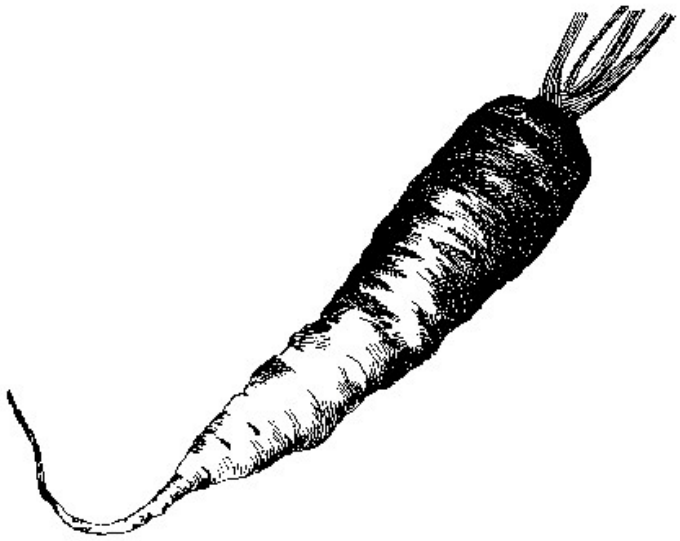
SWEET AND BITTER TASTE IN ORGANIC CARROT



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Summary

Carrot, Daucus carota L., is valuable for its taste, good digestibility and high contents of provitamin A. Both epidemiological and nutritional studies have pointed out its positive impact on human health.

The taste of carrots is a unique composition between sweet, fruity and more harsh or bitter flavours. Many factors affect the balance between the different flavours in carrots and thus contribute to the final taste. Sweet taste is more common in the centre and lower, tip, part of the carrot. The phloem is mostly sweeter and also bitterer than the xylem. Bitter taste is more often detected in the upper and outer part of the carrot.

The amount of sugar in the carrots has a clear correlation to the perception of sweetness. The amount of sugar can also contribute in masking bitter taste in carrots. One possible reason for the increases in bitter taste during storage is decreasing sugar content.

The sugar in carrots consists mainly of sucrose, glucose and fructose. During the seedling phase no soluble sugar is stored, in the second phase only reducing sugar and in the third phase, starting some 50 days after sowing mainly sucrose is stored in the carrot root. The reduction in sugar during storage mainly concerns sucrose. The total amount of sugars do not differ so much between different parts of the carrot.

No particular compound has been found that explain all phenomena connected to the harsh and bitter flavours in carrot. The appearances of such flavours are probably due to a multiplicity of compounds.

Terpenes are connected both with the typical carrot taste as with harsh flavours. There are a large number of terpenes in carrot mainly in the carrot oil. They are more common in the upper part and in the phloem. The concentration of terpenes increases during growth. Higher temperatures during growing season also increase the amount of terpenes. Terpenes can mask for sweet taste but can also be less detectable by increasing sugar concentration.

Phenolic substances, as 6-methoxymellein, are synthesised along the polyketide or shikimic pathway, as a reaction of stress and increased respiration in the carrot. Together with other compounds they can contribute to bitter taste in carrot.

Polyacetylenes, such as falcarindiol, are formed from oleic acid probably as a part of the defence against pathogens. Falcarindiol is however always present in carrots, more commonly in the upper and outer part and in the phloem. There is a correlation between the amount of falcarindiol and bitter taste in carrots.

Sweet and bitter taste in carrots is dependant both on genetic as environmental factors. The choice of cultivars and cultivation methods can therefore highly affect the taste of carrots before they reach the consumer.

Contents

Introduction

Carrot is valuable for its good digestibility and high contents of provitamin A and other nutraceutical substances, (Ranalli, Contento et.al., 2004). Different studies have pointed out its positive impact on human health, (Buttery, Black et.al., 1979). Carrots have been ranked tenth in terms of nutritional value among 38 other fruits and vegetables, and seventh for their contribution to nutrition, (Alasalvar, Grigor et.al., 2001). Carrot is considered to be the major dietary source of carotenes for humans, providing more than 17% of the total vitamin A requirements in the US, (Block, 1994)

Organic farming has attracted an increasing attention in recent years. Comparing soils and biodiversity over a longer time period has revealed differences between farming systems, (Mäder, Fliessbach et.al., 2002).However comparative studies have shown only minor differences between organic and conventional products, (Woese, Lange et.al., 1995). Either there are only small differences in quality or the wrong methods have been used when trying to find it.

Sensory analysis is an important tool for the consumers when selecting food. Also in science it is commonly used to describe some of the properties of food, (Lawless and Heymann, 1999). Many efforts have been made to describe the connection between sensory and chemical properties in carrots, (Martens, Fjeldsenden et.al., 1979; Simon, Peterson et.al., 1980b; Fjeldsenden, Martens et.al., 1981; Simon, Peterson et.al., 1982; Simon and Lindsay, 1983; Kaminski, Wasowicz et.al., 1986; Yoshino, Kawaguchi et.al., 1993; Howard, Braswell et.al., 1995; Shamaila, Durance et.al., 1996; Baardseth, Rosenfeld et.al., 1996; Haglund, 1998; Gills, Resurreccion et.al., 1999; Suojala and Tupasela, 1999; Talcott and Howard, 1999a; Seljåsen, 2000; Seljåsen, Hoftun et.al., 2001; Seljåsen, Bengtsson G. B. et.al., 2001; Alasalvar, Grigor et.al., 2001; Czepa and Hoffmann, 2003; Seljåsen, Hoftun et.al., 2003; Seljåsen, Hoftun et.al., 2004; Surles, Weng et.al., 2004; Czepa and Hoffmann, 2004; Marabi, Thieme et.al., 2006). In recent years the development of multivariate analysis has encouraged these efforts, (Martens, Fjeldsenden et.al., 1983; Rosenfeld, Martens et.al., 1984; Martens, Rosenfeld et.al., 1985; Baardseth, Rosenfeld et.al., 1996; Hogstad, Risvik et.al., 1997; Rosenfeld, Risvik et.al., 1997; Rosenfeld, Baardseth et.al., 1997; Rosenfeld, 1998; Rosenfeld, Samuelsen et.al., 1998a; Rosenfeld, Samuelsen et.al., 1998b; Rosenfeld, Samuelsen et.al., 1998c; Rosenfeld, Samuelsen et.al., 1999; Rosenfeld and Samuelsen, 2000; Rosenfeld, Aaby et.al., 2002; Rosenfeld, 2003; Varming, Jensen et.al., 2004; Rosenfeld, Vogt et.al., 2004).

Bitter taste in carrots is sometimes a problem, (Sondheimer, 1957b; Carlton, Peterson et.al., 1961; Yates and England, 1982; Abe and Yoshimura, 1993; Schaller, Broda et.al., 1998; Talcott and Howard, 1999b; Rosenfeld, 2003; Czepa and Hoffmann, 2003; Zidorn, Johrer et.al., 2005; Baranska and Schulz, 2005; Baranska, Schulz et.al., 2005). Many suggestions has been given on what substances that causes bitterness, (Sondheimer, 1957a; Condon, Ku´c et.al., 1963; Müller, 1978; Yates and England, 1982; Lafuente, Cantwell et.al., 1991; Mercier, Arul et.al., 1993; Mercier and Arul, 1993; Talcott and Howard, 1999b; Zidorn, Johrer et.al., 2005) and to describe the factors contributing to it, (Simon, 1985; Abe and Yoshimura, 1993; Talcott and Howard, 1999a; Seljåsen, Hoftun et.al., 2003; Rosenfeld, 2003; Czepa and Hoffmann, 2004; Kidmose, Hansen et.al., 2004). The interaction between sweet and bitter properties seems to be of vital importance for the off-taste of carrots, (Simon, Peterson et.al., 1980a; Seljåsen, Hoftun et.al., 2003; Rosenfeld, Vogt et.al., 2004; Czepa and Hoffmann, 2004). Still, many factors need to be examined more before the whole picture of the interaction between bitter and sweet taste in carrots is revealed.

The carrot, Daucus carota L

The general description of the carrot given in this section is collected from different encyclopaedias and introductory textbooks. The main source has been the book "Carrots and related vegetable Umbelliferae, (Rubatzsky, Quiros et. al., 1999).

Origin and domestication

Cultivated carrots can be divided into two types. Eastern, asiatic, carrots have reddish purple or yellow roots, pubescent leaves and a tendency for early flowering. Western carrots have orange, yellow, red or white roots, less pubescent, green leaves and less tendency to bolt, (Rubatzsky, V. E., Quiros, C. F.et. al., 1999).

The origin of the Eastern cultivated carrot is regarded to be in the Inner Asiatic Centre, mainly Afghanistan, and the origin of western cultivated carrot in the Asia Minor Centre, primarily Turkey, (Vavilov, 1951)

It exist little evidence of cultivating western carrots before the 10th century. Carrot seeds of this type have been found in Switzerland and Germany, dating from 2000- 3000 BC. Probably at this time the seed was the plant part used, (Banga, 1963). Purple, red and yellow carrots of the western type were cultivated in Iran in the 10th century and spread to China and Europe during the 13th century. The origin of the western orange type is not clear. The first appearance goes back to oils paintings from Holland during the 17th century. Written documentation of orange carrots first appears in 1721 with the description of 4 different orange carrot types. At approximately the same time the first white carrot was described in Holland also, (Banga, O., 1963). A brief overview of the origins of cultivated carrot is given in table 1.

Table 1. History of cultivated carrot. Reprinted with permission from (Rubatzsky, V. E., Quiros, C. F.et. al., 1999). Copyright 1999 by CABI Publishing.

Time	Location	Colour
Pre-900s	Afghanistan and vincity	Purple and yellow
900s	Iran and northern Arabia	Purple and yellow
1000s	Syria and North Africa	Purple and yellow
1100s	Spain	Purple and yellow
1200-1300	Italy and China	Purple and yellow
1300s	France, Germany, The Netherlands	Purple and yellow
1400s	England	Purple and yellow
1600s	Japan	Purple and yellow
1600s	Northern Europe and North America	Orange and white
1700s	Japan	Orange

Botany

The edible carrot, Daucus carota var. sativus Hoffm., is part of the Apiaceae- family. Some of the representatives of this family and their common uses are listed in table 2.

Table 2. Representatives of the Apiaceae-family and their uses. Reprinted with permission from (Rubatzsky, V. E., Quiros, C. F.et. al., 1999). Copyright 1999 by CABI Publishing.

English name	Swedish name	Botanical name	Uses	Plant portion used
Carrot	Morot	Daucus carota	F	R
Dill	Dill	Anethum graveolens	F	L, Fl, S
Parsnip	Palsternacka	Pastinaca sativa	F	R
Celery	Selleri	Apium graveolens	F	R
Parsley	Persilja	Petroselium crispum	F	L, R
Caraway	Kummin	Carum carvi	F	S
Fennel	Fänkål	Foeniculum vulgare	F	S, R
Anise	Anis	Pimpinella anisum	F, M	S
Lovage	Libsticka	Levisticum officinale	F, M	L
Coriander	Koriander	Coriandrum sativum	F	L, S
Angelica	Kvanne	Angelica archangelica	M	L,R, S, St
Bishop's weed	Kirskål	Aegopodium podagraria	W (F)	L
Hemlock	Odört	Conium maculatum	M	

(F=food, M=medical, W=weed, Fl=flower, L=leaves, R= roots, S=seeds, St= stems)

Characteristic of the Apiaceae family is their compound umbel (umbrella-like) inflorescence. The separate flowers and umbels are often arranged in a well-coordinated inflorescence. The separate flowers are not so outstanding, they are often white or yellowish, and more seldom pale red or blue. Although the scent of the flowers often is weak, many species of the Apiaceae possesses a strong distinctive aroma. This aroma is due to essential oils, often produced in special oil ducts situated in the leaves, stem or roots. The composition of these oils is unique for each species and is sometimes poisonous. In Apiaceae alternate compound leaves are common characteristic.

Anatomy

Soon after emergence the young carrot seedling show a clear difference between the taproot and the hypocotyl. The latter is, at first, thicker and bears no lateral roots. The upper part of the hypocotyl is terminated at the cotolydonary node. Here the bases of the cotyledons gradually merge with the hypocotyl.

Most of the storage root is comprised of phloem and xylem together with cambium sections gradually joining together in a cylinder. The anatomy of the carrot storage root is shown in figure 1 on the next page.

The shape of the storage root varies from round over conical to cylindrical. Depending on the pigment composition carrots can appear orange, yellow, red, purple or white. Shape and colour are mainly caused by genetic factors but can also be influenced by environmental conditions and differ of course between stages of plant development.

