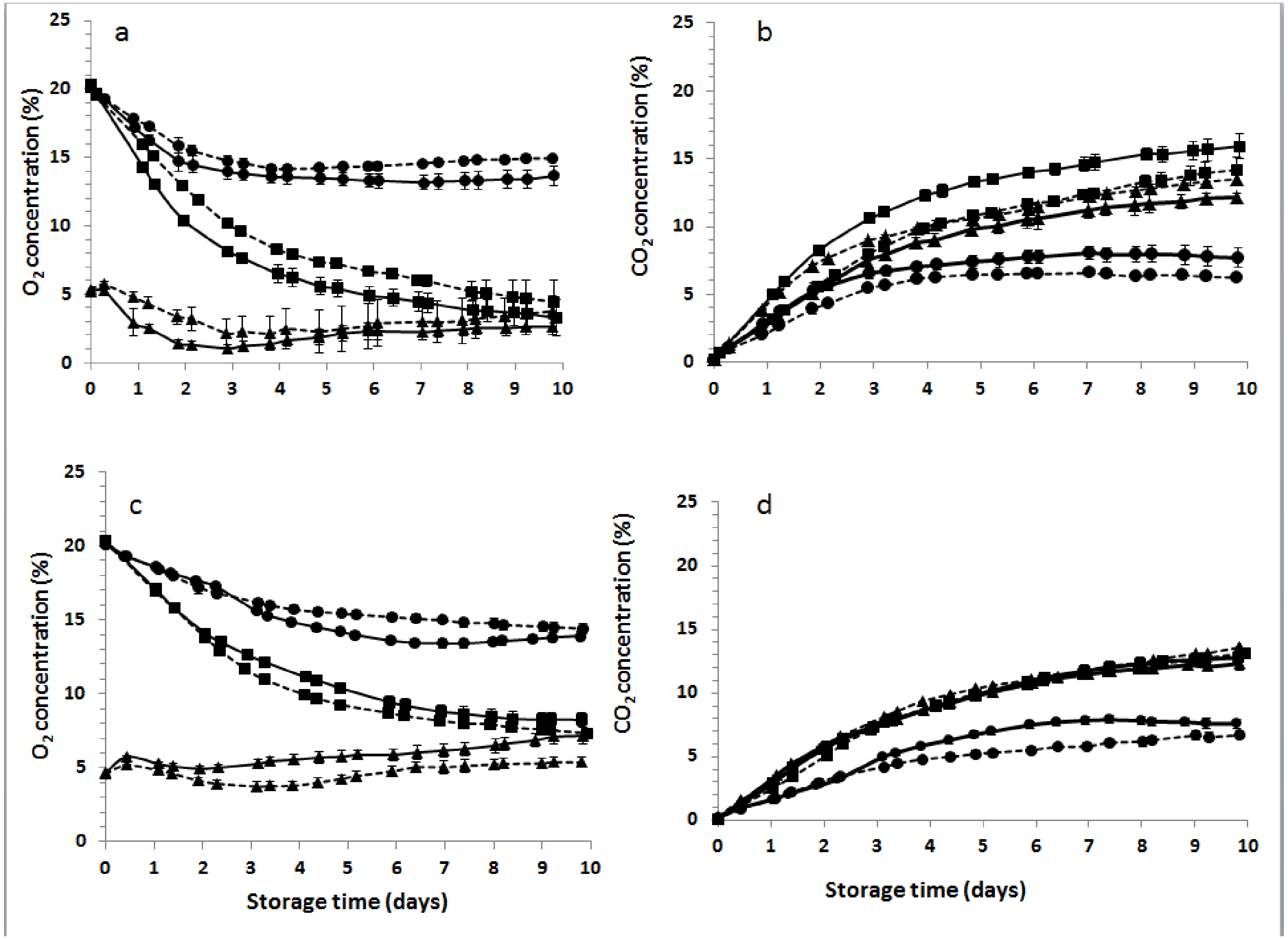

Fig. 1 O_2 and CO_2 developments in packages containing swede (a and b) or turnip (c and d) stored at 5 °C (----) and 10 °C (——). Passive modified atmosphere developments, MA-1 (●) and MA-2 (■), results from combinations of product weight and perforations at given temperatures. Active modified atmosphere, MA-5% (▲)was created at given temperatures using 5% O_2 as initial atmosphere, combined with packaging conditions as used for MA-2.

Table 2 Effects of storage time, temperature and modified atmosphere on vitamin C and sugars in fresh-cut swede and turnip (n=4).

	Vitamin C (mg 100g^{-1} FM)	Glucose (g 100g^{-1} DM)	Fructose (g 100g^{-1} DM)	Sucrose (g 100g^{-1} DM)	Total sugars (g 100g^{-1} DM)
Swede					
5 Days	18.53	35.09	23.29	1.77	60.15
10 Days	18.13	34.73	23.25	1.36	59.34
P	**n.s**	**n.s**	**n.s**	***	*
5 °C	18.56	35.06	23.51	1.60	60.18
10 °C	18.10	34.76	23.03	1.52	59.31
P	**n.s**	**n.s**	**	**n.s**	*
MA-1	17.80	34.12b	23.00b	1.56	58.67b
MA-2	18.78	36.02a	23.43a	1.54	60.99a
MA-5%	18.41	34.60b	23.38ab	1.59	59.57b
P	**n.s**	***	*	**n.s**	***
Control (±SD)	17.16±1.47	34.64±0.53	23.79±0.32	3.20±0.16	61.62±0.70
Turnip					
5 Days	10.88	33.26	20.59	3.23	57.07
10 Days	10.84	33.32	20.24	2.51	56.07
p	**n.s**	**n.s**	*	***	***
5 °C	10.95	33.58	20.57	3.07	57.22
10 °C	10.77	33.00	20.26	2.67	55.92
p	**n.s**	**	*	***	***
MA-1	10.89	33.16	20.06b	2.76	55.98b
MA-2	10.47	33.44	20.59a	2.81	56.84a
MA-5%	11.22	33.27	20.59a	3.03	56.90a
p	**n.s**	**n.s**	**	**n.s**	*
Control (±SD)	10.63±0.27	32.41±0.77	19.33±0.76	6.55±0.56	58.29±0.86

n.s, not significant $p \geq 0.05$, * $p < 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$

For the MA part of the table, values within column followed by different letters are significantly different with Tukey`s test (p=0.05).

3.3 Sugars

Storage time, temperature and atmosphere had a significant effect on total sugar content in both swede and turnip, although the changes were only 1-4 % (Table 2). Swede and turnip stored for 10 days or at 10 ^{0}C contained less total sugar compared with storage for 5 days or at 5 ^{0}C. The decrease in total sugar during storage at 10 ^{0}C was probably due to increased respiration. This has been shown for shredded cabbage, in which total sugar decreased during storage at 5 ^{0}C and especially 20 ^{0}C, due to increased respiration rate (Nei et al., 2006). In contrast to cut swede, sugar content in whole swede stored at 0 ^{0}C or 10 ^{0}C, increased during 2 weeks of storage (Shattuck et al., 1991a). For whole turnip, total sugar decreased during 2 weeks of storage at 0 ^{0}C (Shattuck et al., 1991b). The different behaviour between cut and whole swede could be due to increased respiration in fresh-cut swede as a response to cutting (Zhu et al., 2001).

Cleavage of sucrose to fructose and glucose during storage might explain the decrease of sucrose in swede and turnip (Table 2), as reported for cut kohlrabi (Escalona et al., 2003; Escalona et al., 2006). Longer storage time reduced sucrose content in both swede and turnip, while higher temperature gave significant lower sucrose content in turnip. A decomposition of sucrose would be expected to increase levels of glucose and fructose. However, at the same time, glucose and fructose are substrates for sugar metabolism in plants (Halford et al., 2011), which could explain a decrease, rather than increase in glucose and fructose.

Total sugar contents in swede and turnip were significantly affected by atmosphere composition (Table 2). Swede from MA-2 had higher total sugar content than samples from MA-1 and MA-5%. The higher total sugar content was mainly due to higher glucose content. Fructose content in swede was higher for MA-2 than MA-1, but not significantly different from MA-5%. For turnip, MA-2 and MA-5% gave higher total sugar content than MA-1. This could be explained by reduced respiration rate due to low O_2 level or elevated CO_2 concentration (Zhu et al., 2002). Similarly to swede, glucose and fructose in turnip differed in response to atmosphere. Different behaviour of glucose and fructose in asparagus during storage has also been observed (Irving and Hurst, 1993). The results indicate that glucose, fructose and sucrose, respond differently to storage time, temperature and atmosphere composition in swede and turnip.

3.4 Glucosinolates

Aliphatic glucosinolates identified in both fresh-cut swede (Table 3) and turnip (Table 4) are progoitrin, glucoerucin and glucobrassicanapin. In addition, swede contained glucoberteroin, gluconapoleiferin and glucoalyssin, while turnip contained gluconapin. Indolic glucosinolates in swede and turnip were glucobrassicin, 4-hydroxyglucobrassicin, 4-methoxyglucobrassicin and neoglucobrassicin. The aromatic glucosinolate gluconasturtiin was detected in turnip, whereas no aromatic glucosinolates were found in swede. These findings are to a large extent in accordance with glucosinolate profiles previously reported for whole swede (Birch et al., 1992; Carlson et al., 1981; Sang et al., 1984; Shattuck et al., 1991a) and turnip (Aires et al., 2012; Li et al., 2007; Zhang et al., 2008), but deviations can be explained by differences between cultivars and possibly also by differences in analytical methods . Glucoberteroin (5-(methylthio)pentyl glucosinolate) has been identified in both swede and turnip by its volatile hydrolysis product (Carlson et al. 1981). In turnip tubers, recent analytical methods have quantified both gluconasturtiin and glucoberteroin, which have very similar retention times in HPLC analysis. (Lee et al. 2013).

Table 3 Effects of storage time, temperature and modified atmospheres on glucosinolates (GLS) in fresh-cut swede. Values are given in µmol g^{-1} DM (n=4).

	Aliphatic GLS							Indolic GLS					Total GLS
	Progoitrin	Glucoerucin	Glucobrassicanapin	Glucoberteroin	Gluconapoleiferin	Glucoalyssin	Total aliphatic GLS	Glucobrassicin	4-Hydroxyglucobrassicin	4-Methoxyglucobrassicin	Neoglucobrassicin	Total indolic GLS	
5 Days	6.17	0.67	0.30	1.96	0.67	0.41	10.18	1.03	0.77	0.42	0.25	2.47	12.66
10 Days	6.90	0.71	0.34	2.17	0.74	0.43	11.28	1.33	0.75	0.57	0.27	2.92	14.20
p	***	**n.s**	***	***	***	**n.s**	***	***	**n.s**	***	*	***	***
5 °C	6.60	0.70	0.34	2.07	0.70	0.43	10.83	0.98	0.81	0.43	0.25	2.47	13.30
10 °C	6.47	0.68	0.30	2.06	0.70	0.41	10.63	1.38	0.71	0.56	0.27	2.92	13.56
p	**n.s**	**n.s**	***	**n.s**	**n.s**	**n.s**	**n.s**	***	*	***	*	***	**n.s**
MA-1	6.42	0.66	0.30b	2.01	0.71	0.42	10.52	1.32a	0.77	0.49	0.27a	2.84a	13.36
MA-2	6.70	0.70	0.33a	2.07	0.70	0.40	11.03	1.25a	0.80	0.50	0.23b	2.78a	13.67
MA-5%	6.49	0.71	0.33ab	2.12	0.71	0.43	10.89	0.97b	0.71	0.50	0.28a	2.47b	13.25
p	**n.s**	**n.s**	*	**n.s**	**n.s**	**n.s**	**n.s**	***	**n.s**	**n.s**	**	**	**n.s**
Control	6.69	0.71	0.34	2.31	0.82	0.40	11.39	0.33	1.13	0.34	0.36	2.16	13.55
(±SD)	±0.53	±0.08	±0.02	±0.24	±0.06	±0.04	±0.88	±0.06	±0.19	±0.03	±0.06	±0.30	±1.17

n.s, not significant $p \geq 0.05$, * $p < 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$

For the MA part of the table, values within column followed by different letters are significantly different with Tukey`s test (p=0.05).

Table 4 Effects of storage time, temperature and modified atmosphere on glucosinolates (GLS) in fresh-cut turnip. Values are given in µmol g^{-1} DM (n=4).

