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Effects of storage on the visual quality, ascorbic acid and total phenolic content of fresh-cut rutabaga, kohlrabi and parsnip

by

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Abstract

The market for minimally processed fruit and vegetables is growing rapidly and root vegetables may be interesting as fresh-cut products. The effect of cutting size and storage time on the quality of the fresh-cut rutabaga, kohlrabi and parsnip was studied. Two different sizes of fresh-cuts were compared; big slices and small sticks. For rutabaga and kohlrabi half of the fresh-cuts were stored directly after cutting whereas the other half was immersed in water before storage. The parsnip fresh-cuts were subjected to two different treatments before storage. They were immersed in dip solutions containing ascorbic acid or citric acid. The fresh-cuts were stored in plastic boxes for 3, 5 or 8 days. Content of ascorbic acid was decided for rutabaga and kohlrabi. Total phenolic compounds and dry weight were measured and the visual quality evaluated for all three root vegetables.

The ascorbic acid content was relatively high in both rutabaga and kohlrabi, and ranged from 30 to 55 mg/100 g FW. Storage had no effect on the content of ascorbic acid. Total phenolic content was comparatively low in all three vegetables and varied between 15 – 70 mg gallic acid equivalents/100 g FW. A decrease in total phenolic content during storage was demonstrated in rutabaga and kohlrabi. Storage had only minor effects on the visual quality of rutabaga and kohlrabi. In parsnips, extensive browning rapidly reduced the visual quality, making the fresh-cuts unmarketable.

From the results gained in this study, rutabagas and kohlrabi seem to have large potential as fresh-cut products, whereas parsnip does not seem to be suitable for minimal processing with the chosen cultivar and the processing and storage techniques used in this investigation.

Sammanfattning

Försäljningen av färdigskurna frukt och grönsaksprodukter har ökat de senaste åren. Nya produkter utvecklas hela tiden och rotfrukter skulle kunna vara ett intressant inslag bland dessa.

I den här studien undersöktes effekten av snittningsstorlek och lagring på kvaliteten hos färdigskuren kålrot, kålrabbi och palsternacka. Två olika storlekar på de färdigskurna rotfrukterna jämfördes; stora skivor och små stavar. Bitarna var också uppdelade i två olika behandlingar. För kålrot och kålrabbi doppades hälften av bitarna i vatten innan lagring, medan den andra hälften var obehandlade. Palsternacksbitarna doppades i askorbinsyra eller citronsyralösning. Bitarna lagrades sedan i platsförpackningar i3, 5 eller 8 dagar. I kålrot och kålrabbi analyserades halten av askorbinsyra. Mätning an totalfenolinnehåll och bedömning av den visuella kvaliteten gjordes för alla tre rotfrukterna.

Relativt höga halter av askorbinsyra, 30 till 55 mg/100 g FW, uppmättes i både kålrot och kålrabbi. Askorbinsyrainnehållet påverkades inte av lagringen. Totalfenolinnehållet var jämförelsevis lågt i alla rotfrukterna och varierade mellan 15 och 70 mg gallsyra-ekvivalenter/100 g FW. I både kålrot och kålrabbi minskade mängden totalfenoler under lagring. Den visuella kvaliteten var hög för kålrot och kålrabbi under hela lagringstiden. Palsternacksbitarna brunfärgades kraftigt vilket snabbt gjorde dem osäljbara.

Från resultaten i denna studie kan man dra slutsatsen att både kålrot och kålrabbi har bra förutsättningar att fungera som färdigskurna produkter. Palsternacka däremot, verkar inte fungera som färdigskuren produkt under de förutsättningar som undersöktes i detta experiment. Andra process och lagringstekniker eller sortval skulle kunna minska brunfärgningen.

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Introduction

The topic of this report is the quality aspects associated with minimal processing of root vegetables into fresh-cut products.

The health benefits of a regular consumption of fruit and vegetables have been shown in numerous studies. Also, consumer are becoming more and more aware and demanding convenient ready-to-eat fruit and vegetables with a fresh-like quality containing only natural ingredients (Ahvenainen, 1996). The market is growing rapidly and new products are developed continuously. Root vegetables should have good potential as fresh-cuts products. However, studies on the effect of minimal processing on root vegetables are scarce.

Different parameters can be used to evaluate the quality and deterioration of fresh-cuts. This report will cover relevant background information about fresh-cut products, vitamin C, phenolic compounds, enzymatic browning and root vegetables in general. The results of a practical study will also be presented. Three different root vegetables; rutabaga, kohlrabi and parsnip, were chosen for investigation. The aim was to study the effect of cutting size and storage time on the quality of the fresh-cut root vegetables. The content of ascorbic acid was decided for rutabaga and kohlrabi. Total phenolic compounds and dry weight was measured and the visual quality evaluated for all three root vegetables.

Background

Minimally processed / Fresh-cut products

"Minimally processed" means that the produce is prepared and handled to maintain their fresh nature while providing convenience to the user. The production involves cleaning, washing, trimming, coring, slicing and shredding (Cantwell, 1992).

The International Fresh-cut Produce Association (IFPA) defines fresh-cut as "any fruit and vegetable or combination thereof that has been physically altered from its original form, but remains in a fresh state"(Lamikanra, 2002).

The minimally processed vegetable and fruit industry was initially developed to supply restaurants, hotels and other institutions, and more recently was expanded to include food retailers for home consumption (Irtwange, 2006).

Many studies has shown that regular consumption of fruit and vegetables is linked to reduced risks of chronic diseases such as cancer, coronary heart disease, diabetes, Alzheimer's disease, cataracts and age-related functional decline (Dewanto et al., 2002). Practical strategies with dietary modifications can prevent these chronic diseases to some extent. This has led to new nutritional recommendations to increase the consumption of fruit and vegetables. Both the growth in consumers' awareness of the health benefits and the rising need for convenience due to a fast-paced lifestyle has increased the demand for ready-to-use fruit and vegetable products (Dewanto et al., 2002).

Growth in demand of minimally processed fruits and vegetables has led to increased sales and the market is growing rapidly in the US and Europe (Ahvenainen et al., 2003). In the US the market size of the fresh-cut business is estimated at $10-12 billion which is about 15% of the total fresh produce market (Irtwange, 2006).

Whereas most food processing techniques stabilize the product and lengthen their storage and shelf life, light processing of fruit and vegetables increases their perishability. As a result of peeling, grating and shredding the rates of metabolic processes increase resulting in a shorter shelf-life (Cantwell, 1992). The deterioration of the produce is caused by physiological ageing, biochemical changes and microbial spoilage, which may result in degradation of the colour, texture and flavour of the produce (Ahvenainen, 1996).

Knowledge of the nature of fresh-cut fruits and vegetables as they relate to pre- and post-harvest handling, processing, packaging and storage are essential for ensuring their wholesomeness and nutritional value, and for developing the most effective procedures and

innovative technologies for maintaining their quality to meet increasing consumer demand (Ahvenainen, 1996).

Vitamin C

Vitamin C is defined as the common term for all compounds exhibiting the biological activity of L-ascorbic acid (AA). AA is the principal biologically active form but L-dehydroascorbic acid (DHA), an oxidation product, also exhibits biological activity. In many horticultural crops DHA represents less than 10% of total vitamin C but DHA tends to increase during storage. DHA can be reduced to AA by reducing agents and it can also be irreversibly oxidized to form diketogulonic acid, which has no vitamin C activity. DHA can easily be converted into AA in the human body (Lee et al., 2000).

Vitamin C in the human diet

Vitamin C plays an important role in the human body as it is a constituent of many coenzymes and thus involved in different body functions. It is vital for the production of collagen and helps protect the fat-soluble vitamin A and E as well as fatty acids from oxidation. It also prevents and cures the disease scurvy, and can be beneficial in the treatment of iron deficiency anemia (Gordon, 2008).

Vitamin C can not be synthesized by primates, including humans, due to a mutation in our genes. Therefore, it is essential that we obtain it from our diet (Horton et al., 2002). In Sweden, the recommended daily intake is approximately 75 mg (Livsmedelsverket, 2008a). More than 90% of vitamin C in human diets is supplied by fruits and vegetables (including potatoes).

AA is present in plant tissues undergoing active growth and development, and the amount of AA varies among species and cultivars. Vitamin C contents are also variable among tissues. Usually skin tissues have more AA content to protect the fruit from outside stress caused by light and oxidation (Lee et al., 2000).

Generally, leafy vegetables, citrus fruit and some tropical fruit have high levels of AA (Yahia et al., 2001). Citrus fruits and potatoes are known to be the most important sources of vitamin C in the western diet because of the large quantities consumed (Lee et al., 2000).

Factors influencing degradation of vitamin C

The mechanisms for vitamin C losses are still not fully understood. AA is easily oxidized especially in aqueous solutions, and the oxidation is greatly favoured by the presence of oxygen, heavy metal ions, alkaline pH and high temperature (Lee et al., 2000). In addition to oxidative damage, enzymes may also function indirectly to lower the vitamin C content (Ball, 1997). Ascorbate oxidase is a copper-containing enzyme that oxidizes AA to DHA in the presence of molecular oxygen. It is thought to be the major enzyme responsible for the enzymatic degradation of AA (Lee et al., 2000).