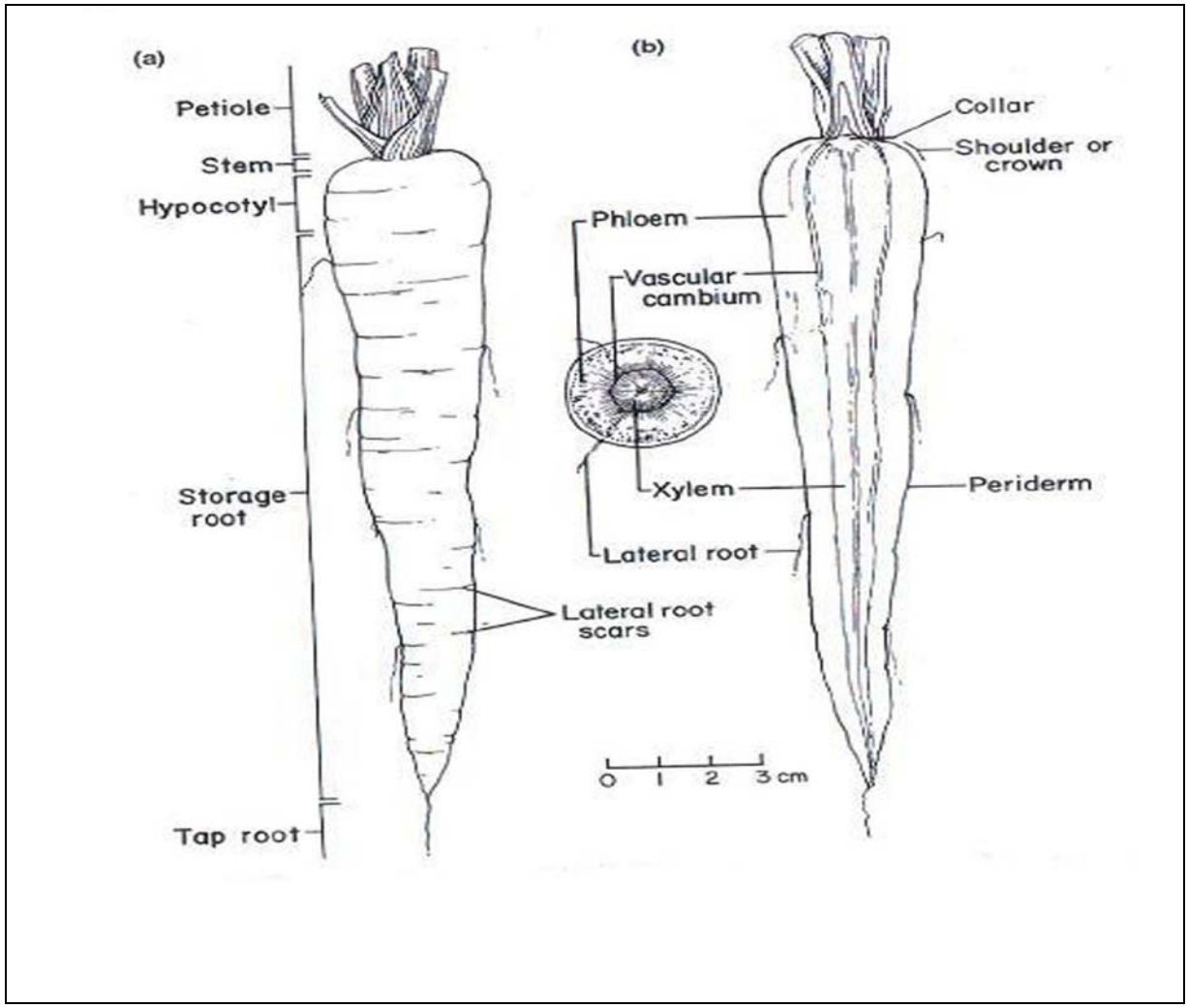


Figure 1. Carrot storage root anatomy. Reprinted with permission from (Rubatzsky, V. E., Quiros, C. F.et. al., 1999). Copyright 1999 by CABI Publishing.

Growth

The taproot develops from the pro-meristem of the embryo. The storage roots of carrots originate from a cylindrical vascular cambium in the hypocotyl and the taproot. At first this cambium consists of separate strips of cells formed from cell divisions between the primary xylem and primary phloem. Thereafter secondary cambium develops between the phloem and the xylem. This cambium extends to form a complete cambial tissue around the central primary xylem. Here cells are produced that develops to form phloem to the outside and xylem to the inside. These cells expand and differentiate into vessels and storage parenchyma. In carrots, initiation of the secondary cambium usually precedes the development of foliage leaves, (Esau, 1940).

The storage organ is developed largely by secondary growth from the vascular cambium. Due to cell divisions in the xylem and phloem parenchyma considerable carbohydrate accumulation and enlargement occur. During secondary development the taproot apex continues to increase the length of the root. Simultaneously lateral, fibrous, roots develop. These roots do not undergo secondary growth, (Rubatzsky, V. E., Quiros, C. F.et. al., 1999).
Oil ducts in the intercellular spaces of the pericycle contain essential oil responsible for the characteristic aroma and flavour of the carrot, (Senalik and Simon, 1987).

The enlargement of the storage root results in shedding of the cortex tissue. The morphological development of the carrot root is shown in figure 2. The surface then becomes covered with periderm originating from the pericycle. Scars marking the exit of the lateral roots appear on this periderm. Wild carrots and primitive cultivars have pronounced root scars on their surface. Fibrous roots are absent on the hypocotyl portion of the storage root. Fine, highly branched lateral, fibrous roots usually grow from the mid and lower portion of the storage part of the taproot. These roots are usually concentrated within 30 cm of the soil surface, (Rubatzsky, V. E., Quiros, C. F.et. al., 1999).

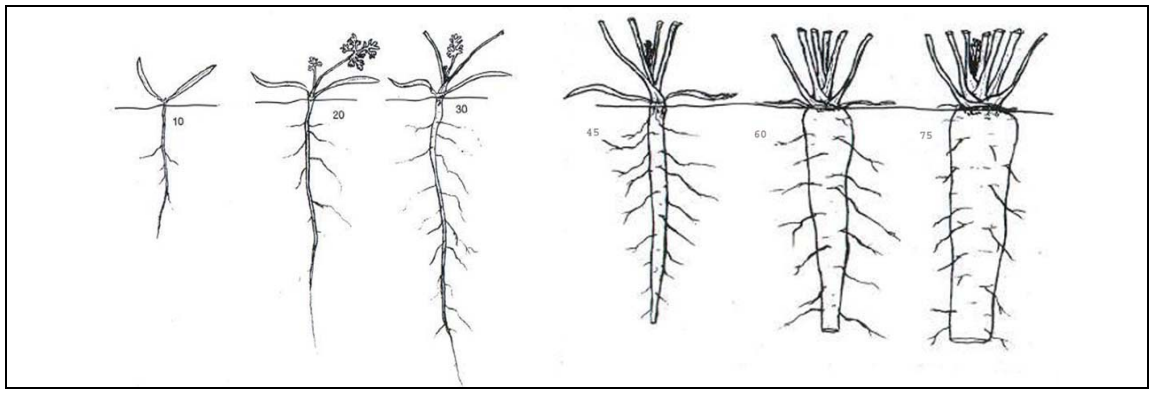


Figure 2. The development of the carrot root 10, 20, 30, 45, 60 and 75 days after planting. Reprinted with permission from (Rubatzsky, V. E., Quiros, C. F.et. al., 1999). Copyright 1999 by CABI Publishing.

The length increase of the storage roots is rapid. Usually it is finalized around 50 days after germination. The growth in length is considerably faster than that of weight. After the first third of the growth period root weight begins to increase. This continues until harvest. The size of the root diameter start increasing somewhat earlier than the root weight. At the end of the growing season the root weight increases faster than the size of the root diameter measured at the shoulder of the carrot, (Rubatzsky, V. E., Quiros, C. F.et. al., 1999)

There are no distinct outer signs of the ripeness of the storage root, (Fritz and Habben, 1975; Nilsson, 1987). The colour and shape of the root tip are sometimes regarded as a mark for maturity. A pointed tip is more common at the early stages of development. At harvest time the tip is often more blunt. Different shapes of the root tip are shown in figure 3. At early stages the tip is also often paler growing more and more coloured as the harvest approaches.

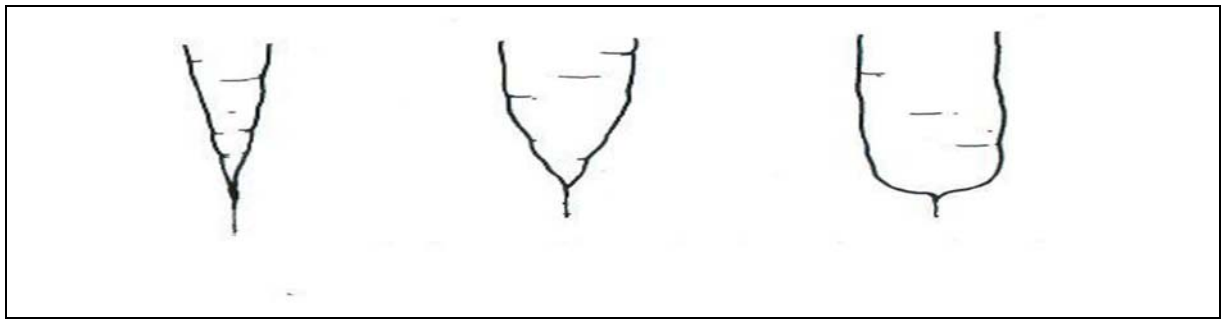


Figure 3. Different shapes of the carrot storage root tip, left pointed tip, right blunt tip. Reprinted with permission from (Rubatzsky, V. E., Quiros, C. F.et. al., 1999). Copyright 1999 by CABI Publishing.

Genetics

Daucus is one of the largest genera in the Apiaceae. It consists of about 25 species. Different species are identified by differences in fruit shape, size, ridges, appendages and ducts. Pollen shape, bract, and leaf characteristics, umbel arrangement and diameter, petal and style size, and chromosome numbers also assist identification, (Rubatzsky, V. E., Quiros, C. F.et. al., 1999).

Differences in chemical composition, mainly among the phenolics, have been demonstrated useful in distinguish some Daucus species, whereas polyacetylenes, coumarins and sugars have not provided useful distinction, (Crowden, 1969; Heywood, 1971).

The carrot is a diploid plant with nine chromosome pairs. Within the temperate carrot there are several types determined primarily by root shape. An overview of some of these types is given in figure 4.

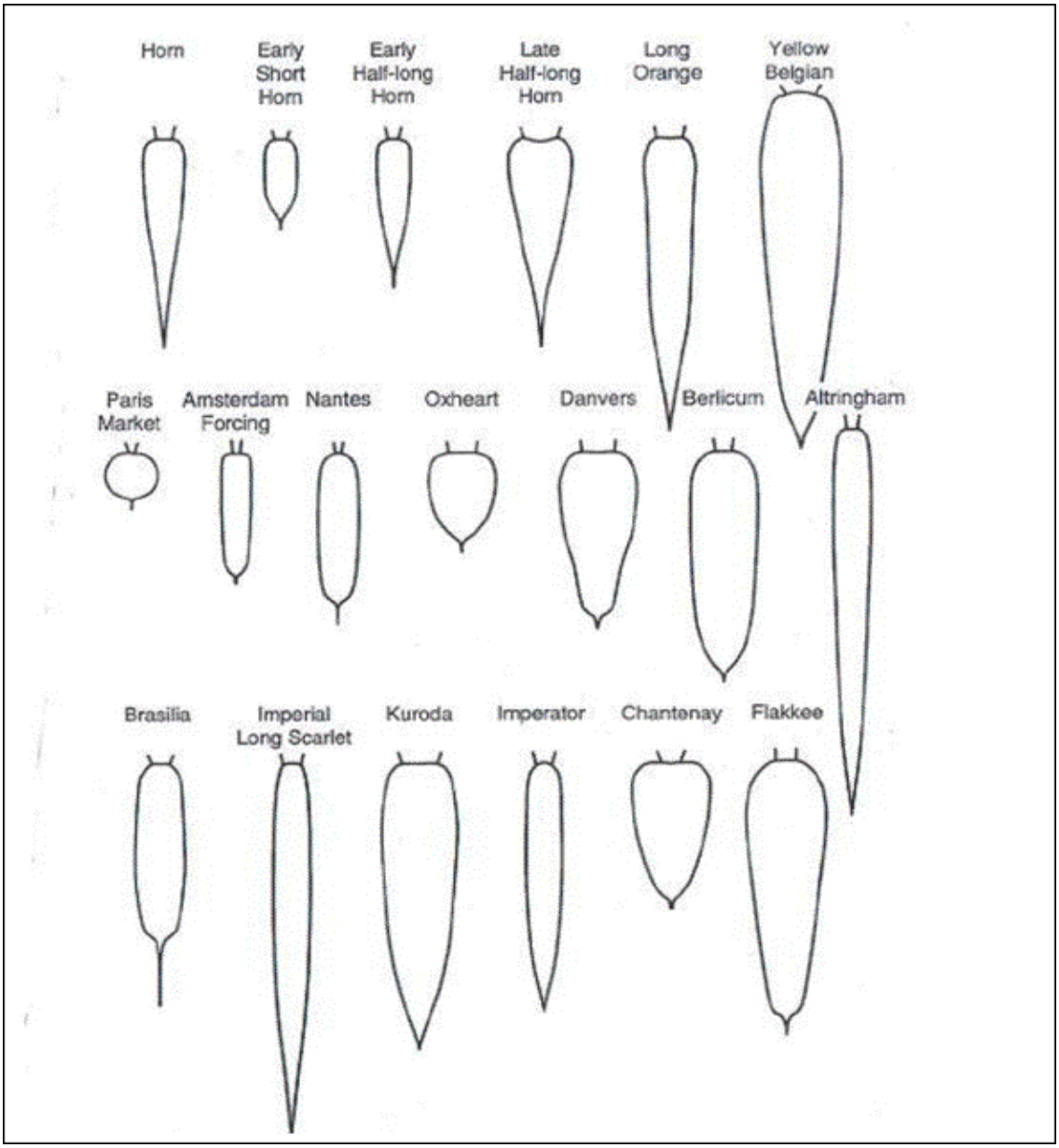


Figure 4. The shape of a collection of carrot varieties. (Rubatzsky, V. E., Quiros, C. F.et. al., 1999)

Chemical composition

The chemical composition of the carrot storage root varies over time, between cultivars and as a result of cultivation measures. At the time of harvest the carrot storage root consist of about 85 to 90% of water. The rest of the carrot is dry matter. The ash content is usually between 5 and 10% in dry matter, (Odebode and Unachukwu, 1997).

The mineral composition of carrot does not show any remarkable features although high content of cadmium can cause problems occasionally, especially on soils low in pH, (Jansson and Öborn, 2000)

Primary metabolites

The amount of different compounds changes during the season. If not noted otherwise the figures mentioned here are collected from the situation at harvest.