	Aliphatic GLS					Indolic GLS					Aromatic GLS	Total GLS
	Progoitrin	Glucoerucin	Glucobrassicanapin	Gluconapin	Total Aliphatic GLS	Glucobrassicin	4-Hydroxyglucobrassicin	4-Methoxyglucobrassicin	Neoglucobrassicin	Total Indolic GLS	Gluconasturtiin	
5 Days	2.17	0.79	1.93	9.26	14.16	1.65	1.16	1.03	0.13	3.98	4.58	22.72
10 Days	2.24	0.82	1.53	8.63	13.23	2.09	1.12	1.48	0.14	4.83	4.67	22.73
p	**n.s**	**n.s**	***	**	**	***	**n.s**	***	**n.s**	***	**n.s**	**n.s**
5 °C	2.43	0.86	1.82	9.18	14.29	1.74	1.17	1.01	0.14	4.06	4.69	23.04
10 °C	1.99	0.75	1.64	8.71	13.09	2.00	1.11	1.50	0.14	4.76	4.56	22.41
p	***	***	**	*	***	***	**n.s**	***	**n.s**	***	**n.s**	**n.s**
MA-1	2.43a	0.78	1.79a	8.41b	13.42b	2.21a	1.19	1.33a	0.14	4.87a	4.97a	23.25a
MA-2	1.74b	0.79	1.48b	9.38a	13.39b	1.83b	1.11	1.16b	0.15	4.24b	4.26b	21.89b
MA-5%	2.46a	0.85	1.93a	9.06a	14.28a	1.57c	1.14	1.28a	0.13	4.12b	4.64ab	23.03ab
p	***	**n.s**	***	**	*	***	**n.s**	***	**n.s**	***	***	*
Control (±SD)	2.57 ±0.68	0.74 ±0.06	2.40 ±0.15	7.56 ±0.71	13.27 ±0.33	1.12 ±0.04	1.34 ±0.05	0.48 ±0.02	0.14 ±0.01	3.09 ±0.10	5.65 ±0.42	22.01 ±0.69

n.s, not significant $p \geq 0.05$, * $p < 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$ (n=4)

For the MA part of the table, values within column followed by different letters are significantly different with Tukey`s test (p=0.05).

Total aliphatic glucosinolates in cut swede increased with storage time but were unaffected by storage temperature (Table 3), while total aliphatic glucosinolates in turnip decreased as a response to increasing storage time and storage temperature (Table 4). So far, studies of glucosinolate content in fresh-cut swede and turnip have not been found. For white and red cabbage there were no changes in the content of total aliphatic glucosinolates due to cutting, while a decrease was observed for cut broccoli (Verkerk et al., 2001). In the present study, three modified atmospheres did not give different contents of total aliphatic glucosinolates in swede. However, the content of total aliphatic glucosinolates was higher in turnip stored in MA-5% compared to the other atmospheres (Table 4). Similar results were observed for broccoli (Fernández-León et al., 2013), where total aliphatic glucosinolates were better preserved in controlled atmosphere (10% O_2 and 5% CO_2) than in air.

In swede, the individual aliphatic glucosinolates progoitrin, glucoberteroin, gluconapoleiferin and glucobrassicanapin increased in response to prolonged storage time, whereas glucoalyssin and glucoerucin were unchanged (Table 3). In turnip, gluconapin and glucobrassicanapin were significantly lower in samples stored for 10 days than 5 days, but progoitrin and glucoerucin were stable (Table 4). Only glucobrassicanapin of the aliphatic glucosinolates in swede changed by increased storage temperature, with a decreased level (Table 3). The same effect was observed in turnip for all individual aliphatic glucosinolates (Table 4). This indicates a different response to storage conditions for individual aliphatic glucosinolates in swede and turnip. Shattuck et al. (1991a) reported increased progoitrin content in whole, peeled swede during storage that agrees with the present study. In contrast to the present results for cut turnip, progoitrin and glucobrassicin content increased during storage of whole, peeled turnip (Shattuck et al., 1991b).

Of aliphatic glucosinolates in swede, only glucobrassicanapin was influenced by modified atmosphere (Table 3). In turnip, progoitrin and glucobrassicanapin were better preserved in MA-5% and MA-1 than in MA-2, a result difficult to explain from differences in concentrations of O_2 and CO_2. A significantly lower content of gluconapin was found in turnip from MA-1 (Table 4), which could indicate that reduced O_2 or elevated CO_2 concentrations preserved gluconapin content better.

Total indolic glucosinolate content in swede (Table 3) and turnip (Table 4) increased considerably as a response to increased storage time and temperature. An increase in indolic glucosinolates during storage subsequent to cutting has also been shown for red and white cabbage, and broccoli (Verkerk et al., 2001). For swede, the content of total indolic glucosinolates was higher in samples from MA-1 and MA-2 than in MA-5%. An explanation for this is not obvious. For turnip, the content was highest for MA-1, indicating that total indolic glucosinolates during storage in turnip was diminished by reduced O_2 or increased CO_2.

The contents of glucobrassicin and 4-methoxyglucobrassicin increased considerably in both swede and turnip as an effect of prolonged storage and higher temperature. For swede 4-hydroxyglucobrassicin showed a small decrease at 10 ^{0}C, while for turnip 4-hydroxyglucobrassicin and neoglucobrassicin were not significantly affected by storage temperatures. The effect of active modified atmosphere on glucobrassicin in both swede (Table 3) and turnip (Table 4) could indicate that low O_2 during the entire storage reduced a possible increase of glucobrassicin.

Total glucosinolates content in swede stored for 10 days was significantly higher than after 5 days (Table 3), due to increase in both total aliphatic and indolic glucosinolates. Turnip, on the other hand, had no significant difference in total glucosinolates content between storage times or temperatures (Table 4), as total aliphatic glucosinolates decreased and total indolic glucosinolates increased.

3.5 Sensory attributes

In general, odour attributes for both vegetables lost intensity during storage, except for cloying odour in turnip that was more intense in samples stored for 10 days at 10 ^{0}C (Table 5). For swede, changes in odour attributes were mainly related to storage time, while for turnip both storage time and temperature influenced odours. Evaporations of aroma compounds from the surface during storage could be a possible explanation for a decrease in odour intensity. Previous studies have shown that MAP may cause anaerobe respiration resulting in off-odours (Barry-Ryan et al., 2000; Cliffe-Byrnes and O' Beirne, 2005). In the present study, the atmosphere composition had no influence on odour, suggesting that no anaerobic respiration occurred.

Swede flavour was mainly influenced by storage temperature, while turnip flavour was affected by both storage temperature and time (Table 6). The intensity of sour flavour and green flavour decreased in both vegetables with increased storage time and temperature, whereas cellar flavour and cloying flavour increased in turnip. In swede, when stored at 10 ^{0}C in relation to 5 ^{0}C, cellar flavour and bitter taste increased, but green flavour and earthy flavour decreased. Correspondingly, aftertaste increased and sulphurous flavour decreased in turnip at 10 ^{0}C. The composition of the atmosphere had no effect on flavour, except for sour flavour in turnip, where MA-2 gave highest intensity. Flavour changes in carrots in relation to package atmosphere have been previously reported, but then anaerobic conditions were present (Seljåsen et al., 2004).

Table 5 Effects of storage time, temperature and modified atmospheres on odour (O) attributes from fresh-cut swede and turnip.

	Sour-O	Green-O	Sulphurous-O	Metallic-O	Cloying-O	Earthy-O	Pungent-O	Cellar-O
Swede								
5 Days	2.29	1.72	2.91	2.42	2.57	1.43	2.03	2.50
10 Days	1.83	1.42	2.55	2.23	2.80	1.34	1.85	2.43
p	**	*	*	**	**n.s**	*	**n.s**	**n.s**
5 ^{0}C	2.24	1.73	2.74	2.41	2.63	1.43	1.95	2.33
10 ^{0}C	1.87	1.41	2.71	2.24	2.74	1.34	1.93	2.60
p	*	*	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**
MA-1	2.03	1.58	2.61	2.23	2.43	1.40	2.00	2.34
MA-2	2.02	1.53	2.87	2.39	2.85	1.41	2.02	2.54
MA-5%	2.12	1.6	2.7	2.37	2.77	1.34	1.80	2.51
p	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**
Control(±SD)	5.05±1.37	3.40±1.22	5.00±1.12	2.96±1.13	1.65±0.83	2.78±1.17	3.87±0.90	1.77±1.1
Turnip								
5 Days	2.37	1.70	2.67	2.44	2.73	1.47	1.98	n.d
10 Days	1.41	1.18	2.18	2.27	4.57	1.12	1.56	n.d
p	***	***	*	**n.s**	***	*	*	
5 ^{0}C	2.27	1.68	2.60	2.45	3.11	1.46	1.90	n.d
10 ^{0}C	1.51	1.21	2.24	2.26	4.19	1.13	1.63	n.d
p	***	***	*	**n.s**	**	*	*	
MA-1	1.79b	1.41	2.30	2.28	3.46	1.27	1.71	n.d
MA-2	2.08a	1.52	2.59	2.45	3.77	1.31	1.92	n.d
MA-5%	1.80b	1.40	2.38	2.33	3.73	1.30	1.67	n.d
p	*	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	
Control (±SD)	6.03±1.48	3.81±1.02	5.31±0.66	3.24±0.67	1.06±0.19	2.69±0.89	4.30±0.89	

Intensity (1.0=low intensity and 9.0=high intensity) of sensory attributes was measured by a trained sensory panel.
n.s, not significant $p \geq 0.05$, * $p < 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$. For the MA part of the table, values within column followed by different letters are significantly different with Tukey`s test (p=0.05). n.d, not detected.

Table 6 Effects of storage time, temperature and modified atmospheres on taste (T) and flavour (F) attributes from fresh-cut swede and turnip.

	Sour-F	Sweet-T	Bitter-T	Green-F	Earthy-F	Cellar-F	Pungent-F	Sulphurous-F	Metallic-F	Cloying-F	Astringency	Aftertaste
Swede												
5 Days	3.22	3.53	3.76	2.30	1.91	2.52	3.22	3.81	2.88	2.77	2.88	5.26
10 Days	2.78	3.44	3.91	2.03	1.79	2.99	3.28	3.79	2.88	3.17	2.93	5.26
p	*	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**
5 ^{o}C	3.24	3.57	3.68	2.36	2.02	2.51	3.15	3.79	2.88	2.87	2.83	5.15
10 ^{o}C	2.76	3.40	3.99	1.98	1.68	3.01	3.35	3.81	2.88	3.07	2.97	5.37
p	**	**n.s**	**	*	*	*	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	*
MA-1	3.03	3.4	3.89	2.32	1.92	2.70	3.38	3.93	2.98	2.72	3.01	5.28
MA-2	2.89	3.49	3.80	1.92	1.69	2.99	3.21	3.69	2.78	3.16	2.97	5.36
MA-5%	3.07	3.57	3.82	2.26	1.94	2.59	3.17	3.78	2.88	3.03	2.73	5.14
p	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**
Control (±SD)	4.73±1.27	3.57±0.70	3.79±0.86	3.37±1.30	2.94±0.88	2.11±1.61	3.62±1.07	4.40±1.03	2.98±1.02	1.94±1.15	2.92±1.39	5.41±1.20
Turnip												
5 Days	3.43	3.50	5.11	2.49	n.d	2.33	4.53	4.23	3.29	2.55	3.24	6.02
10 Days	2.72	3.46	5.29	1.94	n.d	3.09	4.72	4.03	3.49	3.81	3.55	6.21
p	**	**n.s**	**n.s**	**		**	**n.s**	**n.s**	**n.s**	***	**n.s**	**n.s**
5 ^{o}C	3.42	3.58	5.10	2.43	n.d	2.33	4.61	4.33	3.36	2.62	3.23	5.94
10 ^{o}C	2.73	3.38	5.31	1.99	n.d	3.09	4.65	3.93	3.42	3.75	3.56	6.29
p	**	**n.s**	**n.s**	*		**	**n.s**	***	**n.s**	***	*	*
MA-1	2.85b	3.43	5.34	2.19	n.d	2.81	4.66	4.10	3.38	3.25	3.43	6.11
MA-2	3.30a	3.40	5.05	2.24	n.d	2.71	4.71	4.10	3.48	3.09	3.47	6.17
MA-5%	3.08ab	3.61	5.22	2.21	n.d	2.62	4.51	4.19	3.31	3.22	3.29	6.05
p	***	**n.s**	**n.s**	**n.s**		**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**
Control (±SD)	5.30±1.48	4.04±1.06	4.69±1.22	3.51±0.90		1.19±0.52	4.92±1.02	4.84±0.80	3.24±0.56	1.47±0.90	2.86±1.03	5.97±0.93

Intensity (1.0=low intensity and 9.0=high intensity) of sensory attributes was measured by a trained sensory panel. n.s, not significant $p \geq 0.05$, * $p < 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$. For the MA part of the table, values within column followed by different letters are significantly different with Tukey`s test (p=0.05).