Vitamin C is most sensitive to destruction when the product is subjected to unfavourable handling and storage conditions. Losses are enhanced by extended storage, higher temperatures, low relative humidity, physical damage and chilling injuries (Lee et al., 2000). Many pre- and postharvest factors influence the vitamin C content of horticultural crops. The preharvest factors include climatic conditions and cultural practices such as light and temperature during growth and amount of fertilizer and irrigation applied to the crop. Maturity at harvest and harvesting method also affect the vitamin C content in fruit and vegetables (Lee et al., 2000).

In general, freshly harvested fruits and vegetables contain more vitamin C than those held in storage and they show a gradual decrease in AA content as the storage temperature or duration increases (Lee et al., 2000).

Earlier studies have shown that the amount of AA lost during storage differs with the vegetable. Fruit do not loose as much AA as inflorescence and leafy vegetables which can loose as much as 60-80 % (Watada, 1987).

Temperature management is the most important tool to extend shelf-life and indirectly delay losses in nutrients such as vitamin C. Accelerated losses in vitamin C at higher temperatures has been shown in many types of fruits and vegetables (Lee et al., 2000). In chilling sensitive crops low temperatures can cause decrease of vitamin C content (Watada, 1987).

Losses in vitamin C also occur when vegetables are severely cut or shredded as in the case when they are sold in salad mixes. The metals in the knife blades and blades of blenders are known to catalyze oxidation of ascorbate (Ball, 1997). Cooking is often responsible for the greatest loss of vitamin C, and the extent of the loss depends upon variations in cooking methods (Lee et al., 2000).

In general atmospheric modification reduces physiological and chemical changes of fruits and vegetables during storage but the effect differs with the commodity, atmosphere and

storage temperature. Low O_2 content has been shown to prevent loss of vitamin C in for example, parsley, corn, salad and apples (Watada, 1987).

Phenolic compounds

Phenolic compounds are widely distributed in both edible and nonedible plants (Kähkönen et al., 1999). The substances classified as phenolics are a large group of compounds, all of which contain a phenol group – a hydroxyl group (-OH) attached to an aromatic ring. Plant phenolics are a chemically diverse group of nearly 10 000 different compounds. Some are water-soluble carboxylic acids and glycosides, some are soluble only in organic solvents, and some are large insoluble polymers. Plant phenolics include important groups like flavonoids, phenolic acids, tannins and lignins (Taiz & Zeiger, 2002).

Although phenolic compounds represent the most studied of secondary metabolites, the function of many phenolics is still unknown (Raven et al., 1999). Due to their chemical diversity they play a wide range of roles in the plant. Many are important for defence against herbivores, infection by pathogens or other injuries. Some, like the lignins, function in mechanical support (Taiz & Zeiger, 2002). Some flavonoids, the anthocyanins partly provide the plant colours present in flowers, fruits and leaves (Kähkönen et al., 1999). Others absorb harmful ultraviolet radiation or reduce the growth of nearby competing plants (Taiz & Zeiger, 2002).

Phenolic compounds in the human diet

During recent years researchers and food manufacturers have become increasingly interested in phenolic compounds because of their health promoting properties (Manach et al., 2004). For example, flavonoids found in red wines and grape juice has received considerable attention because of their reported lowering of cholesterol levels in the blood (Raven et al., 1999).

The phenolic compounds have been accounted to have multiple biological effects, including antioxidant activity. Antioxidant constituents have an important role in the maintenance of health and protection from coronary heart disease and cancer (Kähkönen et al., 1999). They can protect the human body from reactive oxygen species, which may have potential to damage cell components, such as DNA, proteins and lipids (Halliwell & Gutheridge, 2007).

In addition to their antioxidant properties phenolics modulate the activity of a wide range of enzymes and cell receptors. However, these specific biological actions are yet poorly understood (Manach et al., 2004).

The health effects of phenols depend both on the amount consumed, their bioavailability and the absorption in the body. The bioavailability can vary greatly and not all phenolics are absorbed with equal efficacy (Manach et al., 2004). The knowledge in these areas remains fragmentary and diverse, and there are many challenges to overcome in order to fully understand their health effects (Naczk & Shahidi, 2003). More epidemiological and clinical studies should be preformed to fully understand the actions of phenolic compounds (Mattila & Hellström, 2007)

Factors influencing degradation of phenolic compounds

Phenolics are a diverse group of substances, and for many plant products the exact composition is relatively unknown. Just like in the case of vitamin C, several factors may affect the phenolic content of plants. They include environmental factors during cultivation, ripeness at time of harvest, storage and processing. Some phenols are directly involved in the plants responses to different kinds of stress. Their concentrations may increase after injury or infection.

Storage and processing can reduce the content of phenolic compounds as some of them are easily oxidized, while others are more stablie. Oxidation results in the formation of more or less polymerized substances, as in the case of enzymatic browning (bescribed below).

Processing in the form of simple peeling of fruit and vegetables can remove a major portion of the phenols, as the concentrations of these substances are often higher in the outer than the inner parts (Manach et al., 2004).

Enzymatic browning

Ezymatic browning is the most limiting factor on the shelf life of fresh-cut products (Lamikanra, 2002). During peeling and grating operations, many cells are ruptured and intracellular products such as oxidizing enzymes are liberated (Ahvenainen, 1996). Enzymatic browning is the discoloration, caused to a large extent by the action of a group of enzymes called polyphenoloxidases (PPO) (Lamikanra, 2002). Consequences of enzymatic browning are not restricted to discoloration, undesirable flavours can occur and loss of nutrient value may result (Irtwange, 2006).

The polyphenoloxidases were first discovered in mushrooms and have been reported to occur in all plants (Marshall et al., 2000). It is found in particularly high amounts in apple, pear, banana, peach, potato and avocado (Lamikanra, 2002). The susceptibility to enzymatic browning varies a lot between different fruits and vegetable species, and can also differ between cultivars within the same species (Irtwange, 2006).

The polyphenoloxidases exist in the plastids and chloroplasts of plants and also free in the cytoplasm of senescing or ripening plants. They are thought to play an important role in plant resistance to microbial and viral infections and to unfavourable climatic conditions. Polyphenoloxidase catalyses the initial step in the polymerization of phenolics into quinones, which undergo further polymerization to form dark, insoluble polymers referred to as melanins. The melanins form barriers and have antimicrobial properties which prevent the spread of infection or bruising in plant tissues (Marshall et al., 2000).

PPO is considered as one of the most damaging enzymes to quality maintenance of fresh produce (Irtwange, 2006). It is estimated that over 50 % of the losses in fruit is a result of enzymatic browning. Such losses have encouraged considerable interest in understanding and controlling of phenoloxidase enzymes in foods (Marshall et al., 2000).

Appearance, which is significantly influenced by colour, is one of the first attributes consumers use when evaluating food quality. As a result of that the control of browning is one of the most important issues for the food industry as brown foods are considered as spoiled (Marshall et al., 2000).

Enzymatic browning can be controlled by a wide range of physical and chemical methods. Low temperature is one of the most commonly used approaches for controlling enzymatic activity in fresh-cut products. At low temperatures enzymatic activity is reduced. Additionally, general metabolic rates are also lower, which helps in extending product shelf life (Irtwange, 2006). Other physical methods can include reduction of oxygen availability by the use of modified atmosphere packaging (MAP) or edible coatings and treatment with gamma irradiation or high pressure (Irtwange, 2006, Marshall et al., 2000).

Addition of different inhibitors can also be used in preventing enzymatic browning. For example lowering of the pH inhibits the enzyme activity. One of the most commonly used acidulants in the food industry is citric acid. It is normally applied at levels between 0.5 and 2% (w/v). Furthermore, several kinds of reducing agents like ascorbic acid and sulphating agents are used as browning inhibitors. A combination of acidulants and a reducing agent is often utilized to achieve the best effect (Marshall et al., 2000).

Heat inactivation such as steam blanching is also an effective method for preventing browning. However, heat treatment can only be used for canned or frozen vegetables, not fresh-cut products (Marshall et al., 2000).

Root vegetables

Root vegetables are the term used for vegetables with a "root-like-appearance". Botanically they include both true roots and other plant parts like swollen stems and tubers. Regardless of anatomical type, root vegetables are generally storage organs. The root vegetables mainly belong to the families *Brassicaceae* and *Apiaceae*.

Root vegetables have many positive properties which should gain them an important part in the human diet. They are healthy, nutritional meal components that give a good satiety. In addition, they are relatively cheap and can be locally produced and stored for a long time. However, root vegetables are not as popular and appreciated as they could be. The largest reason for this is probably that many consumers considered the preparation of root vegetables too time consuming. To increase the demand for these vegetables fresh-cut products would be a good alternative. Stir and fry preparations to be served with meat are increasingly popular in Europe. These products, already developed in the U.S., are being adapted to the European market (Lamikanra, 2002). Ready-to-eat stews and microwave casserole packs are other examples of products that could make root vegetables more accessible.

Brassicaceae family

The *Brassicaceae* family (former *Cruciferae*) includes a wide range of horticultural crops, some of them with economic significance, extensively used in diet throughout the world (Fernandes et al., 2007).

Health-care professionals have long considered several members of the plant family *Brassicaceae* as important dietary contributors to good health. First of all, they provide important nutrients such as vitamins C and A, folic acid, calcium and potassium. They also contain dietary fibres and are low in calories and fat. Furthermore, crucifers are a good source for obtaining glucosinolates of which some are considered health-promoting (West et al., 2004).