Carbohydrates

About half of the dry matter content is soluble sugar. The sugar concentration varies between 30 and 70% of the dry matter. At harvest the sugar content mainly consist of the disaccharide sucrose and the two monosaccharides, glucose and fructose. Measured as percent of the dry matter the sucrose concentration varies between 20 and 45% and the concentrations of the two monosaccharides are about 10% each. Glucose is present both as α- and β-glucose,(Nilsson, 1987).

Maltose has been reported present in carrots but only in quantities lower than 0.5% of dry matter, (Odebode and Unachukwu, 1997). Galactose, (Odebode and Unachukwu, 1997; Galindo, Bråthen et.al., 2004), lactose and arabinose (Odebode and Unachukwu, 1997) are also found in carrots. Other "sugarlike" compounds reported are glucose-1-phosphate, glucose-6-phosphate, fructose-6-phosphate, nucleoisid- mono-, di- and tri- phosphate, (Alabran and Mabrouk, 1973).

Carrots are low in starch. Only seldom does the concentration of starch reach more than 1% in dry matter. The amount of crude fibre is 3-4% on a dry weight basis, (Svanberg, Nyman et.al., 1997).

Nitrogenous compounds

Free nitrogenous compounds accounts for about 1 to 0.5% of the fresh weight. The most important amino acids are aspartic acid, α-alanine, serine, glutamic acid, arginine, valine and threonine. Together with amino sugars, like glucosamine, the free amino acids account for 90% of the total free nitrogenous compounds, (Alabran and Mabrouk, 1973). The amount of protein is between 5 and 10% of the dry matter.

Lipids

The total lipid content in carrot is approximately 0.3% in dry weight. The amount of oil is correlated with the rate of oils ducts in the plant, (Rubatzsky, V. E., Quiros, C. F.et. al., 1999). The composition of the carrot oil is complex. It is mainly genetically determined. The amounts of different oils vary however depending on growing condition, (Heatherbell, Wrolstad et.al., 1971; Heatherbell and Wrolstad, 1971).

Organic acids

The total amount of organic acids is about 0.2% in fresh weight, (ėkesson, 2003) The most common organic acids in carrots are pyrovatic, oxalic acetic, isocitric and malic acid, (Phan, Hsu et.al., 1973). ,

Secondary metabolites

There is a large amount of secondary metabolites in carrots. The ones mentioned here are more or less connected to the sensory properties, especially taste and flavour.

Vitamins

Carrots are the major single source of provitamin A, as α- and β-carotene, providing more than 17% of the total vitamin A consumption in the US, (Block, 1994). Higher levels of carotenoids is normally found in the phloem than in the xylem, (Koch and Goldman, 2005).
The carotenoids are commonly divided into two main groups:

1. carotenes or hydrocarotenoids, containing only carbon and hydrogen
2. xanthophylls or oxycarotenoids, the oxygenated derivates of the carotenes.

Six carotenes has been reported in carrots; α-, β-, γ- and ξ-carotenes, lycopene and β-zeacarotene. The most predominant in orange and yellow carrots are α- and β-carotene, (Simon and Wolff, 1987). Lycopene is found in red carrots, (Surles, Weng et.al., 2004).
Xanthophylls, such as lutein, are common in yellow carrots. In purple carrots we find anthocyanins, belonging to the flavonoids, beside the carotenoids (Surles, Weng et.al., 2004). An example of the concentrations of carotenoids found in different types of carrots is found in table 3.

Table 3. Concentrations of carotenoids in different types of carrots, nd =not detected. Reprinted with permission from (Surles, Weng et.al., 2004). Copyright 2004 American Chemical Society.

Carrot type	Concentrations of carotenoids (mg/100 g carrot, fresh weight)				
	carotenes			xanthophyll	Total
	α-carotene	β- carotene	lycopene	lutein	
Orange	2,2 ±0,8	12,8±3,3	nd	0,26±0,08	15,2±4,1
Purple	4,1±1,2	12,3±5,1	nd	1,1±0,73	17,5±7,0
Red	0,11	3,4±0,89	6,1±0,6	0,32±0,26	9,8±1,4
Yellow	0,05±	0,18±0,17	nd	0,51±0,27	0,71±0,38
White	nd	0,006±0,003	nd	0,009±0,002	0,014±0,001

The amount of C-vitamin, ascorbic acid, is between 3 and 5 mg/100g fresh weight in orange varieties and about 1 to 2 mg/100g fresh weight in white and yellow varieties, (Alasalvar, Grigor et.al., 2001).

The concentration of vitamin E, in the form of α-tocopherol, is reported to be 0.04- 0.18 ppm, on a dry weight basis. The concentrations are almost the same in the xylem as in the phloem. The concentration of α-tocopherol in the xylem is positively correlated with the concentrations of both α- and β- carotene, (Koch and Goldman, 2005).

Volatiles and essential oils

The group of volatile compounds is of great importance for the taste and flavour of carrots, (Buttery, Seifert et.al., 1968; Heatherbell, 1970; Heatherbell, Wrolstad et.al., 1971;

Heatherbell and Wrolstad, 1971; Buttery, Black et.al., 1979; Simon, Lindsay et.al., 1980; Simon, 1982; Kaminski, Wasowicz et.al., 1986; Senalik and Simon, 1987; Shamaila, Durance et.al., 1996; Yoo, Pike et.al., 1997; Alasalvar, Grigor et.al., 1999; Alasalvar, Grigor et.al., 2001; Seljåsen, Bengtsson G. B. et.al., 2001; Rosenfeld, Dalen K.S. et.al., 2002; Rosenfeld, 2003; Kjeldsen, Christensen et.al., 2003). Analyses of carrot roots commonly detect between 30 and 40 volatile substances. Mono- and sesquiterpenes account for about 98% of the total volatile compound mass in carrot, (Kjeldsen, Christensen et.al., 2001). Other volatile compounds are alcohols, styren, and alkane, (Alasalvar, Grigor et.al., 2001). The number of volatile compounds is determined genetically. The actual amounts of the different volatile compounds is however dependent on the environment, (Rosenfeld, Aaby et.al., 2002). Two examples of volatile compounds found in carrots are given in figure 5 and table 4.

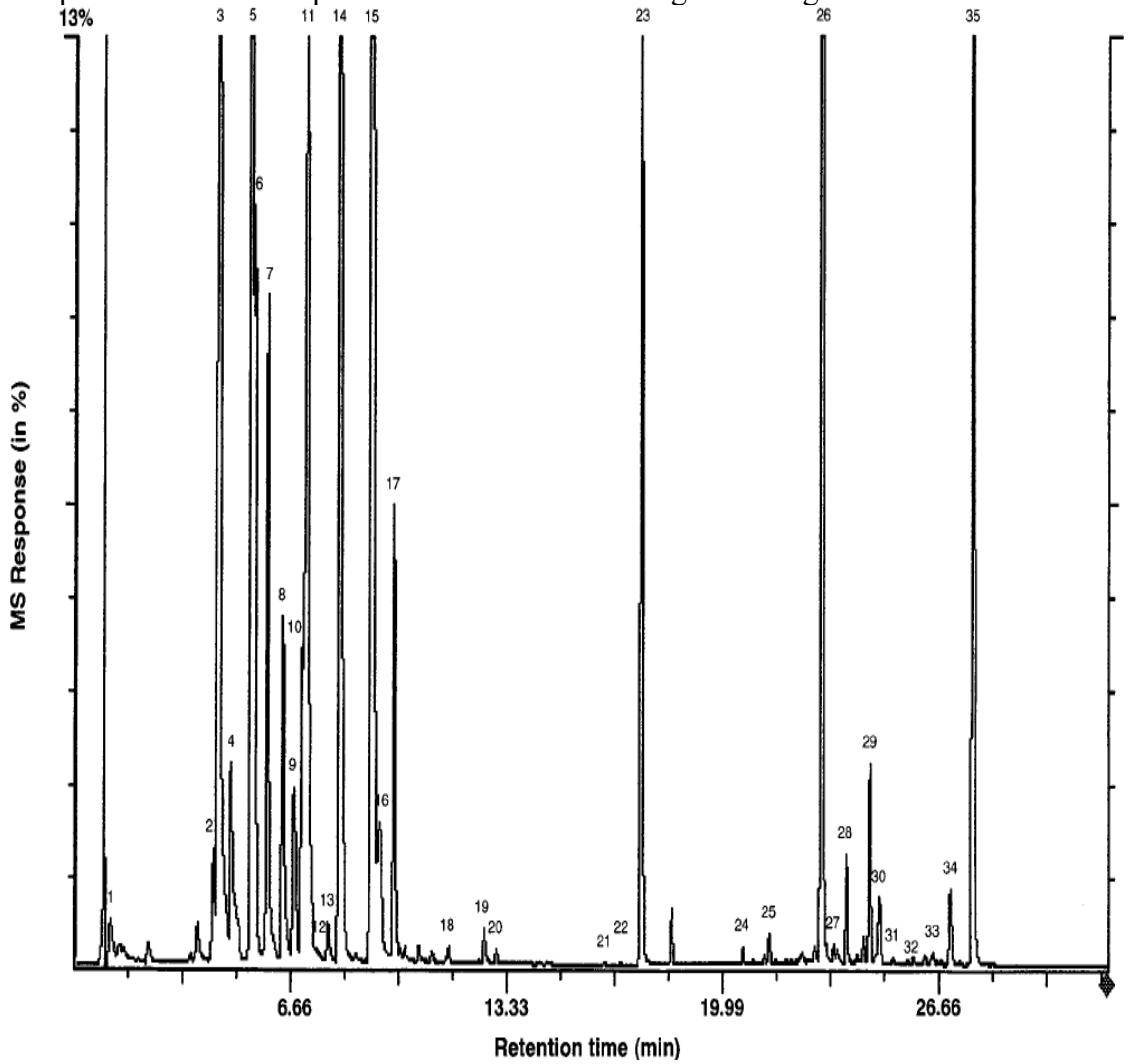


Figure 5. Typical total ion chromatograph of volatile compounds in orange carrots. Peak identification: propanol {1}, α-thujene {2}, α-pinene {3}, camphene {4}, sabinene {5}, β-pinene {6}, myrcene {7}, α-phellandrene {8}, α-terpinene {9}, ρ-cymene {10}, limonene {11}, cis-ocimene {12}, trans-ocimene {13}, γ-terpinene {14}, terpinolene {15}, 2,5-dimethylstyrene {16}, undecane {17}, camphor {18}, borneol {19}, terpinen-4-ol {20}, linalyl acetate {21}, β-citronellol {22}, bornyl acetate {23}, α-santalene {24}, longifolene {25}, β-caryophyllene {26}, α-selinene {27}, trans-α-bergamotene {28}, α-humulene {29}, cis-β-farnesene {30}, γ-elemene {31}, α-zingiberene {32}, valencene {33}, β-bisabolene {34}, and γ-bisabolene {35}. Reprinted with permission from (Alasalvar, Grigor et.al., 2001). Copyright 2001 American Chemical Society.

Table 4. Example of volatiles isolated from the headspace of four carrot cultivars by dynamic headspace sampling and quantified by capillary GC using LVI technique[a]. Reprinted with permission from (Kjeldsen, Christensen et.al., 2001). Copyright 2001 American Chemical Society.