Both swede and turnip are susceptible to surface discolouration after peeling and cutting (Alexander and Francis, 1964a, b). For swede, whiteness decreased with increasing storage time, and colour evenness decreased with both increasing storage time and temperature (Table 7). For turnip, whiteness and colour evenness decreased, while scores for hue and colour intensity increased, indicating increased discolouration with increasing storage time and temperature.

The atmosphere had a significant influence on colour evenness and colour intensity for swede, although the differences were minor between the three atmospheres. A lower O_2 or higher CO_2 appeared to give lower colour intensity. However, there were no significant difference between MA-1 and MA-5%. For turnip, MA-2 and MA-5% gave a higher score for colour evenness and lower score for hue. This indicates that a lower O_2 or higher CO_2 concentration reduced a change in appearance. Thus, for both swede and turnip, there was no evident difference between active and passive MAP related to appearance attributes.

Storage at 10 ^{0}C gave a lower juiciness in swede compared to 5^{0} C, while 10 ^{0}C gave a higher fibrousness score for turnip (Table 7). Juiciness in swede and fibrousness in turnip were also affected by the atmosphere, with the highest scores for the active atmosphere. An increased hardness for swede with storage time was minor. Change in texture attributes could be related to water loss (Leceta et al., 2015). Overall, the few and minor changes among texture attributes suggest that the texture quality was little affected by time, temperature and atmosphere during storage.

Table 7 Effects of storage time, temperature and modified atmospheres on appearance and texture attributes from fresh-cut swede and turnip.

	Colour evenness	Hue	Colour intensity	Whiteness	Hardness	Crispiness	Juiciness	Fibrousness
Swede								
5 Days	4.14	5.57	4.50	5.38	4.64	5.54	5.46	2.71
10 Days	3.72	5.64	4.38	5.19	4.74	5.43	5.49	2.60
p	***	**n.s**	**n.s**	**	*	**n.s**	**n.s**	**n.s**
5 ^{o}C	4.18	5.58	4.59	5.32	4.68	5.58	5.59	2.61
10 ^{o}C	3.67	5.63	4.29	5.24	4.71	5.39	5.36	2.71
p	***	**n.s**	**n.s**	**n.s**	**n.s**	**n.s**	*	**n.s**
MA-1	3.94ab	5.7	4.62a	5.05	4.77	5.41	5.35b	2.78
MA-2	3.79b	5.51	4.21b	5.48	4.69	5.54	5.45ab	2.64
MA-5%	4.05a	5.61	4.49ab	5.31	4.62	5.51	5.63a	2.56
p	*	**n.s**	*	**n.s**	**n.s**	**n.s**	*	**n.s**
Control (±SD)	7.16±0.91	5.59±0.84	5.51±0.96	4.49±0.81	5.24±0.83	6.15±0.69	6.17±0.97	2.75±1.51
Turnip								
5 Days	5.72	4.05	2.43	6.98	4.44	6.16	6.39	1.53
10 Days	3.87	6.28	3.02	5.93	4.58	5.98	6.34	1.74
p	***	***	***	***	**n.s**	**n.s**	**n.s**	**n.s**
5 ^{o}C	5.87	3.76	2.31	7.11	4.50	6.13	6.32	1.55
10 ^{o}C	3.72	6.57	3.14	5.79	4.52	6.01	6.42	1.72
p	***	***	**	***	**n.s**	**n.s**	**n.s**	*
MA-1	4.49b	5.53a	2.89a	6.27b	4.50	6.18	6.37	1.67ab
MA-2	5.04a	5.11b	2.65ab	6.57a	4.57	6.08	6.35	1.53b
MA-5%	4.85a	4.85b	2.64b	6.52ab	4.46	5.95	6.38	1.71a
p	***	**	*	*	**n.s**	**n.s**	**n.s**	*
Control (±SD)	8.45±0.51	1.13±0.22	1.44±0.34	8.47±0.35	4.46±0.87	6.58±0.88	6.59±0.83	1.58±0.91

Intensity (1.0=low intensity and 9.0=high intensity) of sensory attributes was measured by a trained sensory panel. n.s, not significant $p \geq 0.05$, * $p < 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$ For the MA part of the table, values within column followed by different letters are significantly different with Tukey`s test (p=0.05).

3.6 Relating sensory and chemical measurements

Partial least square regression (PLSR) was used to investigate whether sensory attributes could be predicted by chemical composition of swede and turnip. The first two PLSR components for sensory attributes explained 62 % and 72% of the variance in sensory data for swede (Figure 2) and turnip (Figure 3), respectively.

Sweet taste and contents of fructose, total sugar and sucrose for swede are positively correlated along PLSR component 1 (Fig. 2, right). Positive correlations between bitter taste, cellar odour, cellar flavour and glucobrassicin, 4-methoxyglucobrassicin and total indolic glucosinolates were also observed (Fig. 2, left).

For turnip, sweet taste correlated positively with sucrose and total sugar content (Fig. 3), and the correlation appears to be stronger than for swede. In addition, sulphurous flavour, sulphurous odour, green flavour, green odour, sour flavour, sour odour, 4-hydroxyglucobrassicin and glucobrassicanapin were positively correlated. On the other hand, bitter taste, cloying flavour, cloying odour, cellar flavour, astringency, colour intensity, hue, total indolic glucosinolates, glucobrassicin and 4-methoxyglucobrassicin correlated positively. In addition, to a bit less extent, metallic flavour and neoglucobrassicin also correlated with the mentioned parameters. As found for swede, glucobrassicin, 4-methoxyglucobrassicin and total indolic glucosinolates were correlated to bitter taste, and sweet taste and bitter taste were negatively correlated.

The negative correlation between sweet and bitter taste found has also been shown for cabbage (Beck et al., 2014) and cooked cauliflower (Engel et al., 2002). The variation in sweet and bitter taste could therefore be due to either an increase or reduction in bitter or sweet compounds, or a combination. Bitter taste in cabbage was found to correlate with

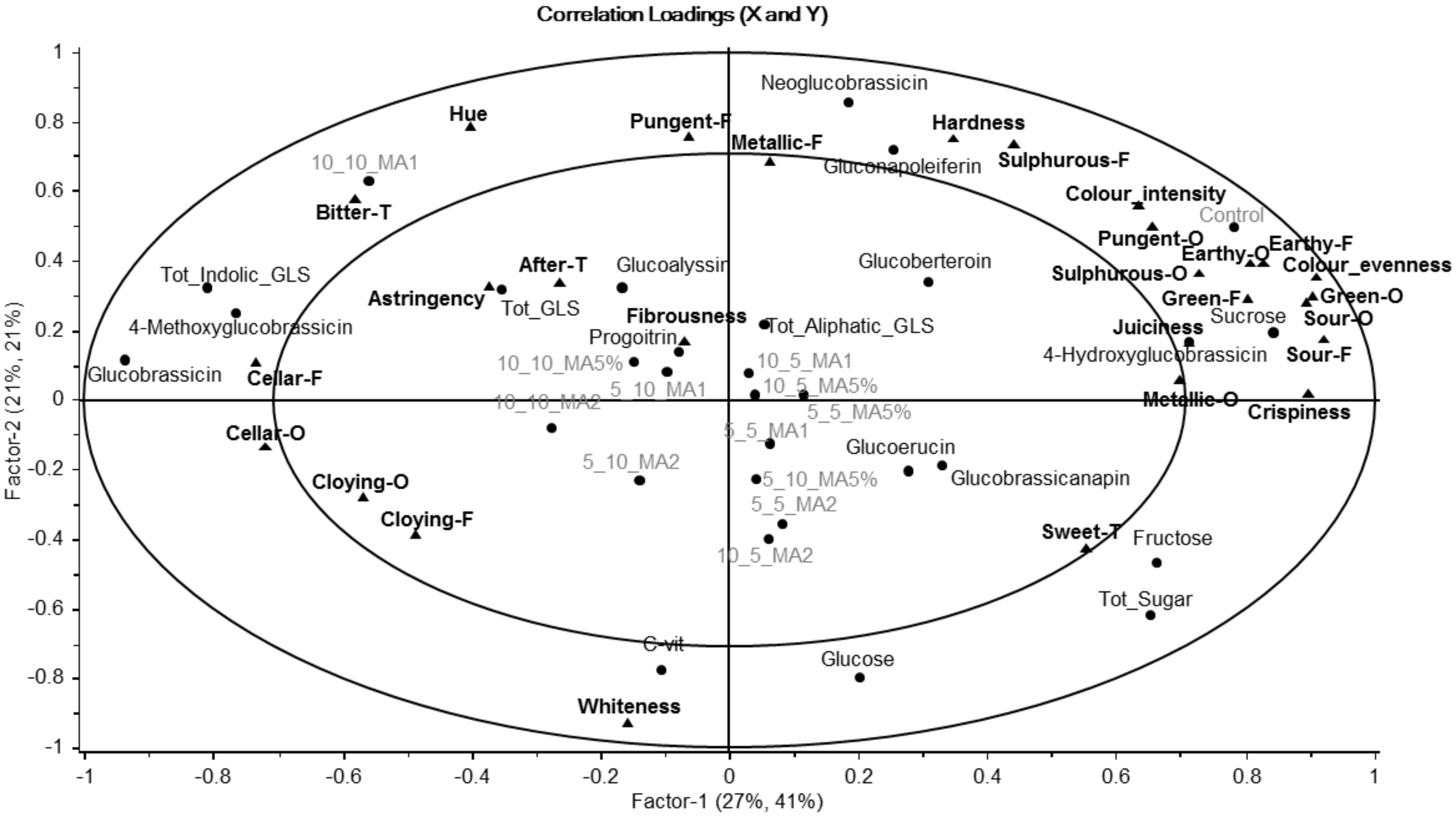

Fig. 2 Correlation loading plot from a PLSR of sensory attributes (bold) and chemical measurements of fresh-cut swede samples stored for 5 or 10 days (first number in sample name), 5 or 10 ^{0}C (second number in sample name) and passive (MA-1 or MA-2) or active (MA-5%) modified atmosphere. A non-stored control sample (Control) was also included. Ellipses represent r^2= 50 and 100 % explained variance, respectively. Explained variance in chemical (X) and sensory (Y) data by the PLS factors are given by first and second percentage, respectively.