Rutabaga

Rutabaga (*Brassica napus* L. *napobrassica* group*)* is a root crop belonging to the *Brassicaceae* family that originated as a cross between cabbage and turnip. The name "Rutabaga" comes from dialectal Swedish "rotabagge" (root ram) and is the common American English term for the plant. In much of England, Australia and New Zealand "Swede" is the preferred term used in. Its common name in Sweden is "Kålrot" (cabbage root) (Israelsson, 2000).

The origin of the rutabaga is uncertain but it is either North Euorpe or Siberia. From there, it reached Scotland, and spread to the rest of Great Britain and to North America. The Rutabaga has been used both for human consumption and animal fodder (LivsmedelsSverige, 2008).

Rutabaga is a cool-weather crop and is grown primarily in the northern parts of the Europe and United States, in Great Britain and in Canada (Nascimento Nunes, 2004).
The rutabagas may be purple, green or yellow with a white or yellowish flesh. If stored in 0°C rutabagas can be kept for 4 to 6 month (LivsmedelsSverige, 2008, Nascimento Nunes, 2004). The early, small rutabagas have a mild cabbage taste and can be shredded and served raw. Larger specimens can be cut into pieces and used in casseroles, soups, stews or wok dishes. In Sweden rutabagas is mostly used in “rotmos”, where they are mashed together with potatoes (LivsmedelsSverige, 2008).

According to Zhu et al., (2002) and Nascimento Nunes, (2004) rutabagas are good candidates for fresh-cut products. Pre-peeled rutabagas packaged in consumer film bags have a shelf life of 3 weeks at 0 °C. Fresh-cut rutabagas stored in 15% O_2 will keep for 10 days at 10 °C and 20 days at 1 °C (Nascimento Nunes, 2004). However, the correct choice of variety is particularly important in the case of rutabaga. Some varieties are juicier when grated and therefore not suitable for fresh-cut products (Ahvenainen, 1996).

Kohlrabi

Brassica oleracea L. *gongylodes* group, also known as kohlrabi is a cabbage variety with an enlarged edible stem. Kohlrabi is grown as an annual, and thrives best in cool, humid weather. Only young kohlrabi should be harvested, since mature product becomes woody and tough. The enlarged stem may have light green or purple skin but the flesh is always white (Forney & Toivonen, 2004). Kohlrabi can be stored in 0°C for 2 to 3 month (Forney & Toivonen, 2004, Escalona, 2005).

Kohlrabi has a mild sweet cabbage taste and a crispy texture. It can be eaten raw as well as boiled served with butter, in soups, casseroles, stews and gratins (Israelsson, 2000).

Studies on postharvest behaviour of whole and fresh-cut kohlrabi are scarce. However, according to Escalona et al., 2005 and Forney & Toivonen, 2004, peeled and sliced kohlrabi has potential as a fresh-cut product. Escalona et al., 2005 found that slicing of kohlrabi did not dramatically affect the metabolic activity compared to whole stems when stored for 14 days at 5°C. Respiration rate, ethylene production, and sugar and acid contents were similar for whole and sliced kohlrabi. Furthermore, the bacterial growth was low and no significant colour change was detected when measured with a colorimeter. The limiting factor for storage life of sliced kohlrabi was the loss appearance, texture and taste. (Escalona et al., 2006)

Parsnip

The parsnip (*Pastinaca sativa*) is biennial plant, belonging to the Apiaceae or parsley family. It is a native of Europe and Asia where it has been eaten since ancient times. The crop is grown as an annual and is a long season crop (~ 100 days) that thrives best in cool growing climates. The thickened, cream-color root is the edible part of the parsnip. (Toivonen, 2004 & Israelsson, 2000). It has a mild celery-like fragrance and a sweet nutty flavour. Parsnips can be eaten raw, boiled, roasted or used in gratins, soups and casseroles (LivsmedelsSverige, 2008).

Parsnips are harvested in the late fall, preferable after frost. An important component of parsnip quality is sweetness, which is enhanced by exposure to frost. The roots can then be stored 2 to 6 month in 0°C with 95-100% RH (Toivonen, 2004, Israelsson, 2000, LivsmedelsSverige, 2008).

Surface browning in parsnips is a significant problem that has been recognized for many years (Toivonen, 1992). Parsnips are white when harvested but turn light brown soon after, even without the physical damage (Springett, 2001). However, the degree of browning have been suggested too be associated with injury during harvest and handling. Also, crops grown on coarse sandy soils are more susceptible, and there are cultivar differences in susceptibility to browning. Postharvest dips have been demonstrated to reduce browning in whole parsnips during storage. Dip solutions can contain compounds known to reduce tissue browning in fruits, like ascorbic acid, citric acid or calcium chloride (Toivonen, 1992).

Materials and Methods

The study was carried out at SLU in Alnarp. Three different root crops were used; rutabaga (*Brassica napus ssp. napobrassica*), kohlrabi (*Brassica oleracea ssp. acephala v. gongylodes*) and parsnip (*Pastinaca sativa L.*) They were all obtained from the wholesaler, Grönsaksmästarna AB. The rutabagas and the parsnips were grown in Sweden, while the kohlrabi was imported from Italy.

Experimental design

Two different sizes of fresh-cuts were compared in this experiment; big slices and small sticks. For the rutabaga and kohlrabi half of the fresh-cuts were stored directly after cutting whereas the other half was immersed in water before storage.

The parsnip fresh-cuts were subjected to two different treatments before storage. They were immersed in dip solutions containing ascorbic acid or citric acid.

The fresh-cuts were stored for 8 days in 2.5°C. At the start, day 1, samples were taken for extraction to decide the initial vitamin C and phenolic content. Extractions of samples were then preformed three times, at day 3, 5 and 8. The total amount of samples for each variety was 36, which means 4 groups with 9 samples per group.

Rutabaga

Cutting size	**Slices**		**Sticks**	
Treatment	undipped	H_20	undipped	H_20
No. of samples	9	9	9	9

Kohlrabi

Cutting size	**Slices**		**Sticks**	
Treatment	undipped	H_20	undipped	H_20
No. of samples	9	9	9	9

Parsnip

Cutting size	**Slices**		**Sticks**	
Treatment	AA	CA	AA	CA
No. of samples	9	9	9	9

Processing of root crops for fresh-cut

The roots/stems were hand-peeled with a sharp potato peeler. They were then cut into slices and sticks using a commercial cutting machine (Hällde RG-7 Sweden). The slices were about 10 mm thick and the sticks were 5 x 5 mm.

Half of the rutabaga and the kohlrabi pieces (slices and sticks) were then packed in plastic boxes and covered with oriented polypropylene film (OPP Amcore). The other half was immersed in cold tap water for 30 seconds and then drained in a salad spinner for 45 seconds before packed.

The parsnip pieces were also subjected to two different treatments. Half of the slices or sticks were immersed in a 0.5% (w/v) ascorbic acid solution and the other half in a 0.5% (w/v) citric acid solution. The pieces were immersed in the solution for 5 minutes before drained in the salad spinner, and were then packed in the same way as the rutabaga and kohlrabi pieces.

Each package contained approximately 100 g of fresh-cut product and was stored at 2.5°C.

Vitamin C - extraction and analysis

Vitamin C, ascorbic acid (AA) and dehydroascorbic acid (DHA) were determined in fresh and stored samples. All steps in the analysis were performed in laboratory under green dim light.

The fresh-cuts were put in a blender (Warning, commercial blendor) and homogenized. Samples were prepared in triplicate and 5g of freshly homogenized product were put into a plastic bottle together with 25mL 1.5% *meta*-phosphoric acid. The samples were stored in a freezer at -80°C until high-performance liquid chromatography (HPLC) analysis.

Before HPLC analysis, the sample bottles were thawed in warm water. 1.5mL of extract was put into centrifuge tubes and centrifuged for 10 min at 13000*g*. 500µL of supernatant were transferred to HPLC vials and used for HPLC analysis as described below.

Samples were analysed on a Merck-Hitachi D7000 HPLC system, using an isocratic method with a flow rate of 1.2 mL/min in room temperature for 7 min. The mobile phase consisted of 25% $NH_4H_2PO_4$ (15mM) and 75% acetonitrile, adjusted with H_3PO_4 to pH 3.9. A 10µl portion was injected from each sample. A Waters carbohydrate analysis column, 300 x 3.9 mm with a particle size of 10 µm, was used. Absorbance was measured at 248nm. The peak of ascorbic acid in the samples was identified by comparing the retention time with an external ascorbic acid standard (Merck).

Total Phenolics – extraction and analysis

Extraction for determination of total phenolic content was carried out during the same conditions as the vitamin C extractions. 5g of freshly homogenized product were put into a plastic bottle together with 20mL of 99.7% ethanol. The samples were stored in a freezer at -80°C until analysis.

Before analysis the sample bottles were thawed in warm water. The total phenolic content was determined spectrophotometrically using a modified version of the Folin-Ciocalteu colorimetric method (Dewanto et al., 2002).

The extracts were centrifuged and then diluted with 5% ethanol to a 1:3 dilution in order to make the readings fall within the standard curve concentration range of 0.0-50µg of gallic acid/mL. For each analysis 125µL of diluted extract or standard gallic acid solution was added to 0.5mL of Millipore water in a test tube. Then 125µL Folin- Ciocalteu reagent was added and allowed to stand for 6 minutes, and thereafter 1.25mL of a 7% sodium carbonate solution was added to raise the pH.