peak no.	isolated compound[b]	$RI_{CP-Wax\ 52CB}$	content in ng/50 g/1.5 h[d]				signif.[e]	CV (%)[f]
			Brasilia	Duke	Fancy	Cortez		
1	α-pinene	1008	4350 c	7780 b	13500 a	4680 c	***	10.3
2	camphene	1044	236 bc	194 c	545 a	270 b	***	9.5
3	*β*-pinene	1086	799 c	1730 b	2930 a	1630 b	***	11.5
4	sabinene	1105	353 d	2920 c	6220 a	4310 b	***	8.7
5	α-phellandrene	1147	253 a	21 d	220 b	173 c	***	9.3
6	*β*-myrcene	1153	2960 c	2330 c	13100 a	8750 b	***	12.2
7	α-terpinene	1162	114 c	140 c	188 b	268 a	***	12.5
8	limonene	1183	2430 b	1360 c	3170 a	2120 b	***	10.0
9	*β*-phellandrene	1191	149 c	193 bc	495 a	250 b	***	10.4
10	γ-terpinene	1230	9050 b	4220 c	12500 a	9070 b	***	11.5
11	(*E*)-*β*-ocimene	1241	109 b	68 b	146 b	828 a	***	9.5
12	*p*-cymene	1252	8190 b	5340 c	17300 a	5280 c	***	11.9
13	terpinolene	1266	26700 a	13500 c	25200 a	17700 b	***	10.7
14	octanal	1274	249 a	280 a	332 a	355 a	ns	16.1
15	6-methyl-5-hepten-2-one	1346	1230 a	1110 a	1660 a	1260 a	ns	17.6
16	unknown (*m/z* 135, 150, 91, 79, 107, 77, 105)	1376	156 a	142 a	177 a	45 a	ns	43.6
17	unknown (*m/z* 135, 91, 150, 79, 107, 77, 105)	1389	46 a	51 a	15 b	nd c	***	13.1
18	*p*-cymenene	1411	146 a	105 a	136 a	149 a	ns	25.5
19	unknown monoterpene (*m/z* 79, 110, 95, 77, 67, 91, 152)	1422	241 a	204 a	231 a	67 b	*	23.7
20	α-copaene	1457	202 a	103 b	29 c	nq c	***	19.9
21	unknown sesquiterpene (*m/z* 161, 121, 105, 91, 134, 93, 204)	1459	12 a	12 a	18 a	nq a	ns	47.0
22	camphor	1507	nq a	nq a	15 a	nd a	ns	11.5
23	unknown sesquiterpene (*m/z* 161, 105, 91, 204, 119, 133, 147)	1518	117 c	499 b	1070 a	236 bc	***	26.6
24	bornyl acetate	1574	nq a	nq a	16 a	nd a	ns	23.0
25	*β*-caryophyllene	1576	20200 b	11500 c	24300 b	40700 a	***	11.3
26	thymol methyl ether	1587	185 a	166 a	nd b	nd b	*	23.8
27	aromadendrene	1622	nd a	nd a	109 a	nd a	ns	21.7
28	(*Z*)-*β*-farnesene	1632	nd a	nd a	22 a	nd a	ns	21.7
29	α-humulene	1640	1200 c	740 d	1610 b	2540 a	***	12.4
30	unknown sesquiterpene (*m/z* 91, 93, 119, 161, 77, 133, 69, 204)	1643	29 b	58 b	128 a	86 a	*	35.0
31	(*E*)-*β*-farnesene	1650	117 b	460 a	382 a	465 a	***	14.2
32	valencene	1671	41 d	756 a	315 c	477 b	***	13.1
33	α-terpinyl acetate	1698	36 a	36 a	26 a	nq a	ns	60.0
34	*β*-bisabolene	1708	440 c	508 c	945 a	731 b	***	10.6
35	(*E,E*)-α-farnesene	1713	26 a	25 a	47 a	38 a	ns	31.3
36	unknown sesquiterpene (*m/z* 67, 93, 79, 107, 147, 161, 189, 204)	1722	15 a	13 a	nd b	nd b	***	9.4
37	(*E*)-γ-bisabolene	1737	5620 c	7160 c	12100 a	10400 ab	**	14.9
38	α-zingiberene[c]	1745	11 c	47 a	32 b	nd c	***	15.6
39	(*Z*)-γ-bisabolene	1756	276 b	205 b	866 a	949 a	***	16.1
40	*β*-ionone	1853	51 a	48 a	58 a	25 a	ns	29.4
41	unknown sesquiterpene (*m/z* 91, 79, 93, 105, 121, 131, 187, 205)	1951	30 a	7.2 b	5.4 b	nq c	***	11.7
42	caryophyllene oxide	1969	303 a	230 a	286 a	350 a	ns	20.8
43	elemicin	2202	6.5 c	6.2 c	23 a	15 b	***	20.7
44	myristicin	2225	12 b	8.4 b	58 a	79 a	***	21.1
	total monoterpenes		56300 b	40300 c	95900 a	55600 b	***	10.4
	total sesquiterpenes		28600 c	22300 c	42200 b	56900 a	***	12.1
	total volatiles		86700 c	64200 d	140400 a	114300 b	***	10.3

[a] Sample size injected, 15 μL. Concentrations of aroma compounds were determined relative to that of the internal standard, (*E*)-2-hexen-1-ol. [b] MS and GC retention indices (RI) were consistent with those of reference compounds unless noted. MS of unknown compounds are listed in parentheses with descending intensities of fragment ions [c] Tentatively identified. No standard available but the MS was consistent with published data (*32, 33*). [d] nq, not quantified (less than 5 ng/50 g/1.5 h) and nd, not detected. A minimal content of 0 ng/50 g/1.5 h was assigned to facilitate statistical analysis. [e] Significance: ns, nonsignificant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$. [f] Mean coefficient of variance (CV) for three replicates of each cultivar.

The most frequent essential oils are the monoterpenes; sabinene, β-myrcene, α-terpinolene and β-caryophyllene together with some sesquiterpenes, (Habegger, Müller et.al., 1996).

Terpenes

The terpenes are aromatic compounds occurring naturally in carrot mostly as mono- and sesquiterpenes. Usually between 17 and 20 different simple terpenes contribute to the typical carrot flavour. (Simon, 1982; Seljåsen, Bengtsson G. B. et.al., 2001; Rosenfeld, Vogt et.al., 2004).

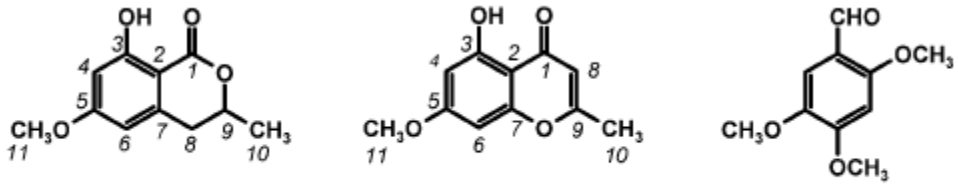
Phenols

Phenols are biosynthesised along the polyketide (acetylcoenzyme A) or the shikimic pathway. The most common phenolic substances in carrot are hydroxicinnamic acid derivates. Also caffeic acid, isochlorogenic acid and chlorogenic acid are found in carrots ((Sarkar and Phan, 1979; Alasalvar, Grigor et.al., 2001). The amount of the most common phenols found in carrots of different colour is listed in table 5.

Table 5. Some phenolic compounds in different carrot varieties. Reprinted with permission from (Alasalvar, Grigor et.al., 2001). Copyright 2001 American Chemical Society.

	levels of phenolic compounds (mg/100 g)			
compound	orange	purple	yellow	white
3′-caffeoylquinic acid	0.28 ± 0.02^{d}	0.88 ± 0.05^{c}	0.09 ± 0.01^{e}	0.09 ± 0.01^{e}
cis-3′-caffeoylquinic acid	nd^{g}	1.94 ± 0.10	nd	nd
5′-caffeoylquinic acid	8.50 ± 0.24^{d}	54.08 ± 3.10^{c}	4.41 ± 0.21^{e}	4.47 ± 0.20^{e}
caffeic acid	nd	2.42 ± 0.16	nd	nd
3′-*p*- coumaroylquinic acid	0.54 ± 0.02^{d}	0.91 ± 0.06^{c}	0.20 ± 0.02^{f}	0.31 ± 0.02^{e}
3′- feruloyquinic acid	0.21 ± 0.02^{def}	7.30 ± 0.20^{c}	0.19 ± 0.01^{f}	0.26 ± 0.02^{de}
3′,4′-dicaffeoylquinic acid	2.08 ± 0.15^{d}	2.78 ± 0.18^{c}	1.30 ± 0.07^{e}	1.06 ± 0.06^{f}
5′-feruloyquinic acid	0.11 ± 0.01^{f}	0.96 ± 0.03^{c}	0.51 ± 0.03^{d}	0.39 ± 0.02^{e}
cis-5′-caffeoylquinic acid	nd	0.49 ± 0.02	nd	nd
5′−*p*-coumaroylquinic acid	0.13 ± 0.01^{d}	0.74 ± 0.03^{c}	0.11 ± 0.01^{d}	nd
4′-feruloyquinic acid	0.40 ± 0.03	nd	nd	nd
3′,5′-dicaffeoylquinic acid	3.80 ± 0.20^{c}	0.44 ± 0.02^{f}	0.75 ± 0.02^{e}	1.74 ± 0.09^{d}
3′,4′- diferuloylquinic acid	0.07 ± 0.01^{e}	0.53 ± 0.03^{c}	0.12 ± 0.01^{e}	0.31 ± 0.02^{d}
3′,5′- diferuloylquinic acid	0.09 ± 0.01^{d}	1.17 ± 0.02^{c}	0.04 ± 0.01^{d}	0.06 ± 0.01^{d}
total phenolics	16.21 ± 0.21^{d}	74.64 ± 3.32^{c}	7.72 ± 0.22^{e}	8.69 ± 0.24^{e}

When discussing bitter taste some specific phenolic substances are often mentioned. The structure of 6-methoxy-mellein and two other of these substances found in carrots are given in figure 6.



1 **2** **3**

1) 3-methyl-6-methoxy-8-hydroxy-3,4-dihydroisocoumarin (6-methoxymellein)
2) 5-hydroxy-7-methoxy-2-methylchromone (eugenin),
3) 2,4,5-trimethoxybenzaldehyde (gazarin).

Figure 6. Structures of phenolic compounds, described as bitter-tasting in carrots, Reprinted with permission from (Czepa and Hoffmann, 2003). Copyright 2003 American Chemical Society.

The phytoalexin, 6-methoxymellein, 6MM (3-methyl-6-methoxy-8-hydroxy-3,4-dihydroisocoumarin), is a secondary metabolite that inhibits the growth of many microorganisms. It is elicited in carrot root tissues inoculated with fungi, as well by treatment with various elicitors (Condon, Ku´c et.al., 1963; Coxon, Curtis et.al., 1973; Müller, 1978; Kurosaki and Nishi, 1983; Mercier, Arul et.al., 1993). It is also induced by numerous mold species (Kurosaki and Nishi, 1983; Hoffman, Roebroeck et.al., 1988), by exposure to UV light (Mercier, Arul et.al., 1994), and from pectinolytic enzymes (Movahedi and Heale, 1990; Marinelli, Ronchi et.al., 1994). However, exposure to ethylene appears to be the most common stimulus for its formation in carrots, (Lafuente, Cantwell et.al., 1989).

Polyacetylenes

Food plants of the Apiaceae plant family such as carrots, celery and parsley, contain a group of bioactive aliphatic C_{17}-polyacetylenes. They form a distinct group of relatively chemically reactive natural products. More than 1400 different polyacetylenes and related compounds have been isolated from higher plants, (Christensen and Brandt, 2006). Aliphatic C_{17}-polyacetylenes of the falcarinoltype are common in the families Apiaceae and Araliaceae, (Bohlmann, Burkhardt et. al., 1973; Hansen and Boll, 1986). Polyacetylenes of the falcarinol-type are formed from oleic acid by dehydrogenation leading to the C_{18}-acetylenes crepenynic acid and dehydrocrepenynic acid, which is then transformed to C_{17}-acetylenes by β-oxidation. Further oxidation and dehydrogenation leads to falcarinol and related C17-acetylenes of the falcarinol-type (Bohlmann, F., Burkhardt, T.et. al., 1973; Hansen and Boll, 1986).

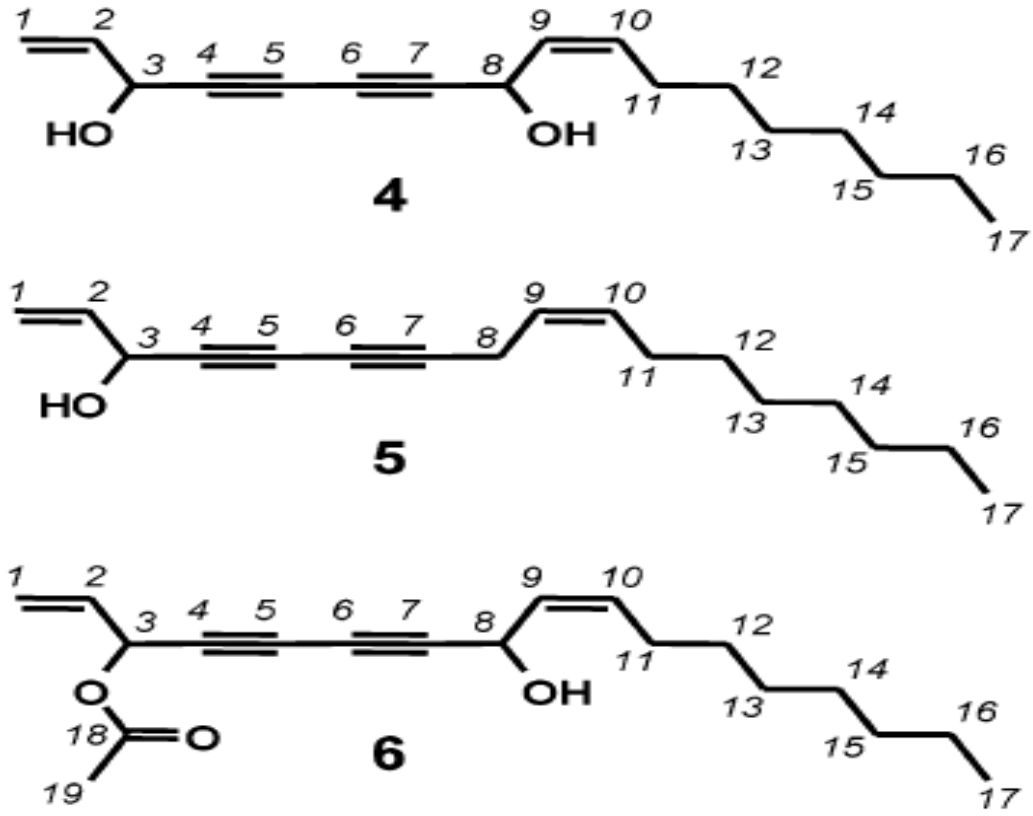
Three polyacetylenes from the falcarin-group are often mentioned in connection with carrots:

- (Z)-heptadeca-1,9-diene-4,6-diin-3,8-diol (falcarindiol, FaDOH),
- (Z)-heptadeca-1,9-diene-4,6-diin-3-ol (falcarinol, FaOH),
- (Z)-3-acetoxyheptadeca-1,9-diene-4,6-diin-8-ol (falcarindiol 3-acetate, FaDOAc).

Falcarindiol, FaDOH, has recently been detected as a bitter tasting constituent in carrot, (Czepa and Hoffmann, 2004). There are some results showing that FaDOH is part of the defence against fungal infection, (Olsson and Svensson, 1996).

Falcarinol, FaOH, is a bioactive metabolite. It has shown cytotoxic activity against human tumour cells in vitro (Matsunaga, Katano et.al., 1990) and possibly also in vivo (Bernart, Cardellina II et.al., 1996). FaOH stimulates differentiation of mammalian cells down to 1 ng/ml and shows toxic effects above 1000 ng/ml (Hansen, Purup et.al., 2003). Furthermore FaOH is said to have anti-inflammatory (Fujimoto, Sakama et.al., 1998), and anti-tuberculosis (Kobaisy, Abramowski et.al., 1997) effect. It also causes allergic dermatitis after skin exposure, (Hansen and Boll, 1986). When eating carrot juice containing falcarinol the concentration in human blood plasma increases with in half an hour after ingestion, reaches its maximum approximately 4 hours after and goes back to starting level after 8 hours, (Haraldsdóttir, Jespersen et.al., 2002).