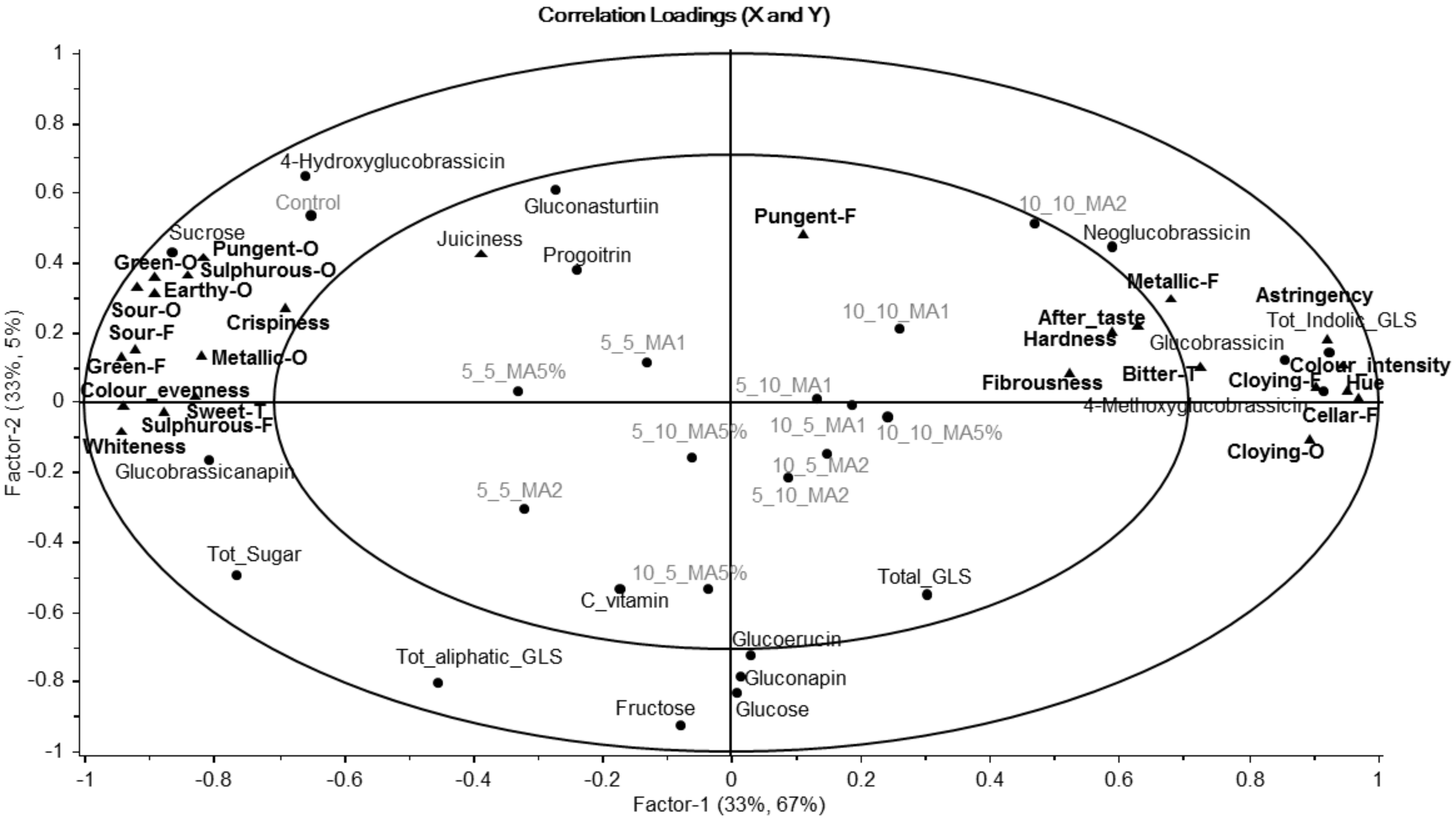

Fig. 3 Correlation loading plot from a PLSR of sensory attributes (bold) and chemical measurements of fresh-cut turnip samples stored for 5 or 10 days (first number in sample name), 5 or 10 ^{0}C (second number in sample name) and passive (MA-1 or MA-2) or active (MA-5%) modified atmosphere. A non-stored control sample (Control) was also included. Ellipses represent r^2= 50 and 100 % explained variance, respectively. Explained variance in chemical (X) and sensory (Y) data by the PLS factors are given by first and second percentage, respectively.

glucobrassicin and neoglucobrassicin, but not with 4-methoxyglucobrassicin (Beck et al., 2014) as in the present study. In 113 varieties of turnip greens Padilla et al. (2007) found bitterness to be related to high glucosinolate content and not to high gluconapin content, whereas in Brussels sprouts bitter taste was correlated with sinigrin and progoitrin contents (Fenwick et al. 1982). There is not yet a good explanation for bitter and sweet taste in brassicas based on contents of specific phytochemicals or sugar.

The control sample was included in the PLSR to represent the cut vegetable on the cutting day for comparison with the stored samples. Values of the sensory and chemical parameters for the control sample are given in Table 2-6. For both vegetables the control sample was given higher scores for the sensory attributes sour odour, sour flavour, green odour, green flavour, earthy odour, pungent odour, metallic odour and sulphurous odour, and colour evenness. For the chemical compounds both vegetables had higher content in the control samples of sucrose, total sugar and 4-hydroxyglucobrassicin, but lower contents of glucobrassicin and 4-methoxyglucobrassicin than the stored samples. And also, for both vegetables, the control sample is separated from the stored samples in the plots (Fig 2 and 3), indicating that cut swede and turnip after storage were different from a non-stored sample regarding the measured parameters. In addition, swede and turnip samples stored for 10 days and 10 ^{0}C were located opposite to the control sample, indicating that these samples were most different from the control sample.

4. Conclusion

Vitamin C content of fresh-cut swede and turnip was not affected by storage time, temperature or modified atmosphere, while levels of sugar and glucosinolates, and sensory scores were. Increased storage time gave higher total glucosinolate content in swede, while total glucosinolates content in turnip did not change with storage time or temperature. However, glucobrassicin and 4-methoxyglucobrassicin contents increased in both vegetables. in response to longer storage time and increased temperature. Total sugar content in both vegetables decreased with increasing storage time and temperature, and reduction of sucrose in both vegetables was affected by increased storage time. Depending on the sensory attributes, either an increase or a decrease in intensity was detected. This could be unwanted changes from consumer's perspectives. A modified atmosphere with low O_2 concentration reduced discolouration related changes, especially for turnip. Sweet taste was negatively correlated with bitter taste. In both vegetables, sweet taste intensity was positively correlated with contents of sucrose and total sugar content, and bitter taste was only related to increased contents of glucobrassicin and 4-methoxyglucobrassicin among the glucosinolates analysed. Low temperature and short storage time were the most important factors to prevent changes of appearance, odour, taste and flavour, and contents of sugar and glucosinolates of fresh-cut swede and turnip.

5. Acknowledgements

This research was administered by the Research Council of Norway (Proj. no. 199409) and funded by Foundation for Research Levy on Agricultural Products and the Agricultural Agreement Research Fund, together with the Norwegian food industry partners Gartnerhallen AL, Bama Gruppen AS, Findus Norge AS, FellesJuice AS, HOFF SA, Graminor AS, NordGrønt, Norgesgrønt, Maarud AS, KiMs Norge AS. Technical assistance from Aud Espedal, Mona Ringstad, Silje Johansen and Trygve Helgerud is highly appreciated.

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Paper III

Storage of fresh-cut swede and turnip at different temperatures, including sub-zero temperature: effect on sensory attributes, sugars and glucosinolates

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Abstract

Freezing point of fresh-cut swede (*Brassica napus* L. var. *napobrassica* Rchb.) and turnip (*Brassica rapa* L. ssp. *rapifera* Metzg.) dice was measured by cooling curve method, and mean equilibrium freezing points were found to be -2.67 and -1.97 °C, respectively. This indicates that storage of fresh-cut swede and turnip at temperatures below 0 °C is possible. Fresh-cut swede and turnip were packed in pouches made of biaxially oriented polypropylene film, and a film based on polylactic acid and stored for 10 days at -2, 0, 5 and 10 °C. One sample of each vegetable was stored at -2 °C for 5 days, followed by 5 days of storage at 5 °C. PLA resulted in higher weight loss than BOPP in both vegetables. Differences in sensory quality between storage at -2 °C and 0 °C were found in appearance attributes only. Both swede and turnip had higher evenness of colour at -2 °C than at 0 °C. Storage at -2 °C vs. 0 °C gave lower whiteness for swede but higher for turnip, and lower intensity of hue for turnip only. Increased storage temperature from 0 °C to 5 or 10 °C did not change appearance in swede, but in turnip hue and colour intensity increased, and colour evenness and whiteness decreased. Differences in odour, taste and flavour during storage at 5 or 10 °C vs. 0 °C were prominent for turnip: decreased sour odour and flavour, green odour and flavour, sulphurous odour and sweet taste, and increased muddy odour and cloying odour and flavour. For swede, higher storage temperature gave only increased intensity of sulphurous odour and pungent odour. Texture changed for turnip only with decreased juiciness. The lowest temperature (-2 °C) gave the highest sucrose content in both swede and turnip, the highest total sugar content in turnip and the lowest glucose content in swede. Higher storage temperature resulted in higher content of total indolic glucosinolates in both fresh-cut swede and turnip, but a lower content of total aliphatic glucosinolates in turnip only. Increased contents with storage temperature were found for glucobrassicin and 4-methoxyglucobrassicin in both vegetables, and decreased contents for glucobrassicanapin and gluconapin in turnip and glucoalyssin in swede.

Keywords: Fresh-cut; Turnip; Swede; Temperature; Glucosinolates; Sugar

1. Introduction

Fresh-cut vegetables are perishable food products with physiological changes during storage faster than in the whole raw materials. This might lead to undesirable quality such as discolouration, flavour, odour and texture alterations, and loss of nutritional value (Barrett et al., 2010). Glucosinolates in *Brassica* vegetables have gained interest due to their possible health-beneficial effects (Jahangir et al., 2009), and since they together with sugar could influence flavour (Beaulieu and Baldwin, 2002).

Temperature is an important factor known to influence quality of fresh-cut vegetables. It is well known that the temperature vary considerably in the distribution chain of different food companies. This will have an impact on product quality, shelf-life and food waste (Nunes et al., 2009).

Storage temperature just below 0 ^{o}C, close to the freezing point of perishable foods, has gained more research attention, especially for fish (Kaale et al., 2011). However, research on keeping fresh-cut vegetables at low temperatures is scarce. Freezing point for garlic cloves have been investigated, and garlic may be stored at -2.7 ^{o}C without freezing (James et al., 2009). Recommended storage temperature for root vegetables, like swede and turnip, are just above 0 ^{o}C (Stoll and Weichman, 1987). However, information on the effect of storage at 0 ^{o}C or just below on the quality of these commodities after peeling and cutting has not been found. To study freezing point of foods, a time-temperature plot from temperature logging of a food sample during freezing can be used (Rahman et al., 2002).

The packages used for vegetables are often made of petroleum-based materials (Mangaraj et al., 2009). As an alternative, materials with polylactic acid (PLA) from renewable sources have gained interest. PLA-based biodegradable films are commercially available, and have been found suitable for packing peppers (Koide and Shi, 2007) and fresh-cut celery (González-Buesa et al., 2014).

The aim of this study was to determine the freezing point of fresh-cut swede and turnip, and to study the effect of different storage temperatures, including sub-zero (^{o}C) temperature, and packaging material on sensory attributes, sugar and glucosinolate contents of fresh-cut swede and turnip.

2. Materials and methods

2.1 Plant material

Swede (*Brassica napus* L. var. *napobrassica* (L.) Rchb. cv. Vigod) and turnip (*Brassica rapa* L. ssp. *rapifera* Metzg. cv. Solanepe) were provided in 2013 from local growers in the Oslofjord-area and south-western part of Norway, respectively. Rutabaga was brought directly to the storage room after harvest. Turnip was transported to Ås in a refrigerated truck holding 4 ^{o}C. Both vegetables (approximately 100 kg) were harvested in October and stored in perforated plastic bags at 0-1 ^{o}C and used for the experiments after 1-2 months.

2.2 Processing

After washing in cold tap water including brushing, swedes and turnips were peeled by hand using a sharp stainless steel knife, or a potato peeler (Victorinox, Ibach-Schwyz, Switzerland), respectively. For each vegetable, 10 kg of peeled commodity were prepared. The roots were rinsed, and cut in 10 mm cubes using a cutting machine (KUJ V, Kronen GmbH, Kehl am Rhein, Germany). The cubes were shortly rinsed in cold tap water, followed by immersion in tap water mixed with crushed ice for 1 minute, to cool the vegetables before packaging. The vegetables were spin-dried for 30 seconds using a vegetable centrifuge at 1000 rpm (Eillert, Machinefabriek Eillert B. V., Ulft, The Netherlands).

2.3 Determining freezing point

Freezing point measurements of diced swedes and turnips were based on the method described by James et al. (2009), with some modifications. A double semi-flexible 1.5 mm diameter probe with a PT 1000 sensor (Ellab AS, Hillerød, Denmark) was used to measure temperature in the centre of vegetable dice. Temperatures were recorded every 10th second using a wireless TrackSense Pro Logger system (Ellab AS). Four sensors connected to two loggers were used, allowing for the temperature to be followed in four vegetable dice in each session. For each vegetable a total of three sessions were carried out. Vegetable dice with sensor and logger were placed in an expanded polystyrene box with lid (230 x 250 x 250 mm, 20 mm thick walls). The polystyrene box was then placed inside a freezer room (-20 ^{o}C). The time and temperature data from the loggers was used to determine equilibrium freezing point and ice crystallisation temperature, as described by Rahman and Driscoll (1994).