The absorbance was measured after 75 min in room temperature at 765nm. The absorbance values were compared to a blank, and prepared standards with known gallic acid concentrations.

Measurement of dry weight and evaluation of visual quality

At each extraction occasion (day 1, 3, 5 and 8) approximately 10 g of freshly homogenized vegetable was taken from each treatment for measurement of dry weight. The 10 g were put in aluminium foil and dried in an oven at 80°C for approximately 72 hours before deciding the dry weight.

Evaluation of visual quality of the fresh-cuts was also performed at each extraction occation. The parameters evaluated were browning, dryness of the surface (white blush) and sliminess caused by microbial growth. Other discolorations were also taken in consideration. All fresh-cuts were documented on photo at each evaluation.

Statistical analysis

All analyses of the vegetable samples of each treatment were preformed in triplicates unless otherwise stated. Values presented are the means ± standard deviation. The values were subjected to a one-way analysis of variance (ANOVA), and the level of significance was $p < 0.05$. Bars in the figures or values in tables, marked with the same letter are not significantly different.

Results

Rutabaga

Ascorbic acid

The ascorbic acid content of the fresh-cut rutabaga varied between approximately 45 to 55 mg/100g FW. Differences between treatments were more evident in the end of the storage period, and at day 5 and 8, slices dipped in H_2O had a significantly higher content of ascorbic acid than the sticks dipped in H_2O. There was also a tendency that the undipped sticks had slightly higher ascorbic acid content than the sticks dipped in H_2O, though not statistically significant for each day (Fig.1).

Time of storage did not seem to influence the ascorbic acid content and there were no significant differences between the days (Table 1).

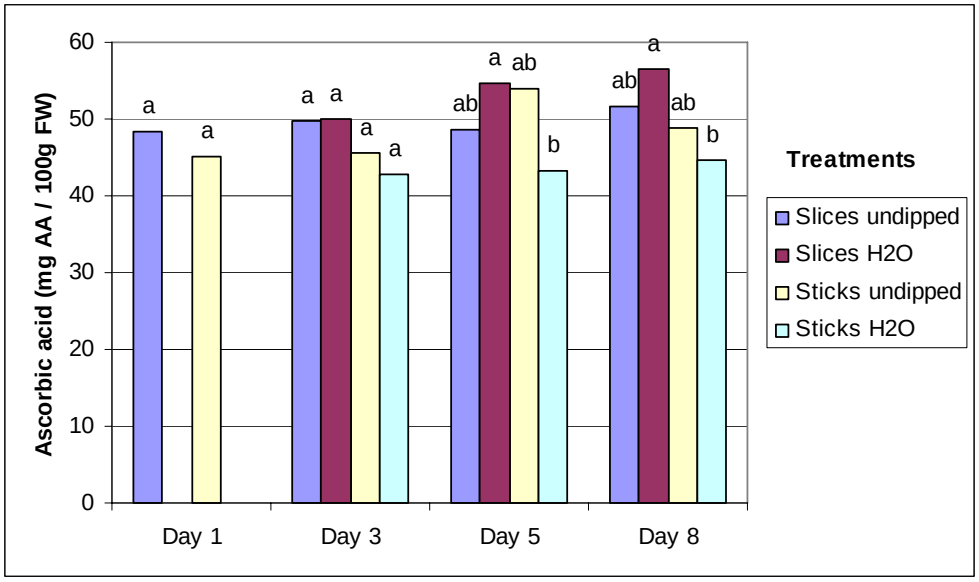

Fig. 1. *Ascorbic acid content of fresh-cut rutabaga stored in 2.5°C, and subjected to four different treatments; slices undipped, slices H_2O, sticks undipped and sticks H_2O. The content was analysed directly after processing (Day 1), and after 3, 5 and 8 days of storage. Each bar represent the mean of triplicate samples (n = 2 x 3 and 4 x 3). Bars marked with the same letter within each day, were not statistically significantly different.*

Table 1. Ascorbic acid content (mg/ 100g FW) in fresh-cut rutabaga, directly after processing (Day 1), and after 3, 5 and 8 days of storage in 2.5°C. The value for Day 1 represent the mean ± standard deviation of two treatments; slices undipped and sticks undipped. The other values represent the mean ± standard deviation of four treatments; slices undipped, slices H_2O, sticks undipped and sticks H_2O. (n = 2 x 3 and 4 x 3)

	Ascorbic acid
Day 1	46.22 ± 4.01 a
Day 3	47.02 ± 4.01 a
Day 5	50.12 ± 4.01 a
Day 8	50.41 ± 4.01 a

Total phenolics

There was a large variation in the total phenolic content of the fresh-cut rutabaga. The content varied between approximately 35 and 70 mg Gallic acid equivalents/ 100g FW (Fig. 2).

Total phenolic content decreased during storage and was significantly higher day 1 and 3 than day 5 and 8. The content was also significantly higher day 8 than day 5 (Table 2).

There were no significant differences between the treatments within each day (Fig. 2). However, if analysed statistically for the whole storage period, the undipped slices had a significantly higher content of total phenolics than the sticks dipped in H_2O.

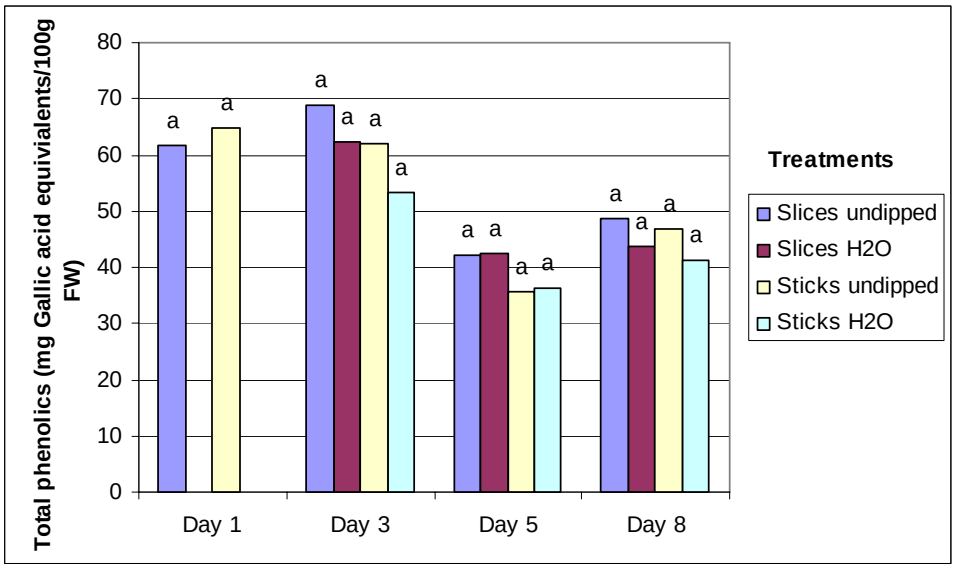

Fig. 2. *Total phenolic content of fresh-cut rutabaga stored in 2.5°C, and subjected to four different treatments; slices undipped, slices H_2O, sticks undipped and sticks H_2O. The content was analysed directly after processing (Day 1), and after 3, 5 and 8 days of storage. Each bar represent the mean of triplicate samples (n = 2 x 3 and 4 x 3). Bars marked with the same letter within each day, were not statistically significantly different.*

Table 2. Total phenolic content (mg Gallic acid equivalents/100g FW) in fresh-cut rutabaga, directly after processing (Day 1), and after 3, 5 and 8 days of storage in 2.5°C. The value for Day 1 represent the mean ± standard deviation of two treatments; slices undipped and sticks undipped. The other values represent the mean ± standard deviation of four treatments; slices undipped, slices H_2O, sticks undipped and sticks H_2O. (n = 2 x 3 and 4 x 3)

	Total phenolics
Day 1	61.18 ± 5.15 a
Day 3	61.54 ± 5.15 a
Day 5	39.18 ± 5.15 c
Day 8	45.09 ± 5.15 b

Dry weight

The dry weight for fresh-cut rutabaga ranged from approximately 0.10 g to 0.11 g. There was a strong tendency that the undipped sticks had a higher dry weight than the other treatments. At day 1 and 5 the undipped sticks had a significantly higher dry weight than the other treatments, and at day 8 the weight was significantly higher than the stick dipped in H_2O (Fig.3).

There were no significant differences in dry weight between the days (Table 3).