Falcarindiol 3-acetate, FaDOAc, has not yet been connected with any specific task. The chemical structure of three of the polyacetylenes from the falcarin-group is shown in figure 7 on the next page.



4) (Z)-heptadeca-1,9-diene-4,6-diin-3,8-diol (falcarindiol, FaDOH)
5) (Z)-heptadeca-1,9-diene-4,6-diin-3-ol (falcarinol, FaOH)
6) (Z)-3-acetoxyheptadeca-1,9-diene-4,6-diin-8-ol (falcarindiol 3-acetate, FaDOAc).

Figure 7. Structures of different polyacetylenes Reprinted with permission from (Czepa and Hoffmann, 2003). Copyright 2003 American Chemical Society.

The organic carrot

The term "organic" is used in many different ways and contexts. In this text an organic carrot refers to a carrot grown without artificial fertilizers and pesticides, in accordance with the EU-regulation 2092/91. Within this framework there is a wide variety of methods to produce an organic carrot. This makes it difficult to describe the typical properties of the "organic carrot".

There are some reviews bringing the result from comparative studies between organic and conventional farming together (Woese, Lange et.al., 1995; Alföldi, Bickel et.al., 1998; Worthington, 1998). The results from these reviews are summarised in table 6 on the next page.

Table 6. Comparison between conventional and organic produce. Reprinted with the kind permission from (Alföldi, Bickel et.al., 2001)

Source	(Woese, Lange et.al., 1995)	(Worthington, 1998)	(Alföldi, Bickel et.al., 1998)
Number of studies compiled	150	86	33
Covering period	1926-1993	1926-1993	1993-1998
Nitrate content	+	+	+
Vitamin content	=	+	(+)
Mineral content	=	(+)	=
Quality of protein	=	(+)	Not mentioned
Quality when processed	-	Not mentioned	=
Fodder quality	=	+	Not mentioned
Fodder preference test	+	Not mentioned	(+)
Sensory test	=	Not mentioned	(+)
	+ organic produce appears as better, (+) organic produce appears as slightly better - organic produce appears as worse		

There are only a few studies on carrots covering the difference between cultivation systems. Most of the results reported are comparisons between mineral and organic fertilizers. The results are based either on samples from field trials or on samples collected from farms or shops.

Annular variation and site-specific factors contribute more to the properties of the carrots than the fertilization system. (Hansen, 1981).

The dry matter content tends to be higher in organic carrots than in conventional, (Nilsson, 1979; Kerpen, 1988).

The concentration of nitrate is often higher in conventional carrots, (Wistinghausen, 1979; Hansen, 1981; Wedler, 1982; Reith, 1982; Rauter and Wolkersdorfer, 1982; Vetter, Kampe et.al., 1983; Wistinghausen, 1984; Pommer and Lepschy, 1985; Abele, 1987; Lieblein, 1993). Also the amount of crude protein is usually higher in conventional carrots, (Wistinghausen, 1979; Hansen, 1981; Wistinghausen, 1984; Abele, U., 1987; Kerpen, 1988) . The proportion of pure protein in relation to the amount of crude protein is reported to be higher in the organic carrots, (Schuphan, 1974; Dlouhy, 1981; Pettersson, 1982; Wistinghausen, 1984; Abele, U., 1987; Reinken, Keipert et.al., 1990).

Composted farm manure in comparison to mineral fertiliser increases the amount of carotene and lowers the amount of ascorbic acid (Brandt and Besson, 1951; Rautavaara, 1973; Wedler, 1982; Pommer and Lepschy, 1985). However the opposite effect has also been reported, (Vetter, Kampe et.al., 1983). The concentration of carotene seems to be more dependent on the amount of manure than on the type, (Lieblein, 1993)

The amount of sugar seems to be slightly higher in organic carrots (Wistinghausen, 1979; Pommer and Lepschy, 1985; Hogstad, Risvik et.al., 1997). This might be due to higher amounts of sucrose in the organic carrots, (Lieblein, 1993; Hogstad, Risvik et.al., 1997). On the other hand lower amounts of monosackarids in the organic carrots has also been reported,

(Wistinghausen, 1979; Wistinghausen, 1984; Abele, U., 1987). These differences can perhaps be explained by different rates in development within the two systems.

Several studies have been published from the Research Institute for Biodynamic Farming at Darmstadt in Germany. The results are compiled in table 7 as an overview of the difference between organic and conventional carrots.

Table 7. Different properties of carrots due to fertilising system. Results from different field trials at the Research Institute for biodynamic farming in Darmstadt, 1964- 1986

	Report			
Amount of	(Abele, U., 1987)	(Klein, 1968)	(Wistinghausen, 1979) /(Samaras, 1977)*	(Wistinghausen, 1984)
Dry matter	+		+	=
Nitrate	-		-	-
Crude protein	-		-	-
Pure protein	-		=	+
Amino acids	-		-	
Monosaccharides	+	=	+	-
Disaccharide	-	=	+	+
Activity of enzymes	-		-*	=
Storage losses	-		-*	=

. + higher in organic farming, - lower in organic farming, = no difference

In discriminating sensory test, triangular test, the assessors could correctly point out the organic carrots, (Hansen, 1981; Vetter, Kampe et.al., 1983; Matthies, 1991). However the assessors could not agree on which carrots tasted the best.

The organic carrots have sometimes shown better sensory ratings (Rautavaara, 1973). This contradicts results where the organic carrots got lower ratings, mainly because of their appearance and their higher woodiness, (Schutz and Lorenz, 1976). Organic carrots are reported sweeter, (Lieblein, 1993; Hogstad, Risvik et.al., 1997), more bitter, (Haglund, 1998), and less bitter, (Hogstad, Risvik et.al., 1997), than the conventional carrots. The differences in taste are more accentuated after storage, (Evers, 1989).

Taste perception

The following description of the human taste perception is a brief presentation collected from the internet, (Jacob, 2007).

The perceptions in connection with a meal involve many senses. Sight, touch, warmth, smell and taste interact to give us an impression of the food we are to eat. The experience of a meal is also influenced by psychological factors such as dining room atmosphere and other guests at the table.

The starting point of the taste analysis is the solution produced when by chewing we mix food and saliva with each other. Special glands in the mouth pit produce the saliva. It is secreted under the tongue, beside the second molar in the upper cheek, and from the walls of the mouth pit. There are two types of saliva. The mucous saliva makes the food easier to swallow. The

serous saliva dilutes the food and also contains enzymes that hydrolysis starch into sugar. The perception of sweet taste is often dependent on the activity of such enzymes.

The taste organ

In mammals taste buds are located throughout the oral cavity, in the pharynx, the laryngeal epiglottis and at the entrance of the eosophagus. Taste buds on the dorsal lingual epithelium are the most numerous. On the tongue taste buds are contained within four major classes of papillae. The anatomy of the human tongue is shown in figure 8.

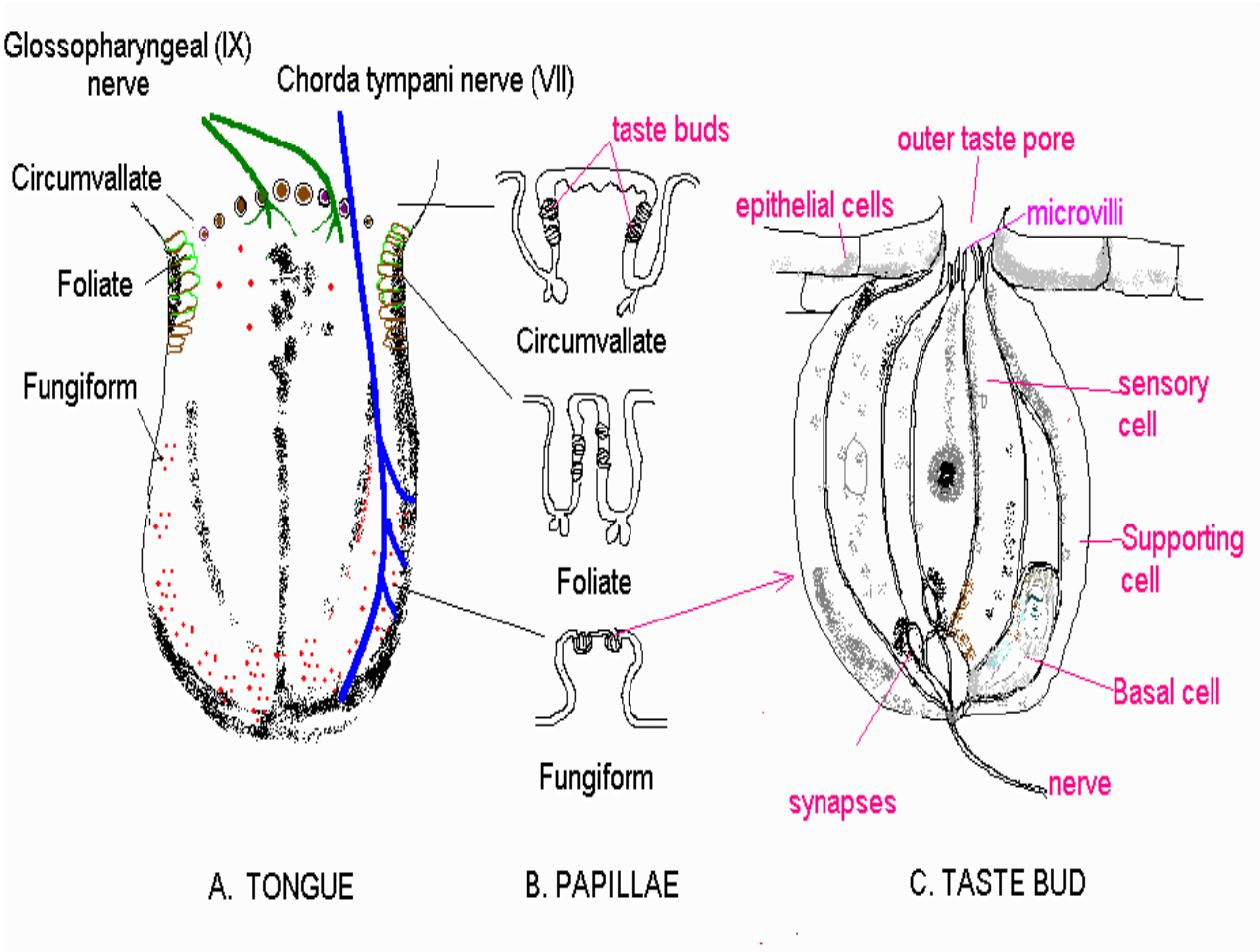


Figure 8. The human tongue as the organ of taste. Reprinted with the kind permission from (Jacob, 2007)

- *Fungiform papillae* are located on the most anterior part of the tongue and generally contain one to several taste buds per papilla. They are innervated by the chorda tympani branch of the facial (Vllth cranial) nerve. They appear as red spots on the tongue - red because they are richly supplied with blood vessels. The total number of fungiform papillae per human tongue is around 200. Papillae at the front of the tongue have more taste buds (1-18) compared to the mid-region (1-9). It has been calculated that there are 1120 fungiform taste buds per tongue.
- *Foliate papillae* are situated on the edge of the tongue slightly anterior of the circumvallate line. They are predominantly sensitive to sour tastes. Innervated by the glossopharyngeal (lXth cranial) nerve. On average 5.4 foliate papillae per side of the tongue, 117 taste buds per foliate papillae, total = 1280 foliate taste buds per tongue.
- *Circumvallate papillae* are sunken papillae, with a trough separating them from surrounding wall. The tase buds are in tiers within the trough of the papillae. They are

situated on the circumvallate line and confer a sour/bitter sensitivity to the posterior 2/3 of the tongue. Innervated by the glossopharyngeal (lXth cranial) nerve. 3-13 circumvallate papillae per tongue with 252 taste buds per papillae, total = 2200 circumvallate taste buds per tongue

- *Filiform papillae* are mechanical and non-gustatory.

In addition there are 2500 taste buds on the epiglottis, soft palate, laryngeal and oral pharynx. The number of taste buds declines with age.

Different taste qualities

There are five basic tastes: salt, sour, sweet, bitter and umami.

1. *Salt taste*
   Na^+ ions enter the receptor cells via Na-channels. These are amiloride-sensitive Na^+ channel. The entry of Na^+ causes a depolarization, Ca^{2+} enters through voltage-sensitive Ca^{2+} channels, transmitter release occurs and results in increased firing in the primary afferent nerve.
2. *Sour taste*
   H^+ ions block K^+ channels. K^+ channels are responsible for maintaining the cell membrane potential at a hyperpolarized level (close to the K^+ equilibrium potential of around -85mV). Block of these channels causes a depolarization, Ca^{2+} entry, transmitter release and increased firing in the primary afferent nerve.
3. *Sweet taste*
   There are receptors in the apical membrane that bind glucose and other saccharides. Binding to the receptor activates adenylyl cyclase, thereby elevating cAMP. This causes a PKA-mediated phosphorylation of K^+ channels, inhibiting them. Depolarization occurs, Ca^{2+} enters the cell through depolarization-activated Ca^{2+} channels, transmitter is released increasing firing in the primary afferent nerve.
4. *Bitter taste*
   Bitter substances cause the second messenger (IP_3) mediated release of Ca^{2+} from internal stores (external Ca^{2+} is not required). The elevated Ca^{2+} causes transmitter release and this increases the firing of the primary afferent nerve.
5. *Umami taste*
   Umami is the taste of certain amino acids (e.g. glutamate, aspartate and related compounds). Recently it has been shown that the *metabotropic* glutamate receptor (mGluR4) mediates umami taste. Binding to the receptor activates a G-protein and this may elevate intracellular Ca^2 .