2.4 Packaging material, packaging and storage

Pouches (150 x 135 mm) were made from a 40 µm biaxially oriented polypropylene film (BOPP) (ScanFresh®, Scanstore, Middelfart, Denmark), and a 40 µm film based on polylactic acid (PLA) (Bio-Flex® F 11390, FKuR Kunststoff GmbH, Willich, Germany), as described by Pettersen et al. (2011), using a manually operated impulse sealer (Magneta 421, Audion Elektro BV, JL Weesp, Holland). Packages were perforated with 20 holes, using a 0.22 mm acupuncture needle to avoid modification of the atmosphere within the pouches. Vegetable dice (200 g) were weighed into the packages, followed by sealing. The packages were stored for 10 days at -2, 0, 5 and 10 ^{o}C. In addition, one set of samples was kept at -2 ^{o}C for 5 days, followed by 5 days storage at 5 ^{o}C in order to simulate a distribution temperature of -2 ^{o}C and a retail temperature of 5 ^{o}C. For every material and temperature combination, 4 packages were prepared.

2.5 Samples for sensory and chemical analysis

On the day of sensory analysis, 70 g material (dice) was sampled from each package for chemical analysis, and the remaining was used for sensory analysis. A control sample was prepared in the same way as the stored samples, taken from the same raw material batch. Material for chemical analysis was frozen in liquid nitrogen and stored at -80 ^{o}C, and then ground frozen using a Krups 708A food processor. For sugar and glucosinolate analyses, the ground frozen material was freeze-dried, further ground with a Retsch ZM100 mill (Retsch GmbH & Co., Haan, Germany), and stored in tight containers at -40 ^{o}C. For dry matter determination, frozen material before freeze-drying was used.

2.5 Sensory analysis

Quantitative descriptive sensory analysis was performed according to ISO 13299:2003(E) by a trained sensory panel of 10 persons at Nofima (Ås, Norway). The assessors were selected and trained according to ISO 8586-1:2012(E), and the analysis was performed according to ISO 8589:2007(E). The sensory panel was calibrated, using the control sample and the sample stored at 10 ^{o}C in PLA material. The assessors agreed on sensory attributes to describe raw swede and turnip during a training session (Table 1). Room temperate vegetables (25 g) from each treatment and control sample were served in plastic trays, coded with a three-digit code, with lids. Each sample was served twice.

Table 1 Sensory attributes describing swede and turnip.

Attribute	Description
Odour	
Sour	Related to a fresh, balanced odour due to the presence of organic acids
Green	Odour of green (i.e. fresh green grass)
Sulphurous	Odour of sulphur
Metallic	Odour of metal (ferrous sulphate)
Cloying	Unfresh and sickeningly sweet odour
Cellar[1]	Odour of cellar, closed-up odour
Earthy	Odour of fresh soil
Pungent	A pungent, burning odour like radish
Muddy[2]	Related to clay, mud and marsh water
Taste and flavour	
Sour	Related to a fresh, balanced flavour due to the presence of organic acids
Green	Flavour of green (i.e. fresh green grass)
Earthy	Flavour of fresh soil
Sweet	Related to the basic taste sweet (sucrose)
Bitter	Related to the basic taste bitter (caffeine)
Cellar	Flavour of cellar, closed-up flavour
Pungent	A pungent, burning flavour like radish
Sulphurous	Flavour of sulphur
Metallic	Flavour of metal (ferrous sulphate)
Cloying	Unfresh and sickeningly sweet flavour
Aftertaste	Taste which occurs 30 seconds after elimination of the product
Astringency	Organoleptic attribute of pure substances or mixtures which produces the astringent sensation
Appearance	
Hue (Swede)	Surface colour evaluated according to NCS-system 1=G80Y (green/yellow), 9=Y30R (yellow/red)
Hue (Turnip)	Surface colour evaluated according to NCS-system 1=Y (yellow), 9=Y30R (yellow/red)
Colour intensity	Surface colour evaluated according to NCS-system
Colour evenness	Uniformity in colour assessed on the entire sample
Whiteness	Surface colour evaluated according to NCS-system
Texture	
Fibrousness	Geometrical textural attribute relating to the perception of the shape and the orientation of particles in a product. Long particles, oriented in the same direction, i.e. celery
Crispiness	Easily breakable
Juiciness	Perception of water after 4-5 chews
Hardness	Mechanical textural attribute relating to the force required to achieve a given deformation or penetration of a product

[1] Attribute not assessed in turnip by the sensory panel. [2] Attribute not assessed in swede by the sensory panel.

The panellists recorded their results at individual speed on a 15 cm non-structured continuous scale. The data registration system, EyeQuestion, v. 3.8.6 (Logic 8, The Netherlands) transformed the responses from 0 – 15 cm on the screen to numbers from 1.0 (low intensity) to 9.0 (high intensity). Due to the number of samples, the sensory evaluation had to be performed during two subsequent days. Which samples to be analysed on which day were randomly chosen before the experiment was started.

2.6 Sugar analysis

Sugars were analysed using a method described by Elmore et al. (2007) with modifications. Freeze-dried samples (50 mg) were weighed into 15 mL tubes. An internal standard (500 µl, 10 mg L^{-1} trehalose) was added followed by 10 mL 50% (v/v) methanol, before shaking for 15 minutes. After 15 minutes of settling, 1.5 mL of the supernatant was centrifuged (ICE Centra-M2 Centrifuge, Heigar, Oslo, Norway) at 15600 x g_{max} for 15 min. The supernatant (50 µL) was diluted with 1450 µL 50% (v/v) methanol and filtered through a 0.22 µm filter (Millex-GV (PVDF), Merck Millipore Ltd., Tullagreen, Ireland). Extracts were analysed using a Thermo Scientific Dionex ICS 5000 ion chromatography system, with Chromeleon software (Thermo Fisher Scientific Inc., Sunnyvale, California). Injection volume was 20 µL, with a gradient program: 50% 200 mM NaOH (solvent A) and 50% water (solvent B), with flow rate 1 mL min^{-1} for 20 min. The column was washed for 5 min with 500 mM sodium acetate in 100 mM NaOH and re-equilibrated with 50% solvent A for 5 min. External standards of glucose, fructose and sucrose were used for quantification, and values are given in g 100 g^{-1} dry matter (DM).

2.7 Glucosinolates

Glucosinolates were analysed according to ISO 9167-1:1992 (E) (ISO 9167-1, 1992) with some modifications. Approximately 0.200 g material was mixed with 4.50 mL of preheated (73 ^{o}C) 70% (v/v) methanol, and incubated at 73 ^{o}C for 3 min. Glucotropaeolin (100 µL, 1 mg mL^{-1}) was added as internal standard. The samples were left on ice for 10 min before centrifugation at 5300 x g_{max} (Heraeus Multifuge 4KR, Thermo Scientific, Osterode, Germany) for 15 min at 4 ^{o}C. The pellet was re-suspended in 3 mL 70% methanol, left on ice for 10 min, and centrifuged. The two supernatants were combined. Thirty mg of glass wool was packed in a 1 mL syringe. After rinsing with 0.5 mL water, 0.5 mL DEAE Sephadex A25 suspension was added, and rinsed (0.5 mL water) before 1 mL of sample was added, and left to drain. One mL of water was added before pH was adjusted by addition of 1 mL of sodium acetate buffer (pH 5). All liquid was drained, and 75 µL sulphatase was added, and left overnight. Desulfated glucosinolates were eluted by adding 1.25 mL water. The eluate was filtered (0.45 µm Millex-PVDF filter), and analysed by HPLC-DAD (Agilent HP 1100 Series, Agilent Technologies, Waldbronn, Germany) on a Spherisorb 5µm ODS2 (4.6 x 250 mm) column (Waters Corporation, Milford, MA, USA). Ultra-pure water (A) and 20% acetonitrile (B) were used as mobile phase. Flow was set to 1.5 mL min^{-1} at 30 ^{o}C, and detection at 227 nm. The injection volume was 30 µL. Gradient programme: 0-1 min, 1% B; 1-21 min, 1-99% B; 21-24 min, 99% B; 24-29 min, 99-1% B; 29-39 min, 1% B. Identification was done by comparing retention time and UV spectra with desulfated standards for progoitrin, glucoraphanin, gluconapin, gluconasturtiin, or tentatively identified by comparing retention time and UV-spectra for desulfo-glucosinolates in swede, previously identified by mass using LC-MS ion-trap. Quantification of desulfo-glucosinolates was based on response factors, and calculated as µmol g^{-1} DM.

2.8 Determination of weight loss and dry matter content

Samples were weighed before and after storage, and the difference reported as % weight loss. Dry matter (DM) content was determined after drying samples of 10 g at 105 ^{o}C for 48 hours.

2.9 Statistical analysis

Analysis of variance (ANOVA) was performed on chemical results, using general linear model in R 3.0.3 (R Core Team, 2014). Sensory data were analysed using a general linear model (Proc GLM) in SAS 9.4 (SAS Institute, Inc., Cary, NC, USA). The assessor effect was taken to be random and statistical significant level was set to $p = 0.05$. Tukey`s HSD test was used for multiple comparisons where applicable. For the relationship between sensory attributes (Y) and chemical measurement (X) a partial least square regression (PLSR) was applied (Martens and Martens, 2001). PLSR were performed using The Unscrambler X v. 10.2 (CAMO Software AS, Oslo, Norway) on centred and standardised data.

3. Results and discussion

3.1 Freezing point

The mean equilibrium freezing points for swede and turnip dice were -2.65 ^{o}C and -1.97 ^{o}C, respectively (Table 2). Freezing points of raw foods are often between 0 ^{o}C and -3.9 ^{o}C (Rahman et al., 2009), and the measured equilibrium freezing points of swede and turnip dice were similar to freezing points reported for potato (Comandini et al., 2013), garlic (James et al., 2009), broccoli and carrot (James et al., 2011), and green cauliflower (Haiying et al., 2007). Ice crystallisation temperature (ICT), the temperature below freezing point without formation of ice crystals, of swede and turnip were lower than the equilibrium freezing points (Table 2). This means that the temperature could decrease below freezing point without ice formation (Rahman et al., 2002). The present results indicate that fresh-cut swede and turnip can be stored at temperatures below 0 ^{o}C.

However, more studies on the effect of storage temperature, conditions and time in relation to ice formation are needed.

Table 2 Equilibrium freezing point and ice crystallisation temperature of swede and turnip dice (mean, SD, minimum (Min), maximum (Max), n=12).

	Equilibrium freezing point (^{o}C)		Ice crystallisation temperature (^{o}C)	
	Swede	Turnip	Swede	Turnip
Mean	-2.65	-1.97	-6.26	-6.37
SD	0.35	0.51	2.45	1.59
Min	-3.25	-3.03	-8.24	-8.50
Max	-1.98	-1.15	-2.08	-3.88

3.2 Effect of storage temperature and packaging material on sensory quality

3.2.1 Appearance and texture

Appearance is an important part of the total quality that affects consumer acceptance of a fresh-cut product (Barrett et al., 2010), and fresh-cut produce are susceptible to changes in appearance (Toivonen and Brummell, 2008). In the present study, scores for colour evenness of swede were higher, and whiteness scores were lower during storage at -2 ^{o}C than at 0 ^{o}C (Table 3).

Table 3 Effect of storage temperature (T) and packaging materials (M) on appearance and texture attributes of fresh-cut swede.

	Colour evenness	Hue	Colour intensity	Whiteness	Hardness	Crispiness	Juiciness	Fibrousness
T (ºC)								
-2	5.49a	5.00	4.90a	5.13b	4.77	4.48	4.53	1.61a[2]
0	4.73b	5.14	4.55ab	5.52a	4.70	4.43	4.47	2.13a
-2/5[1]	4.79b	5.16	4.58ab	5.53a	4.79	4.57	4.52	1.47a
5	4.50b	5.14	4.43b	5.63a	4.93	4.53	4.28	2.14a
10	4.57b	5.22	4.41b	5.72a	4.84	4.58	4.34	1.58a
p	***	n.s	**	***	n.s	n.s	n.s	*
M								
BOPP	4.90	5.15	4.66	5.46	4.85	4.59	4.51	1.71
PLA	4.73	5.12	4.49	5.56	4.77	4.45	4.35	1.86
p	*	n.s	n.s	n.s	n.s	n.s	n.s	n.s
TxM	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
Control	6.44±1.03	5.21±0.48	5.28±0.77	4.71±0.48	5.03±0.73	4.76±0.56	4.74±0.67	2.54±1.26

n.s, not significant P≥ 0.05, * P<0.05, ** P< 0.01 and *** P< 0.001. For the temperature part of the table, values within a column followed by different letters are significantly different with Tukey`s test (p=0.05). [1]Samples were stored at -2 ºC for 5 days and then at 5 ºC for 5 days. [2]Significant differences between temperatures were not found using Tukey`s test.