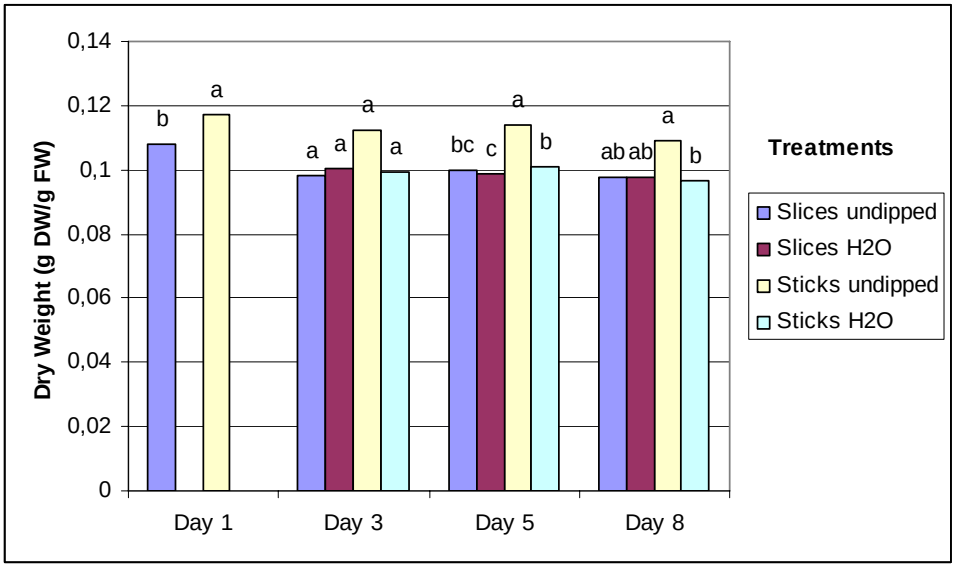

Fig. 3. *Dry weight of fresh-cut rutabaga stored in 2.5°C, and subjected to four different treatments; Slices undipped, slices H_2O, sticks undipped and sticks H_2O. The weights were measured directly after processing (Day 1), and after 3, 5 and 8 days of storage. Each bar represent the mean of triplicate samples (n = 2 x 2 and 4 x 2). Bars marked with the same letter within each day, were not statistically significantly different.*

Table 3. Dry weight (mg dw/g FW) in fresh-cut rutabaga, directly after processing (Day 1), and after 3, 5 and 8 days of storage in 2.5°C. The value for Day 1 represent the mean ± standard deviation of two treatments; slices undipped and sticks undipped. The other values represent the mean ± standard deviation of four treatments; slices undipped, slices H_2O, sticks undipped and sticks H_2O. (n = 2 x 2 and 4 x 2)

	Dry weight	
Day 1	0.1108 ± 0.0066	a
Day 3	0.1064 ± 0.0066	a
Day 5	0.1031 ± 0.0066	a
Day 8	0.1002 ± 0.0066	a

Visual quality

The appearance of the rutabaga fresh-cuts was rather good during the whole storage period. Both the slices and sticks kept in a marketable condition until day 8. The only visual disorder was a slight drying of the surface giving it at whitish colour (white blush) (Fig. 4). It started to appear at day 5, primarily at the slices. At day 8 it was more apparent and also began to show in the undipped sticks. The sticks dipped in H_2O did not develop this disorder.

Fig. 4. a) *Fresh-cut rutabaga (Day 3: Slices undipped)* ***b)*** *Fresh-cut rutabaga suffering from white blush (Day 8: Slices undipped)*

Kohlrabi

Ascorbic acid

The ascorbic acid content of the fresh-cut kohlrabi varied between approximately 30 to 35 mg/100g FW. No significant differences in ascorbic acid content between the treatments within each day could be shown. However, there was a strong tendency that slices had slightly higher ascorbic acid content than sticks. If analysed statistically for the whole storage period, the undipped slices had a significantly higher content of ascorbic acid than both undipped sticks and sticks dipped in H_2O (Fig. 5).

Time of storage did not seem to influence the ascorbic acid content in the kohlrabi fresh-cuts, and there were no significant differences between the days (Table 3).

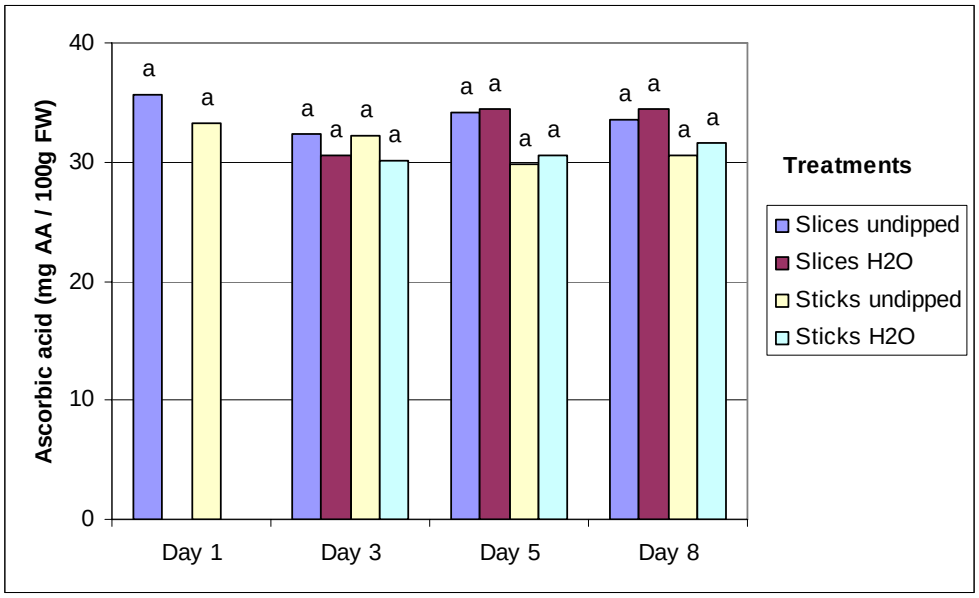

Fig. 5. *Ascorbic acid content of fresh-cut kohlrabi stored in 2.5°C, and subjected to four different treatments; slices undipped, slices H_2O, sticks undipped and sticks H_2O. The content was analysed directly after processing (Day 1), and after 3, 5 and 8 days of storage. Each bar represent the mean of triplicate samples (n = 2 x 3 and 4 x 3). Bars marked with the same letter within each day, were not statistically significantly different.*

Table 4. Ascorbic acid content (mg/ 100g FW) in fresh-cut kohlrabi, directly after processing (Day 1), and after 3, 5 and 8 days of storage in 2.5°C. The value for Day 1 represent the mean ± standard deviation of two treatments; slices undipped and sticks undipped. The other values represent the mean ± standard deviation of four treatments; slices undipped, slices H_2O, sticks undipped and sticks H_2O. (n = 2 x 3 and 4 x 3)

	Ascorbic acid
Day 1	34.43 ± 2.06 a
Day 3	31.35 ± 2.06 a
Day 5	32.27 ± 2.06 a
Day 8	32.55 ± 2.06 a

Total phenolics

The content of total phenolics in the fresh-cut kohlrabi varied between approximately 25 and 45 mg Gallic acid equivalents/ 100g FW (Fig. 6).

Total phenolic content decreased during storage and was significantly higher day 1 and 3 than day 5 and 8 (Table 5).

There were no significant differences between the treatments within each day (Fig. 6). However, if analysed statistically for the whole storage period, the undipped slices had a significantly higher content of total phenolics than the slices dipped in H_2O.

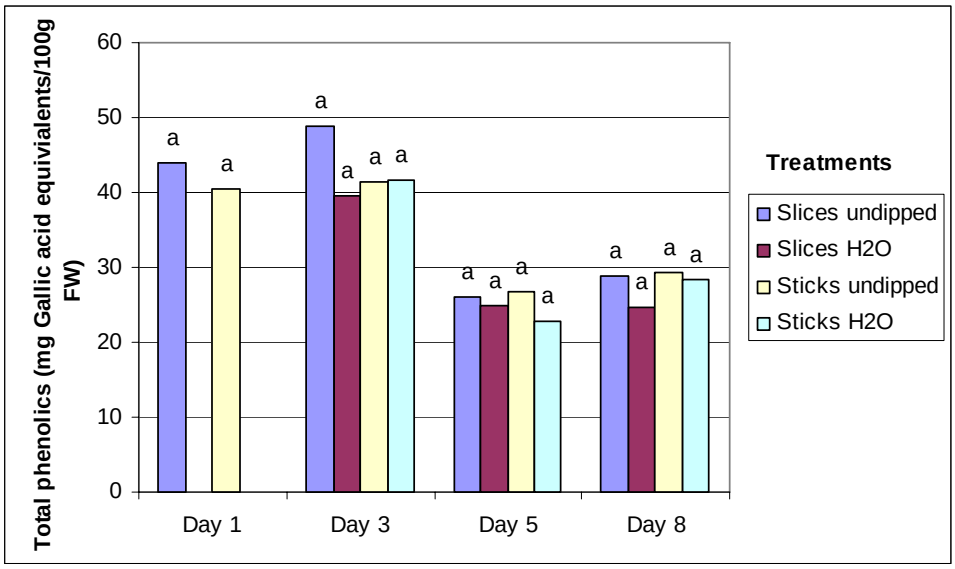

Fig. 6. *Total phenolic content of fresh-cut kohlrabi stored in 2.5°C, and subjected to four different treatments; slices undipped, slices H_2O, sticks undipped and sticks H_2O. The content was analysed directly after processing (Day 1), and after 3, 5 and 8 days of storage. Each bar represent the mean of triplicate samples (n = 2 x 3 and 4 x 3). Bars marked with the same letter within each day, were not statistically significantly different.*

Table 5. Total phenolic content (mg Gallic acid equivalents/100g FW) in fresh-cut kohlrabi, directly after processing (Day 1), and after 3, 5 and 8 days of storage in 2.5°C. The value for Day 1 represent the mean ± standard deviation of two treatments; slices undipped and sticks undipped. The other values represent the mean ± standard deviation of four treatments; slices undipped, slices H_2O, sticks undipped and sticks H_2O. (n = 2 x 3 and 4 x 3)

	Total phenolics
Day 1	40.60 ± 3.77 a
Day 3	42.84 ± 3.77 a
Day 5	25.07 ± 3.77 b
Day 8	27.84 ± 3.77 b

Dry weight

The dry weight for fresh-cut kohlrabi ranged from approximately 0.075 g to 0.095 g. The highest dry weights were found at day 1 and 5 and the lowest at day 3 and 8. The dry weight from day 1 was significantly higher than both day 3 and 8, and day 5 was significantly higher than day 8 (Table 6).