The chemical processes connected to the perception of these primary taste qualities are briefly presented in figure 9 on the next page.

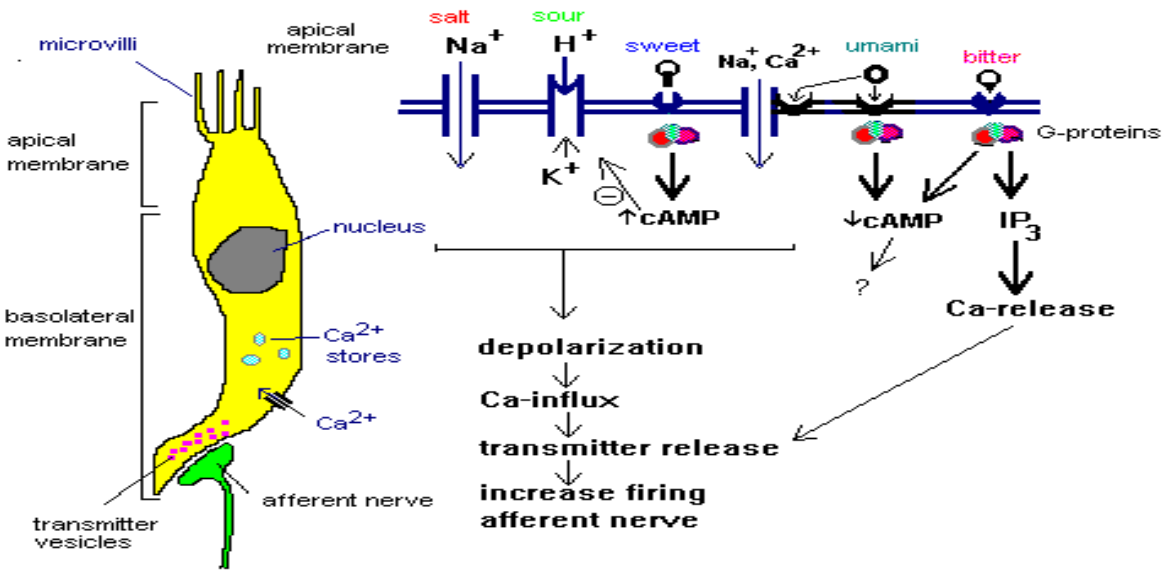


Figure 9. Schematic description of a taste receptor cell and the chemical processes connected to the five taste qualities. Reprinted with the kind permission from (Jacob, 2007)

Sensory evaluation

An overview of sensory evaluation is given in (Lawless, H. T. and Heymann, H., 1999).

Methodology

There are different types of sensory evaluation methods. An *affective evaluation* describes the assessors liking or disliking of a product. The discriminant evaluations focus only on if there are differences between products. The *analytical, or descriptive, evaluation* tries to describe the properties of the product or the differences between products.

Often the context of the testing situation interplays with the assessors' evaluation. The temperature, colour and sound level of the testing room are important factors, as is the protocol that is been used.

There are different standards describing possible ways to do a sensory evaluation. ISO 5492 describes terms to use, ISO 6564 lists different properties of an aroma profile. ISO 8589 describes the testing room, ISO 3972 the training of the panellists and so on. Besides the ISO system there are other standards describing the same issues. ASTM E-2454 and ASTM E - 1885 both describe different types of sensory testing methods. More information on different standards can be found on www.ansi.org, www.iso.org and www.astm.org.

The first step is to "calibrate" the senses. This can be done in at least two ways. One way is by tasting standardised solutions, (Czepa and Hoffmann, 2003; Marabi, Thieme et.al., 2006). This makes it easier to compare the result from one test to another. But at the same time it makes the resolution smaller because the terms used has nothing to do with for example carrots. This method is therefore applicable in test where a limited number of properties, like sweetness and bitterness, are to be evaluated. An other way is to screen the products to be evaluated and after that decide the appropriate terms to use, (Fjeldsenden, Martens et.al., 1981; Simon and Lindsay, 1983; Martens, Rosenfeld et.al., 1985; Baardseth, Rosenfeld et.al., 1996; Haglund, 1998; Talcott and Howard, 1999a; Seljåsen, 2000; Rosenfeld, 2003; Varming, Jensen et.al., 2004). Concerning carrot this means that the panellists start by tasting all the

different carrot samples included in the test. They then discuss their experiences and agree on a common set of terms to use during the "real" test. Each term is evaluated separately, often on a linear scale. The advantage of this procedure is a better resolution in the description and a better discrimination between the samples. The total taste profile is also more detailed using this method. The disadvantage is difficulties to compare one test with another.

The most frequently used discriminant test is the triangle test. Three samples, of those are two the same, are presented to the assessor. The assessor has to recognise the single sample and describe the difference. In a pure descriptive test the properties of the carrots are described more or less independent from each other.

Assessors

The evaluating person can be a trained panellist or an untrained consumer. In both cases the personal set of values of the assessors can influence the result of the evaluation.

In *untrained panellist test* the assessors are mostly picked by random. Most consumers test uses this kind of panels together with an affective method and hedonic ratings. The hedonic rating concerns "the liking, the immediate, qualitative, affective evaluation of a food; the degree of experience of pleasure or displeasure", (Mela, 2000). The assessor has often to relate his opinion to a linear scale. The most commonly used scale is the 9-point scale developed by (Peryam and Pilgrimm, 1957). The results from consumers test often vary a lot. Most tests involve more than 100 assessors to enable an appropriate statistical evaluation.

The number of assessors in a *trained panel test* is often under 10. The panel mostly uses an analytical method in order to describe the product. The terms to use in this description are often standardised and the first step in a panel test is often to screen the material as mentioned earlier.

One important problem is the way the panellist uses the scale. Some of them use the whole scale and the numbers between different samples vary a lot. Other panellist uses only a part of the scale. In one way or the other the difference in variation between the panellists must be dealt with when making a statistical evaluation.

Terms used in sensory evaluation of carrots

There are standardised sets of terms to use when making sensory analysis, for example ISO 5492. However many other terms have been used during the years. To get an overview some of the terms are listed here, arranged "sense by sense".

The sense of sight gives us experiences of colour. Together with other senses this also makes it possible for us to perceive shape (form). Terms used in connection with sight are: *whiteness, colour, colour hue, colour strength, discoloration, freshness, shape, cylindricity, appearance and bluntness.* Sometimes these properties are called outer quality.

Our nose can perceive the flavour of a carrot before we put the carrot into the mouth. The impression of flavour also comes to the nose via the mouth pit. Terms used in connection with flavour are: *overall, intensity, carrot, sharp, green, turpentine, diesel, petrol, ethanol, cardboard, earthly, fruity, fresh, musty, stale, nutty, sweet, bitter, burning, pungent, harsh, and flowery.*

The tactile properties of a carrot can be recognised by our hands, lips, teeth, tongue or palate. There are different terms used to describe this side of our food experience; *firmness,*

crispiness, juiciness, soapiness, oiliness, woodiness, crunchiness, texture, chewy, finger feel, mouth feel, hardness, moistness, spongy, touthpacking and toughness.

The taste qualities are perceived in the oral pit as an experience of the liquid created in the mouth when chewing. Terms used when describing this experience are; *sweet, sickingly sweet, sour, acidic, bitter, salty, intensity, aftertaste, green, foliage, terpene, earthly, peppery, carrot, overall, preference. fruity, turpentine and harsh,*

Some of the terms mentioned also involve our sense of warmth, or temperature. Examples of such terms are; *peppery, burning, pungent, sharp, turpentine and harsh.*

Sweet and bitter taste in carrots

Sweetness is one of the most appreciated features of carrot taste, (Simon, Peterson et.al., 1980b). Although sometimes the sweetness can be almost sickening, (Seljåsen, 2000), most consumers liking is positively correlated with the perceived sweetness of carrots, (Simon, Peterson et.al., 1980b; Fjeldsenden, Martens et.al., 1981; Martens, Fjeldsenden et.al., 1983; Varming, Jensen et.al., 2004).

Bitter taste has been a positive topic in medicine for a long time, (Oberdieck, 1977). In carrots it is more of a problem. Supertasters are very sensible to bitter taste, (Bartoshuk, Duffy et.al., 1994). Also children are more sensitive and often dislike bitter tasting food, (Drewnowski and Rock, 1995). One reason for these differences is probably the fact that children and supertasters have more tastebuds, (Brieskorn, 1990). As both of these groups have a considerable impact on the preferences on our food, (Drewnowski and Rock, 1995), they might have contributed to the attempts of finding more sweet tasting carrots.

Bitter taste is one of the main reasons for low quality score of carrots, (Kuusi and Virtanen, 1979). The term “bitter” has been supplemented with the term “harsh”. This term is used to describe a burning turpentine-like flavour occurring most clearly at the back of the throat, (Simon, Peterson et.al., 1980a). It is sometimes hard to draw a line between these two terms. They are however both well documented in carrot research, (Sondheimer, Phillips et.al., 1955; Sondheimer, 1957b; Simon and Peterson, 1979; Simon, Peterson et.al., 1980b; Fjeldsenden, Martens et.al., 1981; Simon, Peterson et.al., 1982; Martens, Rosenfeld et.al., 1985; Kaminski, Wasowicz et.al., 1986; Yoshino, Kawaguchi et.al., 1993; Howard, Braswell et.al., 1995; Baardseth, Rosenfeld et.al., 1996; Gills, Resurreccion et.al., 1999; Talcott and Howard, 1999a; Seljåsen, 2000; Alasalvar, Grigor et.al., 2001; Rosenfeld, 2003; Varming, Jensen et.al., 2004).

There are differences between carrot varieties both in sweetness and bitterness. This has made it possible for the carrot breeder to influence the bitter and sweet taste of carrots. During the last decades carrots has lost some of their harsh features and gained an increasing sweetness, (Simon, Peterson et.al., 1980b).

Sweet and bitter tasting compounds

The sweetness in carrots is commonly related to sugars. Fructose is considered to have the highest relative sweetness of the three major sackarids in carrot, (Yamaguchi, Howard et.al., 1955). If the sweetness of sucrose is set to 1 the relative sweetness of fructose is 1.75 and of glucose is 0.75 (Schallenberger and Birch, 1975). Some of the terpenes, myrcene , (Habegger, Müller et.al., 1996) and perhaps also terpinolene, (Seljåsen, 2000), is described as slightly

sweet tasting. The influence from the terpenes or other substances besides sugars, on the total sweetness of the carrot must be regarded as low.

Terpenes are also regarded as an important group concerning the harsh and bitter tastes in carrot, (Simon, Lindsay et.al., 1980; Seljåsen, Hoftun et.al., 2003; Rosenfeld, Vogt et.al., 2004). Harsh, turpentine-like flavours are reported associated with the presence of the volatiles, particularly y-terpenine and total volatiles, and a reduction in sugars. The reverse is found for sweetness and overall preference that both are enhanced by sugars and diminished by volatiles. Overall carrot flavour is heightened by a reduction in total volatiles. Sucrose levels correlate positively and reducing sugars negatively with volatile terpene levels, (Simon, Lindsay et.al., 1980). Volatile terpenoid levels above 35-40 µl/l seems to be associated with the characteristic harsh flavour whereas terpenoid content below 10 µl/l diminishes the characteristic carrot flavour and causes a flat taste, (Simon, 1985).

As already been indicated there are interaction between terpenoids and sugar, (Simon and Peterson, 1979; Simon, 1985; Rosenfeld, 2003). Sweeter taste in carrots grown in northern parts of Scandinavia, (Hård, Persson et.al., 1977; Rosenfeld, Risvik et.al., 1997) is stronger correlated to a lower concentration of terpenoids than to increased levels of sugar, (Rosenfeld, 2003). The more harsh taste of stored carrots does not correspond to an increase of terpenoids during storage but to a decrease in the sugar content, (Simon and Peterson, 1979; Simon, 1985; Seljåsen, 2000). The fact that frozen carrots tastes sweeter can partly be a result also of losses of terpenoids in the freezing and thawing process, (Rosenfeld, 2003). .

High scores on the properties oiliness, cut carrot foliage and petrol is related to high concentration of terpenes in the carrot while the attributes bitterness, soapiness, woodiness and fruitiness properties are assumed not to be connected with the concentration of terpenes (Alasalvar, Grigor et.al., 2001). High positive correlation between terpenes (α-terpinene, β-myrcene, trans-caryophyllene, farnesene, α-humulene) and the sensory variables terpene flavour, green flavour, earthy flavour, bitter taste and aftertaste is found in an another study where it was concluded that these terpenes are responsible also for bitter taste and thus suppressed the perception of sweet taste in carrots, (Rosenfeld, Aaby et.al., 2002). Terpinolene probably plays only a minor role in masking sweet taste in carrots, (Rosenfeld, Aaby et.al., 2002).

A wide range of different compounds has been mentioned in connection with bitter taste in carrots. L-tryptofan is considered to be the amino acid tasting most bitter, (Kirimura, Shimitzu et.al., 1969). A bitter tasting glycoside has been detected in carrot leaves, (Gizycki and Herrmanns, 1951) but not in the roots. The complete identification of this compound is however not clear, (Dodson, Fukui et.al., 1956).

The compound gazarin, or 2,4,5-trimethoxybenzaldehyde, has been isolated from carrot seeds, (Starkovsky, 1962). It is reported as bitter but no connection to the taste of the carrot root has been documented, (Seljåsen, 2000). It has been found in very small amounts in carrot roots and its bitter taste threshold concentration has been estimated to 36 ml/l water (Czepa and Hoffmann, 2003).