Storage at -2 ^{o}C also gave a higher score for colour intensity, compared with 5 ^{o}C or 10 ^{o}C. There was no temperature effect on swede appearance neither between 0 ^{o}C and 5 ^{o}C nor between 5 ^{o}C and 10 ^{o}C. The mechanisms of appearance changes in fresh-cut swede are not known. Increase in whiteness could be similar to what has been described as “white blush” in carrots, i.e. caused by drying of cell wall remnants on the cut surface or biosynthesis of cell wall components (Toivonen and Brummell, 2008). The effect of storing swede first at -2 ^{o}C, followed by 5 days at 5 ^{o}C, gave significantly lower scores for colour evenness and higher whiteness scores compared with storage at -2 ^{o}C, similar to storage at 0, 5 or 10 ^{o}C. This demonstrates that the effects of storage at sub-zero temperature on appearance of swede are lost if the temperature is elevated for some days.

The effects of storing turnip samples at -2 ^{o}C compared to 0 ^{o}C were higher scores for colour evenness and whiteness, but lower score for hue (Table 4). Comparing 0 ^{o}C with 5 ^{o}C, 0 ^{o}C gave higher scores for colour evenness and whiteness, and lower scores for colour intensity and hue. No other effects on appearance attributes between storage temperatures 5 ^{o}C or 10 ^{o}C were observed. The appearance of turnip was influenced by storage temperature, and the observed changes could be a discolouration due to enzymatic browning (Toivonen and Brummell, 2008). Another interesting observation was that there were significant differences in appearance between storage temperatures 0 ^{o}C and 5 ^{o}C, but no significant differences between 5 ^{o}C and 10 ^{o}C. Hence, it could be interesting to study changes in appearance for various temperature intervals up to 5 ^{o}C. BOPP gave a little higher colour evenness score for swede, while no significant effects of packaging material on appearance attributes were observed for turnip.

No effects of storage temperature on texture attributes of swede were found (Table 3). In turnip, however, texture was significantly affected by temperature, and samples stored at -2 ^{o}C were given higher scores for crispiness and juiciness than samples stored at either 5 ^{o}C or 10 ^{o}C (Table 4).

Table 4 Effect of storage temperature (T) and packaging materials (M) on appearance and texture attributes of fresh-cut turnip.

T (°C)	Colour evenness	Hue	Colour intensity	Whiteness	Hardness	Crispiness	Juiciness	Fibrousness
-2	8.24a	1.28d	1.39c	8.38a	4.34	5.60a	5.51a	1.32
0	7.24b	2.31c	1.95bc	7.68b	4.53	5.16ab	5.23ab	1.41
-2/5[1]	6.85b	3.29b	2.14b	7.45b	4.51	5.25ab	5.37ab	1.35
5	4.03c	6.18a	3.74a	5.48c	4.53	4.85b	4.85bc	1.50
10	3.06c	6.53a	3.96a	4.96c	4.50	4.69b	4.64c	1.46
p	***	***	***	***	n.s	***	***	n.s
M								
BOPP	5.97	3.88	2.60	6.81	4.57	5.08	5.05	1.41
PLA	5.81	3.96	2.67	6.77	4.39	5.14	5.19	1.41
p	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
TxM	*	***	*	n.s	n.s	n.s	n.s	n.s
Control (±SD)	8.57±0.57	1.10±0.24	1.15±0.26	8.61±0.41	4.46±0.53	5.58±0.82	5.61±0.78	1.23±0.54

n.s, not significant P≥0.05, * P<0.05, ** P< 0.01 and *** P< 0.001. For the temperature part of the table, values within a column followed by different letters are significantly with Tukey`s test (p=0.05). [1]Samples were stored at -2 °C for 5 days and then at 5 °C for 5 days.

Packaging material did not influence texture attributes of neither swede nor turnip. This is in accordance with Koide and Shi (2007), who reported no differences in appearance and texture between peppers packed with low-density polyethylene film or PLA film. A possible relationship between texture and weight loss is discussed in section 3.3.

3.2.2 Odour and flavour

In the present study, sour, green, metallic, cloying, earthy and cellar odour, bitter and sweet taste, aftertaste, and sour, metallic, pungent, cloying, sulphurous, and cellar flavour in swede were neither affected by storage temperature nor packaging material (selected results are shown in Table 5). For turnip, the following attributes were neither affected by temperature nor packaging material: bitter taste, pungent, metallic, sulphurous flavour and aftertaste (results not shown).

No differences in odour and flavour attributes were observed between samples stored at -2 ^{o}C and 0 ^{o}C, for neither swede nor turnip (Tables 5 and 6, respectively). Neither were there any significant differences in odour and flavour intensities between turnip samples stored at 5 ^{o}C and 10 ^{o}C. However, there were differences in odour and flavour attributes between 0 ^{o}C and 5 ^{o}C, especially for turnip. Comparing storage temperatures 0 ^{o}C and 5 ^{o}C, earthy flavour in swede was less intense in samples kept at 5 ^{o}C. For turnip, intensity of sour odour, sour flavour and green flavour decreased as an effect of 5 ^{o}C, while cloying odour, cloying flavour and muddy odour increased. Swede stored at -2 ^{o}C for 5 days and at 5 ^{o}C for the following 5 days was not significantly different in intensity of odour or flavour attributes from samples stored at neither -2 ^{o}C nor 5 ^{o}C. In contrast, corresponding turnip samples had lower intensity of some attributes of odour (sour, sulphurous) and flavour (sour, green) compared with samples stored at -2 ^{o}C, but higher compared with turnip samples stored at 5 ^{o}C (sour and green odours, sour and green flavours) . An exception was cloying flavour with highest intensity at 5 ^{o}C. This indicates that there was a relationship between storage temperature and odour and flavour intensities in turnip (Table 6).

Table 5 Effect of storage temperature (T) and packaging materials (M) on odour (O), flavour (F) and taste (T) attributes of fresh-cut swede.

	Sour-O	Sulphurous-O	Cloying-O	Earthy-O	Pungent-O	Sour-F	Sweet-T	Green-F	Earthy-F	Cloying-F	Astringency
T (^{o}C)											
-2	1.85	2.35b	2.32	1.37	1.44b	3.06	3.61	2.55a	1.89ab	1.78	2.90ab
0	1.90	2.27b	2.30	1.45	1.41b	3.11	3.51	2.36ab	2.02a	1.91	3.33a
-2/5[1]	2.17	2.67ab	1.83	1.61	1.73ab	3.04	3.18	2.46ab	1.95ab	1.61	2.78b
5	1.89	2.43b	2.17	1.49	1.50ab	2.77	3.35	1.99b	1.70b	2.08	2.86ab
10	2.53	3.24a	1.84	1.74	1.88a	2.87	3.38	2.19ab	1.78ab	1.87	2.81b
p	n.s	**	n.s	n.s	**	n.s	n.s	*	*	n.s	*
M											
BOPP	2.11	2.57	2.01	1.57	1.55	3.09	3.45	2.34	1.92	1.78	2.89
PLA	2.03	2.61	2.18	1.50	1.63	2.85	3.35	2.28	1.82	1.92	2.98
p	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
TxM	n.s	n.s	n.s	n.s	*	n.s	n.s	n.s	n.s	n.s	n.s
Control	5.02±1.21	4.91±1.39	1.04±0.13	2.33±1.02	3.56±1.29	4.70±1.00	3.76±0.53	3.34±1.17	2.19±0.96	1.16±0.36	3.23±1.26

n.s, not significant P≥ 0.05, * P<0.05, ** P< 0.01 and *** P< 0.001. For the temperature part of the table, values within a column followed by different letters are significantly with Tukey`s test (p=0.05). [1]Samples were stored at -2 ^{o}C for 5 days and after moved to 5 ^{o}C for 5 days.

Table 6 Effect of storage temperature (T) and packaging materials (M) on odour (O), flavour (F) and taste (T) attributes of fresh-cut turnip.

	Sour-O	Sulphurous-O	Green-O	Earthy-O	Pungent-O	Metallic-O	Muddy-O	Cloying-O	Sour-F	Sweet-T	Green-F	Cellar-F	Cloying-F	Astringency
T (°C)														
-2	3.89a	4.09a	2.50a	2.28a	3.33a	2.96a	1.48c	1.31c	4.15a	3.02a	2.86a	1.72a[2]	1.31b	3.71b
0	3.08ab	3.25ab	2.12a	2.00ab	2.52ab	2.68ab	1.58c	1.24c	3.43ab	2.81ab	2.47ab	1.86a	1.45b	3.90ab
-2/5[1]	2.56b	2.70b	1.94a	1.87ab	2.38ab	2.43ab	1.68bc	1.46bc	3.27b	2.74abc	2.22b	1.99a	1.58b	4.23a
5	1.67c	2.46b	1.19b	1.39b	2.08b	2.20b	2.60ab	2.63ab	2.32c	2.47bc	1.55c	2.27a	2.21a	4.03ab
10	1.48c	2.65b	1.19b	1.51ab	2.05b	2.30b	3.38a	2.93a	1.94c	2.33c	1.43c	2.34a	2.72a	4.34a
p	***	***	***	*	**	**	***	***	***	***	***	*	***	**
M														
BOPP	2.70	3.16	1.92	1.81	2.66	2.59	2.02	1.94	3.09	2.69	2.21	2.05	1.93	3.95
PLA	2.38	2.91	1.65	1.81	2.29	2.44	2.27	1.89	2.96	2.65	2.01	2.02	1.78	4.14
p	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
TxM	n.s	n.s	n.s	n.s	*	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
Control (±SD)	5.71 ±1.28	5.12 ±0.84	3.23 ±1.21	2.21 ±0.96	3.58 ±1.28	3.19 ±1.24	1.03 ±0.09	1.01 ±0.03	5.48 ±1.57	3.49 ±0.84	3.06 ±1.14	1.36 ±0.58	1.01 ±0.03	3.19 ±1.14

n.s, not significant P≥0.05, * P<0.05, ** P< 0.01 and *** P< 0.001. For the temperature part of the table, values within a column followed by different letters are significantly with Tukey`s test (p=0.05). [1]Samples were stored at -2 °C for 5 days and after moved to 5 °C for 5 days. [2]Significant differences between temperatures were not found using Tukey`s test.

Similar effects of storage temperature on odour and flavour attributes have been reported for whole packed carrots stored at 2 °C, 10 °C or 20 °C (Seljåsen et al., 2004).

No significant effects of packaging material on odour and flavour attributes were observed (Table 5-6). Almenar et al. (2008) found different aroma profiles between blueberries packed in a polyethylene terephthalate container and blueberries from a PLA container, however no sensory evaluation was included.

3.3 Effect of storage temperature and packaging material on dry matter content and weight loss

Storage temperature of -2 °C gave a significantly higher dry matter (DM) content in swede, compared with storage at 0 °C, but the effect of storage at 0 °C or 5 °C on DM was not different (Table 7). Storage at 10 °C gave a lower DM content in swede, compared with 5 °C. A higher metabolic activity at higher temperature could affect DM content in swede. However, total sugar content in swede was not affected by the temperatures. For turnip, storage at -2 °C or 0 °C gave significantly higher DM content compared with 5 °C or 10 °C. This could be due to higher total sugar content in turnip observed at lower storage temperatures. For both swede and turnip, the effect of storage at both -2 °C and 5 °C, was not different from the effect of storage at -2 °C or 5 °C. No significant difference between PLA and BOPP for dry matter content of swede was observed, while PLA gave higher DM content in turnip than BOPP.

For both swede and turnip, PLA gave a higher weight loss than BOPP. Similar result was observed by González-Buesa et al. (2014). They found a larger weight loss for celery sticks stored in a 44-µm thick unperforated film made of polylactic acid compared with celery sticks packed in a film made of polypropylene and low-density polyethylene, after storage at 7 °C. This could be due to moisture sorption properties of PLA (Holm et al., 2006). In the present study, temperature also had an effect on weight loss, and storage at -2 °C or 0 °C gave lower weight loss than samples stored for 5 °C or 10 °C, for both vegetables (Table 7).