There was a strong tendency that the undipped treatments had a higher dry weight than the dipped, though not statistically significant for each day. At day 5 and 8 the undipped slices and sticks had a significantly higher dry weight than the sticks dipped in H_2O (Fig. 7). Furthermore, if analysed statistically for the whole storage period, both the undipped slices and sticks had a significantly higher dry weight than the slices and sticks dipped in H_2O.

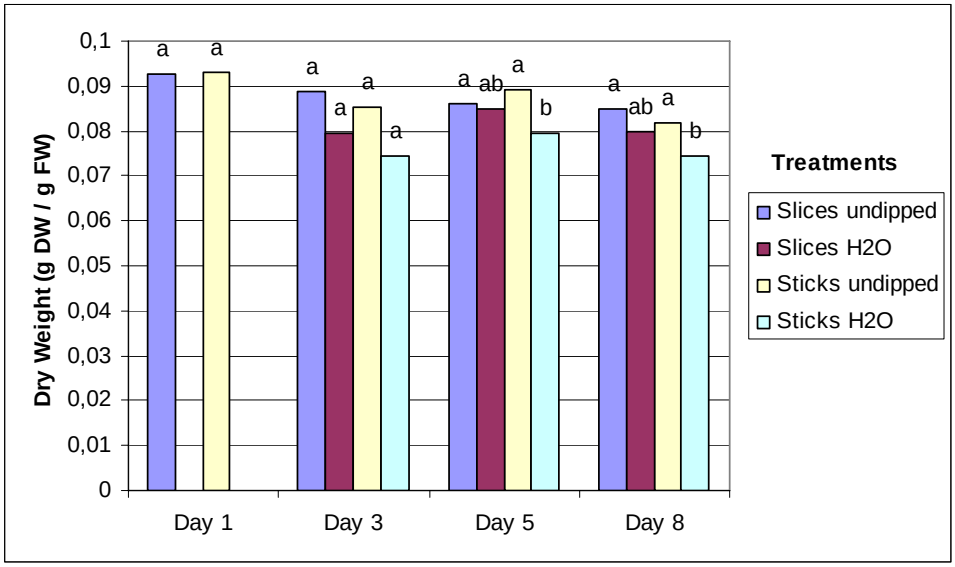

Fig. 7. *Dry weight of fresh-cut kohlrabi stored in 2.5°C, and subjected to four different treatments; slices undipped, slices H_2O, sticks undipped and sticks H_2O. The weights were measured directly after processing (Day 1), and after 3, 5 and 8 days of storage. Each bar represent the mean of triplicate samples (n = 2 x 2 and 4 x 2). Bars marked with the same letter within each day, were not statistically significantly different.*

Table 6. Dry weight (mg dw/g FW) in fresh-cut kohlrabi, directly after processing (Day 1), and after 3, 5 and 8 days of storage in 2.5°C. The value for Day 1 represent the mean ± standard deviation of two treatments; slices undipped and sticks undipped. The other values represent the mean ± standard deviation of four treatments; slices undipped, slices H_2O, sticks undipped and sticks H_2O. (n = 2 x 2 and 4 x 2)

	Dry weight
Day 1	0.08910 ± 0.0026 a
Day 3	0.08167 ± 0.0026 bc
Day 5	0.08488 ± 0.0026 ab
Day 8	0.08030 ± 0.0026 c

Visual quality

The appearance of the kohlrabi fresh-cuts was rather good during the whole storage period. However, the undipped slices and sticks developed some browning. It started to appear on day 5 with a light browning and had developed further on day 8. At day 8, the undipped sticks were no longer in marketable condition, but the sticks dipped in H_2O still look fresh (Fig.8).

Fig. 8. a) *Kohlrabi fresh-cuts (Day 8: Stick H_2O)* ***b)*** *Browning in kohlrabi fresh-cuts (Day 8: Sticks undipped)*

Parsnip

Total phenolics

There was a large variation in the total phenolic content of the fresh-cut parsnip. The content varied between approximately 15 and almost 40 mg Gallic acid equivalents/ 100g FW. The highest total phenolic contents were found in sticks dipped in ascorbic acid (AA). At day 5 and 8 they were significantly higher in phenolic content than all other treatments, and at day 3 they were significantly higher than both slices and sticks dipped in citric acid (CA) (Fig.9). Day 5 the slices dipped in AA also had significantly higher values of total phenolics than the slices and sticks dipped in CA. This could also be seen at day 3 and 8, though not statistically significant.

The total phenolic content was lower day 1 than after storage. However, those fresh-cuts were not treated in the same way and can not be statistically compared with the other days. There were no significant difference between day 3, 5 and 8.

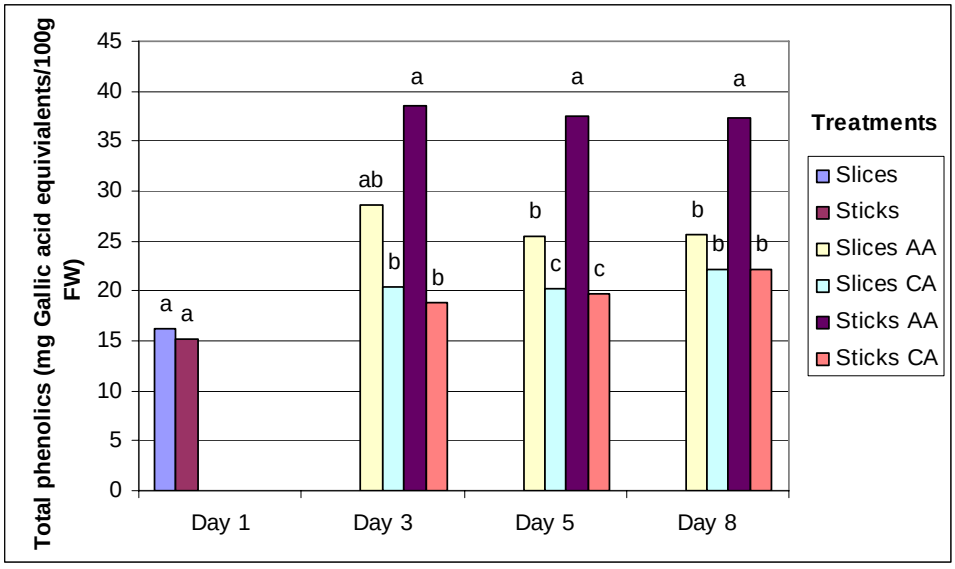

Fig. 9. *Total phenolic content of fresh-cut parsnip stored in 2.5°C. The content was analysed directly after processing (Day 1) in slices and sticks. The slices and sticks were dipped in ascorbic acid (AA) and citric acid (CA) before storage and analysed after 3, 5 and 8 day of storage. Each bar represent the mean of triplicate samples (n = 2 x 3 and 4 x 3). Bars marked with the same letter within each day, were not statistically significantly different.*

Dry weight

The dry weight for fresh-cut parsnips ranged from approximately 0.15 g to 0.20 g. Slices (AA and CA) had significantly higher dry weights than sticks. This could be shown for all days.

The dry weight was higher day 1 than during the storage (Fig 10). However, since the treatments are not the same as for the stored fresh-cuts these can not be statistically compared.

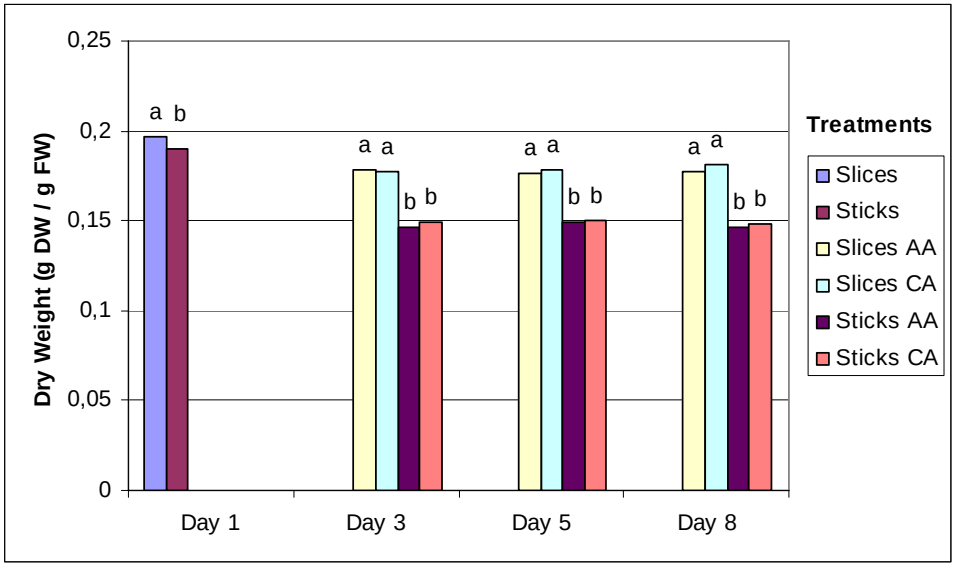

Fig. 10. *Dry weight of fresh-cut parsnip stored in 2.5°C. The weight was measured directly after processing (Day 1) in slices and sticks. The slices and sticks were dipped in ascorbic acid (AA) and citric acid (CA) before storage and dry weight decided after 3, 5 and 8 day of storage. Each bar represent the mean of triplicate samples (n = 2 x 3 and 4 x 3). Bars marked with the same letter within each day, were not statistically significantly different.*

Visual quality

The parsnip fresh-cuts developed extensive browning during storage. The browning was mostly restricted to the tissue around the central pith and in spots near the surface of the roots (Fig. 11a). On slices, the browning was evident after 3 days of storage, while the sticks still looked rather fresh. At day 5 and 8 the browning increased and could be clearly seen in sticks as well (Fig. 11b). The fresh-cuts dipped in ascorbic acid developed slightly less browning than the ones dipped in citric acid.