Chlorogenic acid is the most common phenolic in carrots. Together with some other hydroxicinnamtes it is described as having a mild bitter taste, (Babic, Amiot et.al., 1993). The concentrations of these compounds are normally to low to allow their bitterness to be detected, (Wulf, Nagel et.al., 1978).

More than 50 years ago it was detected that hydrocarbon extracts from bitter tasting carrots had a different UV-absorption spectra, (Sondheimer, Phillips et.al., 1955). Since then one trail of the search for bitter principles in carrots has been pointing towards the two phenolics; 6-methoxymellein and eugenin.

Many reports have been published on 6-methoxymellein, 6MM, (Sarkar and Phan, 1979; Kurosaki, Matsui et.al., 1984; Hoffman, Roebroeck et.al., 1988; Marinelli, Zanelli et.al., 1989; Mercier, Arul et.al., 1993; Mercier, Arul et.al., 1993; Yoshino, Kawaguchi et.al., 1993; Guo and Ohta, 1994; Seljåsen, Bengtsson G. B. et.al., 2000; ėkesson, 2003; Girolamo, Solfrizzo et.al., 2004). Sensory analysis have not been able to find a clear correlation between bitterness and the concentration of 6MM in carrots, (Müller, 1978; Seljåsen, 2000). Studies on purified 6MM has revealed a bitter taste threshold concentration of 100 mg/kg carrot, (Yoshino, Kawaguchi et.al., 1993). The bitter taste threshold concentration in water has been estimated to 20 ml/l water. This is higher than the concentrations found in stress induced bitter tasting carrots, (Czepa and Hoffmann, 2003).

Also in connection with eugenin the results are contradicting, (Coxon, Curtis et.al., 1973; Talcott and Howard, 1999a; Talcott, Howard et.al., 2001; Seljåsen, Bengtsson G. B. et.al., 2001; Czepa and Hoffmann, 2003). Bitter taste has been shown correlated with the amount of eugenin, (Müller, 1978) ,while others report no such connection, (Sarkar and Phan, 1979). The bitter taste threshold concentration in water for eugenin has been calculated to 72 mg / l water, (Czepa and Hoffmann, 2003).

Some reports have attributed the presence of bitter taste to the concentration of water soluble phenolics, (Talcott and Howard, 1999a; Talcott, Howard et.al., 2001). No particular substance has yet been identified, (Czepa and Hoffmann, 2003).

Another trail has put the focus on the polyacetylenes, (Hansen and Boll, 1986; Lund and White, 1990; Mercier, Arul et.al., 1993; Olsson and Svensson, 1996; Kidmose, Hansen et.al., 2004; Kobaek-Larsen, Christensen et.al., 2005; Zidorn, Johrer et.al., 2005; Baranska and Schulz, 2005; Christensen and Brandt, 2006). The bitter taste detection threshold for the falcarinols found in carrots has been estimated to 10 mg FaDOH/ l water, 20 mg FaOH/ l water and 60 mg FaDOAc/ l water. The latter of these substances exhibited a burning, harsh sensation already at 15 mg/ l water, (Czepa and Hoffmann, 2004). A correlation between the concentration of FaDOH and the bitter taste of carrots, especially in carrot puree, has been reported, (Czepa and Hoffmann, 2004).

The development of sweet and bitter taste

Sweet and bitter taste in carrots appears to develop differently in time and on different location.

Different parts and tissues

Sweet taste is often more pronounced in the centre and lower (tip) part of the carrot. The phloem is mostly sweeter than the xylem, (Rosenfeld, 2003).

Bitter taste is more often detected in the upper (crown) part and more strongly connected to the phloem than the xylem, (Rosenfeld, 2003; Czepa and Hoffmann, 2004).

The sugars are mainly stored in vacuoles in the parenchymatic tissues (Nilsson, 1987). The total sugar content does not differ much between different parts of the carrot, (Rosenfeld, 2003). The amount of sucrose is higher in the upper part and in the phloem. Monosaccharides, especially fructose are more common in the centre and lower, tip, part of the carrot and in the xylem, (Habegger, Müller et.al., 1996; Rosenfeld, 2003).

Terpenes are more common in the upper part of the carrot and are evenly spread between phloem and xylem. Terpinolene is an exemption being more evenly spread also in the lower part of the carrot and showing higher concentrations in the phloem (Rosenfeld, 2003). 6MM are more concentrated to the phloem all along the carrot (Czepa and Hoffmann, 2004). Polyacetylenes are more common in the upper part of the carrot and in the phloem, although falcarinol and falcarindiol-3-acetate is more evenly distributed also in the xylem, the later even more concentrated in the xylem, (Czepa and Hoffmann, 2004). The levels of polyacetylenes reported as a mean of 16 carrot cultivars grown in Sweden is presented in table 8.

Table 8. Levels of polyacetylenes in carrot cultivars grown in Sweden. Modified from (Olsson and Svensson, 1996)

Substance	In the peel		In the phloem	
µg/g fresh weight	Mean	Variation	Mean	Variation
Falcarindiol	57	39-92	11	6-19
Falcarinol	3	1-5	6	3-12

During the season

Regarding sugar the development of a carrot crop is divided into three phases: During the first no soluble sugar is stored, in the second phase only reducing sugars are stored and in the third phase mainly sucrose is stored in the taproot, (Steingröver, 1983). The shift into phase three probably takes place about 50 days after sowing, (Ricardo and Rees A.P. 1970). This coincides with an increased sink strength of the carrot storage root, (Linser and Zeid, 1972; Hole, Thomas et.al., 1984). The decline of the reducing sugar content may be caused by a continuous reduction of acid invertase activity, (Ricardo and Sovia, 1974). The accumulation of sucrose in the taproot seems to be more influenced by environmental factors than the storage of reducing sugar, (Rosenfeld, 2003).

The amount of 6MM, falcarindiol and falcarindiol-3-acetate decreases with increasing root weight while the amount of falcarinol does not seem to be affected by root weight, (Kidmose, Hansen et.al., 2004).

Factors influencing sweet and bitter taste in carrots

The following factors are supposed to influence the taste of carrot and are the ones most commonly found in literature.

Variety

The genetic factor is one of the most important sole factors related to the taste properties of carrot, (Simon and Peterson, 1979). The flavour profile from carrots of different colour reveals big differences, is illustrated in figure 10 on the next page.

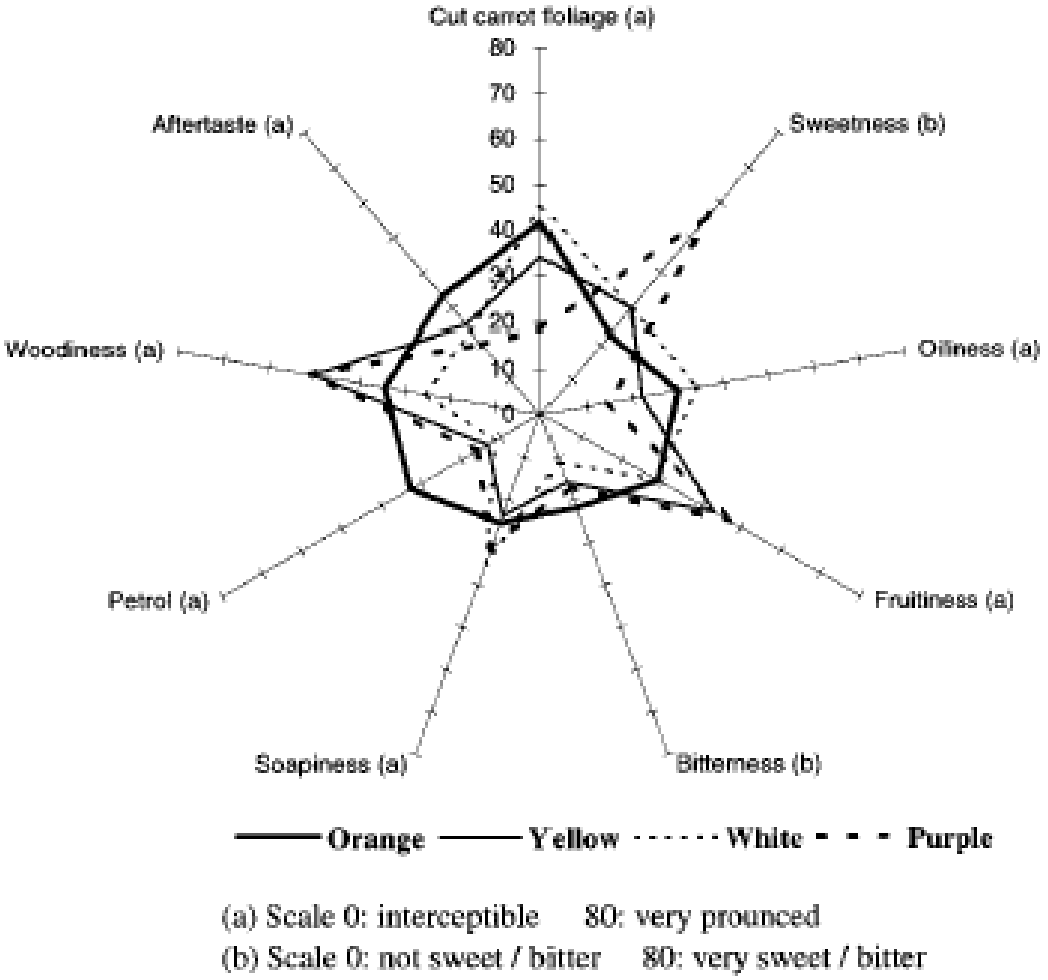


Figure 10. Flavour profile analysis of coloured carrots varieties. Reprinted with permission from (Alasalvar, Grigor et.al., 2001). Copyright 2001 American Chemical Society.

Purple carrots score high on sweetness, fruitiness, soapiness and woodiness and low in oiliness and cut carrot foliage flavour. White carrots are more or less opposite to the purple varieties and yellow and orange carrots score somewhere in between. Orange carrots score high on petrol, after taste and bitterness, (Alasalvar, Grigor et.al., 2001) (Alasalvar et al., 2001).

However when comparing varieties of the same type the differences sometimes are not so big, A Danish study reports the properties of the variety "Bolero" to differ significantly from the other five varieties, also from the Nantes type. The properties among the five other Nantes varieties did not differ so much from each other, (Varming, Jensen et.al., 2004).

Significant differences are reported between varieties concerning sweetness and bitterness, (Howard, Braswell et.al., 1995; Gills, Resurreccion et.al., 1999; Varming, Jensen et.al., 2004).

The composition of volatiles is also dependent on variety, (Simon, Peterson et.al., 1980b; Simon, Peterson et.al., 1982; Habegger, Müller et.al., 1996; Kjeldsen, Christensen et.al., 2003). Out of 36 volatiles differences are found in 31, (Kjeldsen, Christensen et.al., 2003)

The amount of 6MM (Mercier, Arul et.al., 1993; Mercier, Arul et.al., 1994; Talcott and Howard, 1999a; Talcott and Howard, 1999b; Talcott, Howard et.al., 2001; Kidmose, Hansen et.al., 2004) and different polyacetylenes of the falcarinol-group (Yates and England, 1982; Mercier, Arul et.al., 1993; Hansen, Purup et.al., 2003; Kidmose, Hansen et.al., 2004) also varies depending on genetical factors.

The difference between varieties in their concentration of 6MM is reported to depend also on the location of growth, in one location the difference between varieties were high, at another location no differences were noticed, (Kidmose, Hansen et.al., 2004).

Location

The influence of the location is mainly an effect of climate (Rosenfeld, 2003).

The amount of volatiles, 6MM and polyacetylenes varies depending on the location, (Varming, Jensen et.al., 2004; Kidmose, Hansen et.al., 2004).

Carrots grown in a simulation of the Californian winter climate is more sweet and contain more sugar than carrots grown in a simulation of the Florida or Wisconsin summer climate, (Simon, Peterson et.al., 1982).

Much emphasis has been used to compare carrots along a north south axis in Scandinavia, (Ottosson and Nilsson, 1976; Balvoll, Apeland et.al., 1976; Hård, Persson et.al., 1977; Martens, Fjeldsenden et.al., 1979; Fjeldsenden, Martens et.al., 1981; Martens, Fjeldsenden et.al., 1983; Rosenfeld, Martens et.al., 1984; Baardseth, Rosenfeld et.al., 1995; Baardseth, Rosenfeld et.al., 1996; Rosenfeld, Risvik et.al., 1997).

Carrots grown in northern Sweden and Finland are considered to have a higher content of sugar, (Ottosson, L. and Nilsson, T., 1976; Hård, Persson et.al., 1977), although studies in Norway could not confirm this, (Balvoll, Apeland et.al., 1976; Martens, Fjeldsenden et.al., 1983; Rosenfeld, Martens et.al., 1984; Baardseth, Rosenfeld et.al., 1995; Baardseth, Rosenfeld et.al., 1996). The content of monosaccharides are however mostly higher when carrots are grown in the north, (Ottosson, L. and Nilsson, T., 1976; Balvoll, Apeland et.al., 1976; Hård, Persson et.al., 1977). This has been used to explain the observation that carrots grown in the north tastes sweeter and are crisper, (Hård, Persson et.al., 1977).

The sensory profiles from carrots grown on field and in phytotron located in the north and south of Norway are illustrated in figure 11 on the next page. The carrots grown in the north are more sweet and crisp, (Rosenfeld, Risvik et.al., 1997). They are also lower in colour hue and colour strength something that probably has a connection with the measured lower content of carotenoids, (Rosenfeld, Risvik et.al., 1997). Carrots grown in southern Norway scores higher on bitterness, (Baardseth, Rosenfeld et.al., 1996; Rosenfeld, Samuelsen et.al., 1998a).