Table 7 Effect of storage temperature (T) and packaging materials (M) on sugar, dry matter (DM) and fresh weight (FW) loss in fresh-cut swede and turnip (n=4).

	Swede						Turnip					
T (°C)	Glucose	Fructose	Sucrose	Total sugar	DM (%)	FW loss (%)	Glucose	Fructose	Sucrose	Total sugar	DM (%)	FW loss (%)
-2	29.04b	20.38b	3.33a	52.76	9.13a	0.41c	26.57b	14.61ab	5.69a	46.87a	5.52a	0.44d
0	30.21a	21.27a	2.04b	53.52	9.04bc	0.27c	27.94a	14.89a	4.06b	46.89a	5.47a	0.39d
-2/5[1]	30.40a	21.21a	1.96b	53.57	9.15a	0.75b	26.23b	14.89a	2.60c	43.73b	5.46ab	0.68c
5	30.09a	20.77ab	2.00b	52.86	9.11ab	0.87b	27.43a	14.07bc	2.62c	44.12b	5.38b	1.00b
10	30.47a	20.63b	2.08b	53.18	8.96c	1.60a	25.95b	13.65c	2.46c	42.07c	5.36b	1.63a
p	***	***	***	n.s	***	***	***	***	***	***	***	***
M												
BOPP	30.29	20.83	2.27	53.39	9.07	0.15	26.97	14.45	3.44	44.85	5.41	0.28
PLA	29.80	20.88	2.29	52.96	9.08	1.38	26.68	14.40	3.54	44.61	5.46	1.37
p	**	n.s	n.s	n.s	n.s	***	n.s	n.s	n.s	n.s	**	***
TxM	n.s	n.s	n.s	n.s	***	***	*	n.s	n.s	n.s	**	***
Control (±SD)	30.42 ±0.21	20.76 ±0.25	3.22 ±0.09	54.41 ±0.38	9.11 ±0.08		28.28 ±0.27	16.28 ±0.34	4.81 ±0.10	49.37 ±0.64	5.77 ±0.04	

n.s, not significant P≥0.05, * P<0.05, ** P< 0.01 and *** P< 0.001. For the temperature part of the table, values within a column followed by different letters are significantly with Tukey`s test (p=0.05). [1]Samples were stored at -2 °C for 5 days and then at 5 °C for 5 days.

This is in agreement with Manolopoulou and Varzakas (2011) who reported higher weight loss of packed cut cabbage stored at 5 ^{o}C compared with 0 ^{o}C. Weight loss could influence texture (Serrano et al., 2006). However, there were no significant effects of packaging material on texture attributes for either vegetable (Table 7).

3.4 Effect of storage temperature and packaging material on chemical compounds

3.4.1 Sugar

Total sugar content of swede was not significantly affected by temperature (Table 7). This is in line with results for whole swedes stored at 0 ^{o}C or 10 ^{o}C (Shattuck et al., 1991a). Contrary to swede, total sugar content in turnip was affected by temperature. Turnip samples stored at either -2 ^{o}C or 0 ^{o}C had significantly higher total sugar content than samples stored at higher temperatures (Table 7). The difference between ^{o}C 5 and 10 ^{o}C was due to lower glucose content at 10 ^{o}C. It could also be noticed for both vegetables, that storage at -2 ^{o}C resulted in a higher sucrose content compared with 0 ^{o}C. Sugar dynamics due to enzymes cleaving sucrose and metabolizing glucose and fructose (Halford et al., 2011) can at least in part explain the present results with reduction of sucrose content and variable changes in glucose and fructose contents in both swede and turnip by increased storage temperature. Shattuck et al. (1991b) points out that sugar contents in whole swede and turnip respond differently to storage temperature, which could also be the case for fresh-cut swede and turnip. The effect of BOPP, giving a little higher glucose content in swede is difficult to explain, but could indicate lower respiration rate during storage. However, this effect was not observed for turnip (Table 7).

3.4.2 Glucosinolates

Contents of total glucosinolates and total indolic glucosinolates in swede were affected by temperature (Table 8). In turnip total glucosinolates content was not influenced by storage temperature, due to opposite effects of temperature on aliphatic and indolic glucosinolates (Table 9). For both swede and turnip, higher storage temperature gave higher total indolic glucosinolates content, mainly due to changes in contents of glucobrassicin and 4-methoxyglucobrassicin. This was in agreement with Aires et al. (2012), who observed a higher content of 4-methoxyglucobrassicin in turnip stored at 22 °C compared with 4 °C. Among individual glucosinolates, only 4-hydroxyglucobrassicin in swede and 4-methoxyglucobrassicin in turnip had significantly different contents between storage at -2 °C and 0 °C, in both cases highest level at 0 °C. Storage at 5 °C vs. 0 °C gave lower glucoalyssin content in swede and lower content of total aliphatic glucosinolates in turnip, but for both vegetables higher contents of total indolic glucosinolates, glucobrassicin and 4-methoxyglucobrassicin (Table 9). For turnip, storage at 10 °C gave significantly lower gluconapin content compared with storage at 5 °C, while 4-methoxyglucobrassicin and neoglucobrassicin contents were higher at 10 °C. The effect of 5 days storage at -2 °C and then 5 days at 5 °C gave lower glucoalyssin content in swede than after 10 days storage at -2 °C, and lower content of 4-methoxyglucobrassicin than storage for 10 days at 5 °C. For turnip, changing storage temperature after half time gave lower contents of glucobrassicin and 4-methoxyglucobrassicin compared with storage at 5 °C, but higher content of 4-methoxyglucobrassicin than storage at -2 °C. Overall, the profile of glucosinolates in fresh-cut swede and turnip was different after storage at different temperatures in the interval of -2 °C to 5 °C: glucobrassicin and 4-methoxyglucobrassicin levels increased in both vegetables with temperature, whereas gluconapin in turnip and glucoalyssin in swede decreased. The unstored control had lower or similar levels of most glucosinolates as for the stored samples (Tables 8 and 9) indicating that there were effects of both storage time and storage temperature.

Table 8 Effect of storage temperature (T) and packaging materials (M) on glucosinolates (GLS) contents (μmol g^{-1} DM) in fresh-cut swede (n=4).

	Aliphatic GLS							Indolic GLS					Total GLS
	Progoitrin	Glucoerucin	Glucobrassicanapin	Glucoberteroin	Gluconapoleiferin	Glucoalyssin	Total Aliphatic GLS	Glucobrassicin	4-Hydroxyglucobrassicin	4-Methoxyglucobrassicin	Neoglucobrassicin	Total Indolic GLS	
<u>T (°C)</u>													
-2	4.34	0.61	0.13	1.56ab	0.64abc	0.49a	7.77	0.77c	0.34b	0.36c	0.79	2.26b	10.03ab
0	4.31	0.61	0.15	1.52ab	0.63bc	0.47ab	7.69	0.73c	0.43a	0.36c	0.81	2.33b	10.02ab
-2/5[1]	4.14	0.56	0.14	1.41b	0.62c	0.44bc	7.31	0.81bc	0.36ab	0.36c	0.80	2.33b	9.64b
5	4.47	0.62	0.13	1.62a	0.66ab	0.42c	7.92	0.90b	0.45a	0.43b	0.84	2.62a	10.54a
10	4.31	0.58	0.13	1.57a	0.67a	0.35d	7.61	1.04a	0.37ab	0.48a	0.86	2.75a	10.37ab
p	n.s	n.s	n.s	**	**	***	n.s	***	**	***	n.s	***	*
<u>M</u>													
BOPP	4.23	0.59	0.14	1.50	0.63	0.42	7.51	0.84	0.39	0.39	0.82	2.44	9.95
PLA	4.40	0.60	0.14	1.57	0.65	0.45	7.81	0.85	0.40	0.40	0.82	2.48	10.28
p	*	n.s	n.s	n.s	**	*	*	n.s	n.s	n.s	n.s	*	n.s
TxE	n.s	*	n.s	*	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
Control (±SD)	3.84 ±0.12	0.52 ±0.02	0.15 ±0.01	1.41 ±0.02	0.59 ±0.02	0.27 ±0.02	6.77 ±0.14	0.44 ±0.05	0.34 ±0.02	0.28 ±0.02	0.68 ±0.04	1.73 ±0.15	8.51 ±0.18

n.s, not significant P≥0.05, * P<0.05, ** P< 0.01 and *** P< 0.001. For the temperature part of the table, values within a column followed by different letters are significantly with Tukey`s test (p=0.05). [1]Samples were stored at -2 °C for 5 days and then at 5 °C for 5 days.

Table 9 Effect of storage temperature (T) and packaging materials (M) on glucosinolate (GLS) contents (µmol g^{-1} DM) in fresh-cut turnip (n=4).

	Aliphatic GLS					Indolic GLS					Aromatic GLS	Total GLS
	Progoitrin	Glucoerucin	Glucobrassicanapin	Gluconapin	Total Aliphatic GLS	Glucobrassicin	4-Hydroxyglucobrassicin	4-Methoxyglucobrassicin	Neoglucobrassicin	Total Indolic GLS	Gluconasturtiin	
T (^{o}C)												
-2	2.93	0.92ab	1.92a	11.14a	16.92a	1.90c	1.00	0.67e	0.20b	3.78d	5.53	26.23
0	2.99	0.94a	1.94a	10.90ab	16.76a	2.06bc	0.99	0.84d	0.19b	4.07c	5.41	26.25
-2/5[1]	2.59	0.95a	1.83a	10.42ab	15.80ab	2.15b	0.96	1.01c	0.21ab	4.32c	5.38	25.49
5	2.94	0.89ab	1.64ab	9.77b	15.24b	2.72a	0.93	1.60b	0.20b	5.46b	5.61	26.31
10	3.13	0.76b	1.42b	8.32c	13.64c	2.83a	0.93	2.05a	0.23a	6.04a	5.41	25.08
p	n.s	*	**	***	***	***	n.s	***	**	***	n.s	n.s
M												
BOPP	2.94	0.90	1.79	10.28	15.91	2.31	0.99	1.20	0.21	4.71	5.38	26.01
PLA	2.89	0.88	1.71	9.95	15.43	2.35	0.93	1.26	0.21	4.75	5.56	25.74
	n.s	n.s	n.s	n.s	n.s	n.s	n.s	***	n.s	n.s	n.s	n.s
TxM	n.s	n.s	n.s	n.s	n.s	**	n.s	***	n.s	**	n.s	n.s
Control	1.34	0.91	1.83	10.84	14.92	1.66	0.94	0.66	0.22	3.48	5.15	23.55
(±SD)	±0.12	±0.05	±0.21	±0.40	±0.37	±0.05	±0.02	±0.02	±0.02	±0.15	±0.13	±0.39

n.s, not significant P≥0.05, * P<0.05, ** P< 0.01 and *** P< 0.001. For the temperature part of the table, values within a column followed by different letters are significantly with Tukey`s test (p=0.05). [1]Samples were stored at -2 ^{o}C for 5 days followed by 5 ^{o}C for 5 days.

Packaging with PLA gave significantly higher contents of progoitrin, gluconapoleiferin and glucoalyssin in swede than BOPP. In turnip, packaging with PLA gave higher content of 4-methoxyglucobrassicin (Tables 8 and 9). The effect of packaging material could be a response to higher weightloss caused by PLA (Table 7).

3.5 Relating chemical and sensory measurements

To relate chemical measurements with sensory attributes PLSR was used, and the results for swede and turnip are presented in correlation loading plots (Fig. 1 and 2, respectively). For swede, PLS component 1 explains most of the variation in chemical (53%) and sensory (45%) data. Cloying odour, cellar odour, cloying flavour and cellar flavour correlate with glucoerucin, progoitrin, gluconapoleiferin, neoglucobrassicin, glucobrassicin, 4-methoxyglucobrassicin, total indolic and total aliphatic glucosinolates. Glucosinolates are suggested to be responsible for flavour and odour in *Brassica* vegetables, e.g. bitter taste (Cartea and Velasco, 2008). For swede, bitter taste and total glucosinolates content correlates with PLS component 1 but less than 50% of the variance explain this (Fig. 1). Sucrose and sweet taste correlate in the same way to the two first PLS components. However, since sweet taste is located in the inner ellipse, there is no strong correlation. The weak correlation between bitter and sweet taste and the content of glucosinolate and sugar, respectively, could be due to the small difference in sugar and glucosinolates concentrations between samples. These differences in concentration may not be sufficient for the sensory panel to detect. From the distribution of the samples in the plot, the control sample is separated from the stored samples (values given in Tables 3 and 5) along PLS component 1, which indicates that other parameters e.g. storage time has an effect on fresh-cut swede.