In addition to the browning, a little grey discoloration could be observed at day 5 and 8 (Fig 11c). The texture of the fresh-cuts was also affected in the end of the storage period. Especially in day 8 the fresh-cut were soft and shrivelled.

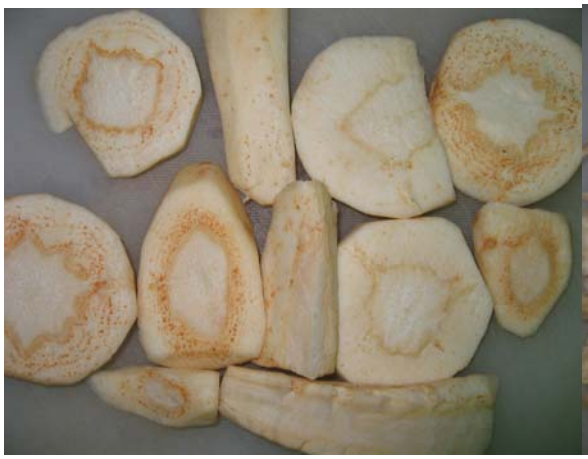

Fig. 11. a) *Browning in fresh-cut parsnip (Day 5: Slices CA)*

b) *Browning in fresh-cut parsnip (Day 8: Sticks CA)*

c) *Grey discoloration in fresh-cut parsnip (Day 8: Slices AA)*

Summary of results

Ascorbic acid

The ascorbic acid content was slightly higher in the rutabaga fresh-cuts (45-55 mg/100g FW) than the kohlrabi fresh-cuts (30-35 mg/100g FW) (Fig. 1, 4). Time of storage did not seem to influence the ascorbic acid content and there were no significant differences between the days in either rutabaga or kohlrabi (Table 1,3).

The only significant difference between treatments was found in rutabaga, were the slices dipped in H_2O had a significantly higher content of ascorbic acid than the sticks dipped in H_2O during day 5 and 8 (Fig. 1). In kohlrabi the highest contents of ascorbic acid was also found in slices dipped in H_2O during day 5 and 8 (Fig. 4).

Total phenolics

The highest total phenolic contents were found in rutabaga (35-70 mg Gallic acid equivalents/ 100g FW), kohlrabi was the second highest (25-45 mg Gallic acid equivalents/ 100g FW) and the lowest values were found in parsnip (15-40 mg Gallic acid equivalents/ 100g FW) (Fig. 2, 6, 9).

Total phenolic content decreased during storage in both rutabaga and kohlrabi, and was significantly higher day 1 and 3 than day 5 and 8. In rutabaga the content was also significantly higher day 5 than day 8. A slight increase from day 5 to 8 can be seen in kohlrabi as well, though the difference is not statistically significant (Table 2, 5).

There were no significant differences between the treatments within each day in either rutabaga or kohlrabi. However, the highest total phenolic contents were found in undipped slices for both vegetables (Fig. 2, 6).

In parsnip, the highest amounts of phenolics were found in sticks dipped in ascorbic acid. Slices dipped in AA hade the second highest contents, whereas slices and sticks dipped in citric acid displayed lower values. The total phenolic content was lower day 1 than after storage in parsnip fresh-cuts (Fig. 9).

Dry weight

Kohlrabi had the lowest dry weights of the three vegetables (0.075-0.095 g), rutabaga slightly higher (0.10-0.11 g) and parsnip the highest (0.15-0.20 g) (Fig. 3,7, 10).

There was a tendency for decreasing dry weights with time in all vegetables, and the highest dry weights were found in day 1 (Table 3, 6 + Fig. 10).

The treatment affected the vegetables dry weights differently. In rutabaga, the undipped sticks had the highest dry weights. In kohlrabi both undipped slices and sticks showed high dry weights, and in parsnips the dry weights were highest in slices (Fig. 3, 7, 10).

Visual quality

Both rutabaga and kohlrabi fresh-cuts kept in marketable state for the whole storage period. The only exception was the undipped stick of kohlrabi, which was to brown on the last day of storage (Fig. 8).

In rutabaga, slight drying of the surface giving it at whitish colour (white blush), was the only thing limiting visual quality (Fig. 4). In kohlrabi, browning was the major problem. However, dipping in H_2O before storage seems to reduce both these disorders.

I parsnips, extensive browning rapidly reduced the visual quality of the fresh-cuts, and made them unmarketable (Fig. 11). Slices were below the limit of marketability after 3 days of storage, and the sticks after 5 days. Dipping in ascorbic acid appeared to reduce browning slightly better than citric acid.

Discussion and Conclusion

Ascorbic acid

The main limiting factor of nutritional quality of fruit and vegetables is the loss of ascorbic acid and carotenes (Ahvenainen, 1996). Because of its lability, ascorbic acid is routinely used as an index to measure processing effects on nutrient retention (Howard et al., 1999).
In this investigation, relatively high contents of ascorbic acid were found in the fresh-cut root vegetables. In rutabaga, contents of 45 - 55 mg/100 g FW were measured during the eight day storage period. Those values are supported by, and are even slightly higher than other values found in literature. Contents of 25, 36 and 44 mg AA/100 g FW respectively, have been reported in rutabaga (Murphy, 1940, LivsmedelsSverige, 2008, Livsmedelsverket, 2008b).

The kohlrabi fresh-cuts had an ascorbic acid content of 30 – 35 mg/100 g, which is slightly lower than reported in previous research for whole kohlrabi. The contents reported are from lowest to highest; 51.5, 56, 62 and 65 mg AA/100 g FW (Wheeler et al., 1939, McCombs, 1957, Livsmedelsverket, 2008b). However, neither of those reports specifies if the kohlrabi peel is included in the analysis. Usually skin tissues have more AA content to protect the fruit or vegetable from outside stress caused by light and oxidation (Kader et al., 2000). In this study the peel was removed before processing for fresh-cuts which might explain the lower ascorbic acid content.

In comparison to rutabaga and kohlrabi, the content of AA in potato is 7 mg/100 g FW, in tomato 10.6 mg/100 g FW and approximately 55 – 75 mg/ 100 g FW in oranges (Lee et al., 2000). Rutabaga and kohlrabi could have an important role as dietary source of vitamin C, as they have relatively high content and the amount consumed as meal components could be large. In Sweden the recommended daily intake of vitamin C is approximately 75 mg (Livsmedelsverket, 2008a). According to the results obtained in this study, roughly 150 g of rutabaga and 200 g of kohlrabi would cover the recommended daily intake of vitamin C.
Time of storage did not seem to influence the ascorbic acid content in either rutabaga or kohlrabi fresh-cuts. Normally, as ascorbic acid is easily oxidized, it will gradually decrease during refrigerated storage (Howard et al., 1999). Losses in AA are also reported to occur when vegetables are severely cut or shredded as in the case of processing for fresh-cuts products (Ball, 1997).

However, not all vegetables respond to storage in the same manner. Stabile contents of ascorbic acid during storage have been reported in both rutabaga and kohlrabi.

Watada, (1997) reported a 0% loss of ascorbic acid in rutabaga stored for 4 weeks at 20°C. In an investigation carried out by McCombs, (1957) kohlrabi was analysed for ascorbic acid content at harvest and after 5 days of storage in 13°C. The content at harvest was 51.5 mg/100 g FW and 56.0 mg/100 g FW after storage. The small increase seen in ascorbic acid content may be due to sample variation. Stability of ascorbic during storage is a desirable property, which makes vegetables suitable as fresh-cut products.

No evident conclusions could be drawn regarding the effect of the different treatments (slices undipped, slices H_2O, sticks undipped, sticks H_2O) on the ascorbic acid content. The only significant difference between treatments was found in rutabaga on the fifth and eights day of storage, were the slices dipped in H_2O had a significantly higher content of ascorbic acid than the sticks dipped in H_2O. In kohlrabi there was a tendency that slices had slightly higher ascorbic acid content than sticks. A better retention of ascorbic acid in slices than sticks would be logical since the destruction of tissue is less in big than small fresh-cuts. As more cells are ruptured rates of metabolic processes increases resulting breakdown of AA. However, variation in ascorbic acid content of the starting material will influence the final AA content in fresh-cuts (Howard et al., 1999). The small differences seen in ascorbic acid content may be due to sample variation.