For turnip, PLS component 1 explains most of the variation in chemical (56%) and sensory (67%) data (Fig. 2).

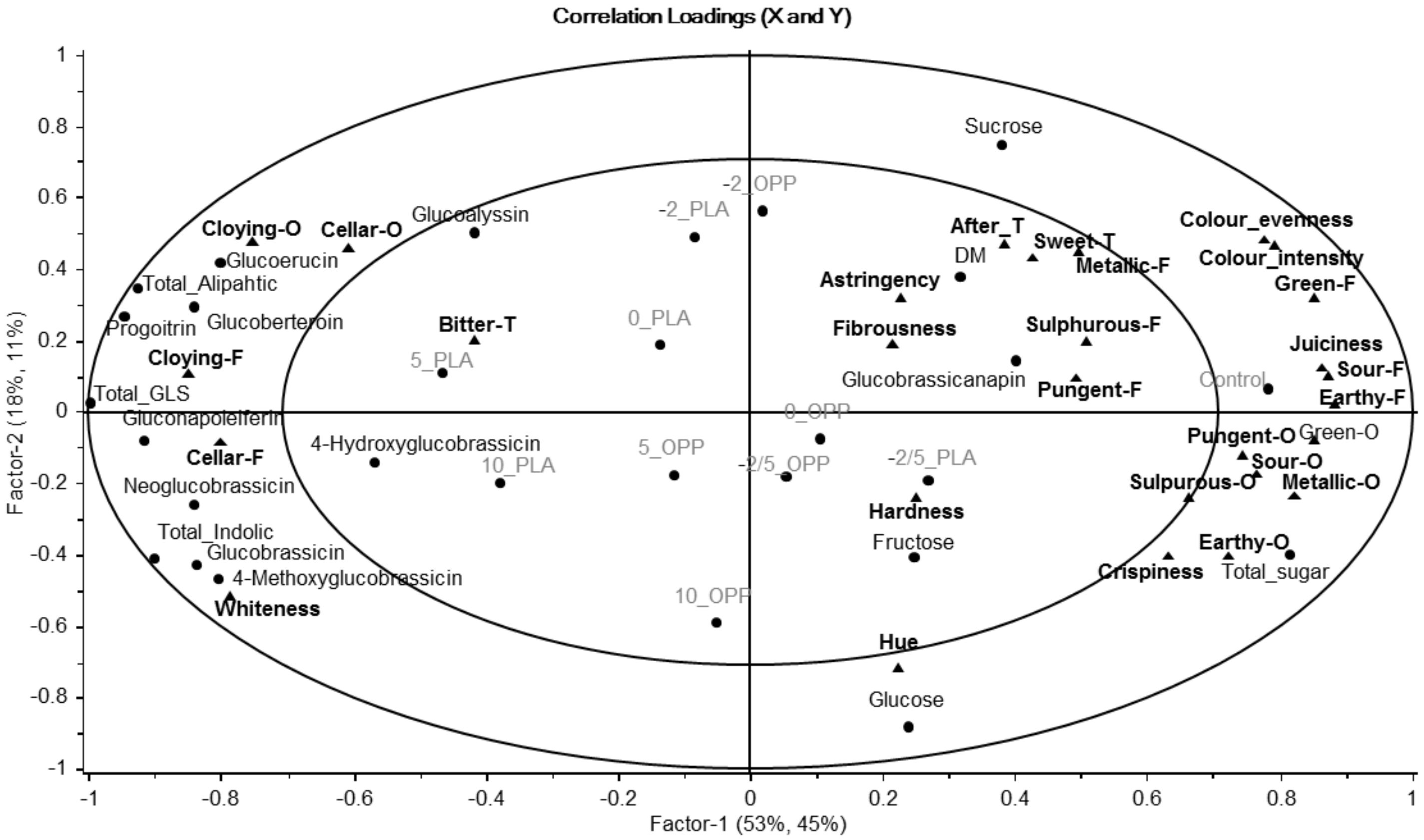

Fig. 1 PLSR correlation loading plot for sensory attributes (▲) chemical measurements (●) of fresh-cut swede samples packed in pouches using two packaging materials (BOPP and PLA) and stored at -2, 0, 5 or 10 ^{0}C (first number in sample name) for 10 days. One set of samples were stored at -2 ^{0}C for 5 days and after followed by 5 ^{0}C for 5 days (-2/5). A non-stored control sample was also analysed together with stored samples. Inner and outer ellipses represents r^2= 50 and 100% explained variance, respectively.

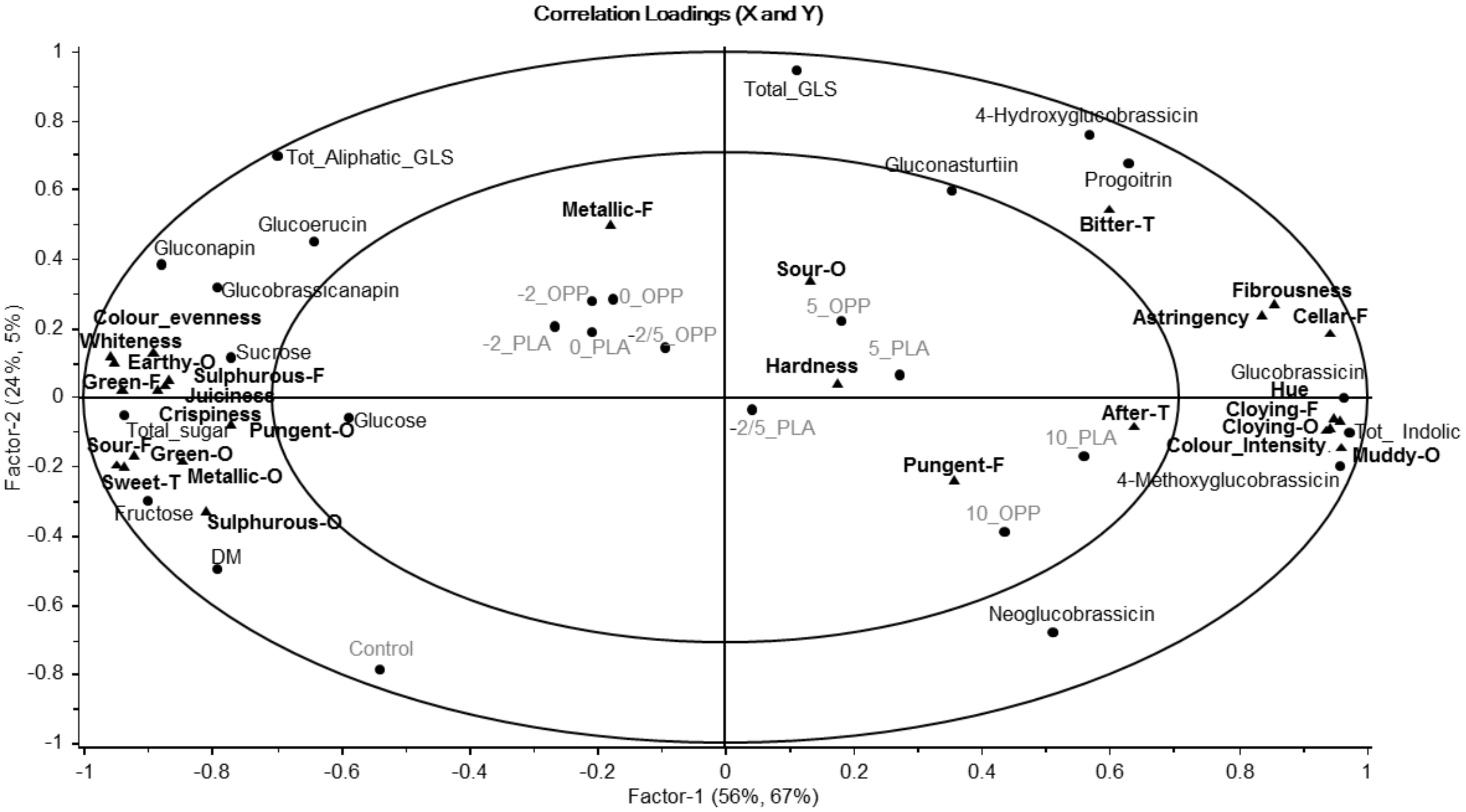

Fig. 2 PLSR correlation loading plot for sensory attributes (▲) as X and chemical measurements (●) as Y of fresh-cut turnip samples packed in pouches using two packaging materials (BOPP and PLA) and stored at -2, 0, 5 or 10 °C (first number in sample name) for 10 days. One set of samples were stored at -2 °C for 5 days and followed by 5 °C for 5 days (-2/5). A non-stored control sample was also analysed together with stored samples. Inner and outer ellipses represents r^2= 50 and 100% explained variance, respectively.

Gluconapin, glucoerucin, glucobrassicanapin, total sugar, sucrose, fructose, dry matter, earthy odour, colour evenness, whiteness, crispiness, juiciness, green flavour, sulphurous flavour, pungent odour, green odour, sour flavour, sulphurous odour and sweet taste are positively correlated together with the control sample along component 1. Bitter taste, astringency, fibrousness, cellar flavour, colour intensity, cloying flavour, cloying odour, muddy odour, hue, glucobrassicin, 4-methoxyglucobrassicin, progoitrin and 4-hydroxyglucobrassicin were, together with samples stored at 10 ^{o}C, positively correlated. Glucosinolates like progoitrin, 4-hdyroxyglucobrassicin, glucobrassicin and 4-methoxyglucobrassicin were related to bitter taste. For both vegetables, there are most probably other chemical compounds than glucosinolates and sugar responsible for flavour and odour (Cartea and Velasco, 2008), which should be studied more in the future. All samples are spanned along PLS component 1 with control sample and samples stored at 10 ^{o}C most separated (Fig. 2). Samples stored at -2 ^{o}C are closest to the control sample, which indicates that samples kept at -2 ^{o}C were more similar to the control sample in terms of sensory attributes. It can also be noticed, that samples stored first at -2 ^{o}C followed by storage at 5 ^{o}C are located between samples stored at -2 and 5 ^{o}C. This indicates that storing first at -2 ^{o}C and then at 5 ^{o}C, gave smaller changes than storage at 5 ^{o}C.

4. Conclusion

Freezing points for dice of swede and turnip indicate that storage of fresh-cut swede and turnip at temperatures below 0 ^{o}C without freezing is possible. Differences between -2 ^{o}C and 0 ^{o}C storage were mainly noticed in appearance attributes of swede, and especially turnip. For flavour and odour attributes no clear differences were found between -2 ^{o}C and 0 ^{o}C, for neither turnip nor swede. However, the differences in flavour and odour attributes between storage at 0 ^{o}C and 5 ^{o}C were more pronounced, and if a lower temperature is used in the first half of the distribution period, changes in sensory attributes could be reduced. Sucrose content was better kept in fresh-cut swede and turnip at low temperature storage, especially for turnip, and turnip stored at low temperatures were also sweeter. Higher storage temperature gave higher content of indolic glucosinolates in fresh-cut swede and turnip. There were few significant differences between the packaging materials, although PLA gave a higher weight loss, compared to OPP. Fresh-cut swede and turnip behaved to some extent similarly at low temperature storage, but also very differently, since turnip significantly changed the intensity of many more sensory attributes with increasing temperature than swede. Changes in glucosinolates were also larger in turnip than in swede. Regression between sensory attributes and chemical compounds measured were to a large extent weak, but sweet taste was positively correlated with sucrose, fructose and total sugar contents, and bitter taste with progoitrin and 4-hydroxyglucobrassicin contents in turnip. In swede these correlations were weaker. It is not possible to conclude on exact relationships from the limited set of compounds quantified in this study.

5. Acknowledgements

This research was administered by the Research Council of Norway (Project Nr. 199409) and funded by Foundation for Research Levy on Agricultural Products and the Agricultural Agreement Research Fund, together with the Norwegian food industry partners Gartnerhallen AL, Bama Gruppen AS, Findus Norge AS, FellesJuice AS, HOFF SA, Graminor AS, NordGrønt, Norgesgrønt, Maarud AS, KiMs Norge AS. Technical assistance from Hanne Zobel is highly appreciated.

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