Phenolic compounds

There are several compounds in foods that exhibit antioxidant capacity, including ascorbic acid, carotenoids, tocopherols and phenolic compounds. However, several studies have shown that antioxidant capacity of fruits and vegetables are primarily attributed to the phenolic compounds (Huang et al., 2007b). Different methods of analysis for phenols and antioxidant activity are reported in the literature. Nevertheless, analysis of phenolic compounds in plant samples is difficult because of the great variety of their structure and the lack of appropriate standards (Huang et al., 2007a). The Folin-Ciocalteu method used in this study for determination of total phenolic content is a widely excepted method. Even though it does not give a full picture of the quantity and quality of the phenolic constituents, it may provide precise information on the overall phenolic compound level in the samples. As mentioned above, total phenolics can also be a good indicator of antioxidant capacity of fruits and vegetables (Kähkönen et al., 1999, Huang et al., 2007b).

In this investigation, the total phenolic contents in rutabaga, kohlrabi and parsnip ranged from 15 – 70 mg Gallic acid equivalents/ 100g FW, with the lowest values in parsnip and the

highest in rutabaga. Published data on the phenolic content of these vegetables are scarce, which makes the results difficult to evaluate.

The total phenolic content measured in the rutabaga fresh-cuts varied between 35 – 70 mg GAE/100 g FW or 3.0 – 6.5 mg GAE/g DW. Kähkönen et al., (1999) reported a content of 1.6 mg GAE/g DW in rutabaga peel, and a content of 14.0 mg GAE/g DW in rutabaga was published by Huang et al., (2007b). These values do not correspond entirely with the results gained in this study. However, variation of total phenolics in vegetables may depend on many factors, like cultivar and time of harvest. Also, in rutabagas, the total phenolic content has been demonstrated to be highly related to its antioxidative capacity. The antioxidative capacity was analysed using the radical DPPH scavenging capacity assay and oxygen radical absorbance capacity assey (ORAC) (Huang et al., 2007b).

In the kohlrabi fresh-cut the total phenolic content ranged from 25 to 45 mg GAE/100g FW. This is supported by Marinova et al., (2005), who reports a phenolic content of 44.9 mg GAE/100 g FW in kohlrabi.

The parsnip fresh-cuts had a total phenolic content of 15 to 45 mg GAE/100 g FW. No published data on total phenolic content in parsnip could be found in literature.

All three root vegetables analysed in this investigation displayed comparatively low total phenolic contents. For example, the total phenolic content in carrots is 96 mg GAE/100g FW, in tomato 77 mg GAE/100g FW and 247 mg GAE/100g FW in green peppers. Exceptionally high phenolic content have been found in blueberries with 671 mg GAE/100g FW (Marinova et al., 2005).

Total phenolic content decreased during storage in both rutabaga and kohlrabi, and was significantly higher day 1 and 3 than day 5 and 8. Between day 3 and 5 the phenolic content decreased with about 15-20 mg GAE/ 100g FW. Storage and processing have been reported to reduce content of phenolic compounds as some of them are easily oxidized. On the other hand, some phenols are directly involved in the plant response to different kinds of stress. Their concentrations could increase after injury, which may explain the initial stability and slight increase in total phenolic content from day 1 to 3 (Manach et al., 2004).

In rutabaga, the phenolic content was also significantly higher day 5 than day 8. A slight increase from day 5 to 8 can be seen in kohlrabi as well, even though the difference is not significant. It seems unlikely that it could be a wound response in this late stage, but may be a part of the senescence processes during storage

There were no significant differences between the treatments within each day in either rutabaga or kohlrabi. Nevertheless, the highest total phenolic contents were found in undipped

slices for both vegetables. That might suggest it is the treatment with the least effect on total phenolic content, though it was not statistically significant for the individual vegetables.
In parsnip the highest contents of phenolic compounds were found in fresh-cuts dipped in ascorbic acid. However, since those values greatly exceeds the initial contents (day 1) of the undipped slices, they are probably not reliable. The principles of the total phenolic method is the reduction of the Folin-Ciocalteu reagent in the presence of phenolates, resulting in the production of molybdenum – tungsten blue, measured spectrophotometrically (Dewanto et al., 2002). However, the Folin-Ciocalteu reagent interacts with other reducing nonphenolic substances, like ascorbic acid, which often leads to an overestimation of polyphenol content (Georgé et al., 2005). The parsnip fresh-cuts dipped in citric acid also had slightly higher phenolic contents than the initial values (day 1). This on the other hand, can not be explained by interference with the method, as citric acid is not an antioxidant.

Dry weight

The highest dry weights for all three root vegetables were found in day 1, and there was a tendency for decreasing dry weights during storage. Typically, dry weight increases during storage, as the product lose water. However, the packaging OPP film might have acted as a barrier to the exchange of gases, including water vapour. This increases relative humidity in the package and helps retention of water in the fresh-cuts. If the respiration rate is still high, the dry weight decreases (Bergquist et al., 2006).

There were no clear effects of the treatments on dry weight for all vegetables. In rutabaga, the undipped sticks had the highest dry weights, and in kohlrabi both undipped slices and sticks showed high dry weights. Dipping in H_2O before storage might help keeping high relative humidity in the packages preventing water loss from the fresh-cuts. That could explain the lower dry weights in dipped fresh-cuts. The higher dry weight in sticks than slices may perhaps be explained by more extensive cell damage which results in bigger water loss. In parsnip on the other hand, dry weights are highest in slices, witch contradicts the results for rutabaga and kohlrabi discussed above.

Visual quality

In rutabaga, the only factor influencing visual quality was a slight white discoloration of the surface. This type of white discoloration is considered as a result of either surface dehydration of outer layers or enzymatic activity and formation of lignin, as a response to peeling or

cutting. In carrots, the rate of surface whitening is reported to increase with decreasing relative humidity and with time. Initial treatments using excess surface moisture reduced the rate of white development (Cisneros-Zevallos et al., 1995). That effect could be observed in this study as well. Especially at the last day of storage (day 8), there was a clear difference between the sticks dipped in H_2O and the undipped sticks. For slices, on the other hand, no benefit of the pre-storage water-dipping could be seen, as the excess moisture was probably insufficient. By wetting the fresh-cuts and not centrifuge them in the salad spinner before storage, a better effect might be gained. However, with higher humidity there could be an increased risk for microbial activity.

Kohlrabi fresh-cuts have also been reported to develop white discoloration. In a study preformed by Escalona et al., 2006 slices of kohlrabi developed white discoloration in the end of a 14 day storage period. No white discoloration of the kohlrabi fresh-cuts were detected in my investigation, though the fresh-cut was only stored for 8 days. The only factor limiting the visual quality in kohlrabi fresh-cuts was some minor browning in the end of the storage period. However, it seemed to be prevented by water-dipping before storage.

In parsnips, extensive browning rapidly reduced the visual quality of the fresh-cuts. The browning was mostly restricted to the tissue around the central pith and in spots near the surface of the roots. The central pith of parsnip consists of xylem scattered in parenchyma tissue. The darker ring visible around the xylem is vascular cambium. Outside the cambium is the phloem, which in parsnip is unusually broad and consists mostly of parenchyma cells. The outermost layers are the pericycle. In the phloem and also partially in the pericycle of parsnips, you can also find scattered resin ducts (Welander & Ottoson, 1999). The small but distinct brown spots on the fresh-cut parsnips probably show these resin ducts.

Several factors can effect in which degree the browning in parsnips occurs. In this study, for practical reasons, the parsnips were collected from a wholesaler and then stored for 6 weeks in 2.5°C before processing into fresh-cuts. At the day of processing, the parsnips did not look fresh. The peel had turned brown and some specimens were soft, shrivelled and mouldy. This may have affected the durability of the fresh-cuts and made them more susceptible to browning.

The parsnip fresh-cuts were subjected to two different pre-storage dips, in ascorbic acid and citric acid. The dipping in ascorbic acid seemed to reduce browning slightly better than citric acid. However, acidulants (ex. citric acid) are often used in combination with other antibrowning agents, such as ascorbic acid (Marshall et al. 2000). In a study preformed by Toivonen, 1992, the most effective dip solution for parsnips contained a mixture of ascorbic

acid, citric acid and calcium chloride. Browning can also be reduced by reduction of oxygen availability by the use of modified atmosphere packaging (MAP) or edible coatings (Marshall et al. 2000).

The degree of browning in parnips is also affected by growing conditions and choice of cultivar (Toivonen, 1992). However, no such information was available in this study.
In addition to the browning, a little grey discoloration could be observed on the parsnip fresh-cuts at day 5 and 8. The grey discoloration, could be some kind of mycela growth.

Potential of rutabaga, kohlrabi and parsnip as fresh-cut products

From the results gained in this study, conclusions can be drawn in agreement with former investigations that rutabagas and kohlrabi are good candidates for fresh-cut products (Nascimento Nunes, 2004, Zhu et al., 2002, Escalona et al., 2006, Forney & Toivonen, 2004). Both visual and nutritional quality was retained during the 8 day storage period. The ascorbic acid content was relatively high and remained stable during storage. Some loss in total phenolic content could be observed. However, since the initial content was relatively low, the loss was of minor importance. The visual quality was only limited by minor white discoloration in rutabaga and browning in kohlrabi. Both disorders could easily be controlled by dipping in H_2O before storage.

The potential of parsnip fresh-cuts is more uncertain. The main problem is not decrease in nutritional quality, but the rapid deterioration in visual quality that browning results in. Brown food is often considered as spoiled by consumers, which quickly makes the fresh-cuts unmarketable. From the results gained in this study, parsnip does not seem to be suitable for processing into fresh-cut products. However, other dip solutions or use of modified atmosphere might be able to reduce browning to acceptable levels. Also, the effect of growing conditions and choice of cultivar on browning has to be further evaluated.

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