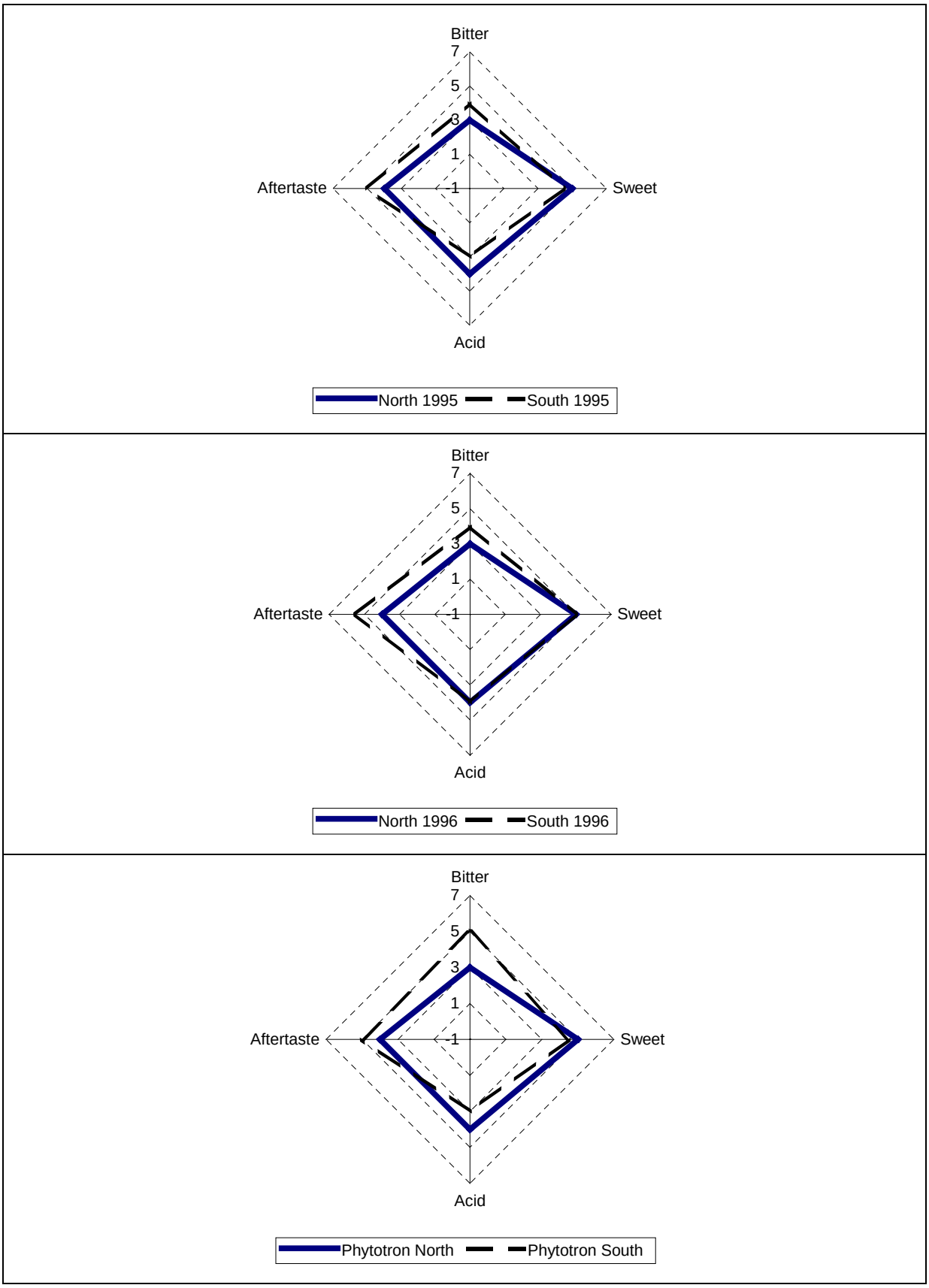


Figure 11. Comparison of sensory profiles of carrots grown at northern and southern locations. Bitter= Bitter taste, Sweet= Sweet taste, Acid= Acidic taste, Aftertaste= Aftertaste. Modified from (Rosenfeld, Risvik et.al., 1997)

Climate

The climate has a greater influence on chemical and sensory parameters than soil type, (Rosenfeld, Aaby et.al., 2002). Light has the major influence on the morphological features of the carrot, while warmth is more important to the sensory and chemical properties, (Rosenfeld, 2003).

Temperature

Carrot is a cool-season crop, with a minimum temperature requirement for growth on 5° C and an optimum temperature for growth between 18-25° C, (Krug, 1991). Carrots becomes shorter and thicker when grown in higher temperature, 18-21 ºC, (Rosenfeld, 2003). Grown at lower temperatures, 9-12 ° C, root length also increases by fusing small root granules into the storage root tip, (Rosenfeld, Aaby et.al., 2002). When carrots are grown in higher temperature, or when they are kept longer in the soil, the formation of lateral root are more frequent and the carrots becomes branched, (Rosenfeld, 2003).

Among the sensory variables; terpene flavour, green flavour, earthy flavour, bitter taste, aftertaste and firmness are more pronounced when the carrots are cultivated at high temperature, between 18-21 ºC. Growing carrots at lower temperatures, 9-12 ºC, has a stronger influence on acidic taste, sweet taste and juiciness, (Rosenfeld, 2003). Carrots grown at temperatures between 9 and 12 ºC taste sweeter than carrots grown at higher temperatures (Rosenfeld, 2003) The bitter taste is not only more pronounced when the carrots are grown in higher temperatures. The duration of the bitter taste sensation is also longer, (Rosenfeld, 2003). Bitter taste is found to be stronger after a season low in temperature and high in precipitation, (Martens, Rosenfeld et.al., 1985).

The total sugar content is lower in the carrots grown in lower temperature, although the amount of monosaccharides, especially fructose, are higher, (Rosenfeld, 2003) and the sucrose content has been positively correlated to low temperatures in June, (Martens, Rosenfeld et.al., 1985)

Most terpenes increase with increasing temperature, while α-terpinolene decreases, (Rosenfeld, 2003)

Light

Growing carrots in phytotrons with constant temperatures but under different seasonal light regimes reveals that higher levels of light causes an increase in many chemical and physical properties of the carrot, (Rosenfeld, Samuelsen et.al., 1998a). Root weight and size increased with increasing amounts of light while cylindricity and bluntness was more typical to carrots grown under short light regimes, (Rosenfeld, Samuelsen et.al., 1998a). The amounts of dry matter, sucrose, glucose, fructose and carotene all increased with increasing daylight, (Rosenfeld, Samuelsen et.al., 1998a). Due to difficulties in comparing sensory analysis made on different occasions it is hard to say something about the sensory profiles of the carrots, but bitter taste tends to be higher during low, and sweet taste higher during high levels of light, (Rosenfeld, Samuelsen et.al., 1998a). The variation between samples is bigger when the carrots are cultivated under more light and there is also a better correlation between the perception of sweetness and the content of monosaccharides, (Hay and Waterman, 1993; Rosenfeld, Samuelsen et.al., 1998a).

Soil

There are no reports found that more systematically has investigated the importance of different soils on the sensory properties of carrots. When grown in an organic, peat, soil carrots tasted sweeter when newly harvested than carott grown in mineral soil. After storage the carrots from the organic soil tasted more bitter, (McCall and Möller, 1999). Carrots grown in the south of Norway showed bigger differences between soil type than carrots grown in the north, (Rosenfeld and Samuelsen, 2000). Carrots grown in peat are more correlated to the amount of sucrose and bitter taste, while when grown in a mineral soil they are more correlated to carotene, earthy taste and firmness, (Rosenfeld and Samuelsen, 2000). The soil also affects the bitter taste intensity and the amount of 6MM and polyacetylenes in the carrots, (Czepa and Hoffmann, 2004).

Cultivation

Carrots grown with lower nitrogen application are found to taste more intensive, fruitier, sweeter and better and at the same time less bitter and less earthy. They have higher contents of total sugar and a higher percentage of dry matter. Fertilization with nitrogen decreases the quantity and alters the composition of the essential oils, (Schaller, Broda et.al., 1998; Schaller and Schnitzler, 2000).

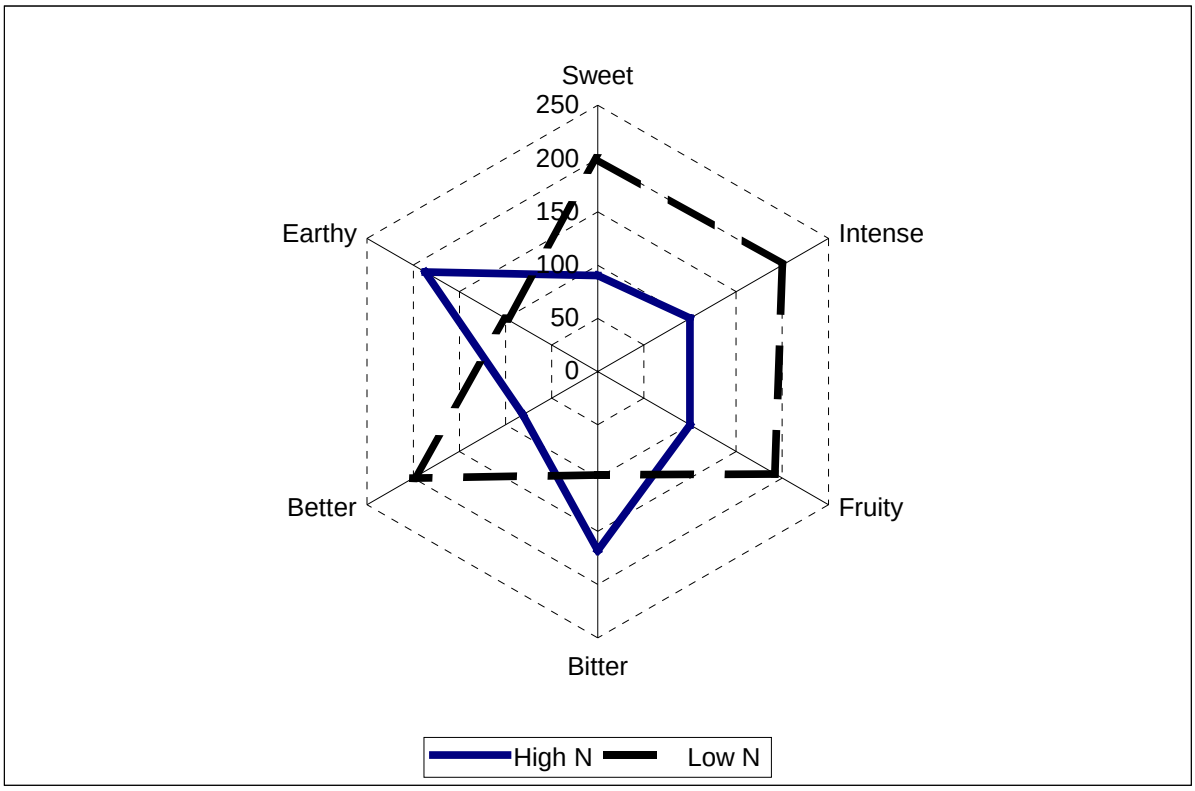


Figure 12. Taste profile of carrots grown with different levels of nitrogen-fertilisers. High N= high nitrogen level, Low N= low nitrogen level. Sweet= Sweet taste, Intense= Intensity of taste, Fruity= Fruity taste, Bitter= Bitter taste, Better= Preference of taste. Modified from (Schaller, Broda et.al., 1998)

Plant density has little or no effect on sensory quality or terpenoid volatiles, (Rosenfeld, Aaby et.al., 2002).

Delaying sowing for one to two months results in a reduction of growth and gives roots with lower dry matter content and glucose/fructose ratio but higher amounts of reducing sugars in

root dry matter. The longer the growing season the higher is the amount of sucrose while the amount of monosaccharides decreased from the first harvest at 70 days to reach a constant level at about 130 days after sowing, (Nilsson, 1987).

Processing

Harsh taste in carrots often arises already in field, (Simon, 1985) , while bitter taste is more common after storage, (Sondheimer, Phillips et.al., 1955; Dodson, Fukui et.al., 1956; Hermann, 1978).

Post harvest handling, especially storage has important impact on the properties of the carrot, (Seljåsen, 2000). Drought, water logging, frost, parasites, heavily shaking during harvest and transportation or storage under unfavourable conditions, can stress carrots. They react on stress with an increase in off-taste, for example bitter taste. Different varieties react differently upon stress, (Seljåsen, 2000).

A common reaction on stress in plants is an increase in ethylene production and a stimulation of respiration (Vines, Grierson et.al., 1968; Elstner and Konze, 1976; Christoffersen and Latties, 1982; Hole, Thomas et.al., 1984; Lafuente, Cantwell et.al., 1991; Mempel and Geyer, 1999). High concentrations of CO_2 in the air inhibit these reactions, (Chalutz and DeVay, 1969; Abe and Yoshimura, 1993).

The fact that carrots sometimes grow more bitter when attacked by pathogens, (Hervey and Schroeder, 1949; Condon, Ku´c et.al., 1963; Superchi, Pini et.al., 1993), when exposed to frost, (Christoffersen and Latties, 1982), or drought, (Lund and White, 1990), can be explained as a result of higher ethylene concentrations and higher respiration rates, (Seljåsen, Hoftun et.al., 2001; Seljåsen, Hoftun et.al., 2003; Seljåsen, Hoftun et.al., 2004).

Higher scores for bitterness during storage are correlated to lower scores for sweetness, (Mempel, 1998; Mempel and Geyer, 1999; Seljåsen, Hoftun et.al., 2001). The amounts of sugar are at the same time lowered as a result of the increase in respiration rate induced by stress. Heavily shaking and storage of carrots exposed to ethylene lowers the amount of sucrose while the amount of reducing sugars remains or increases, (Simon, 1984; Seljåsen, Hoftun et.al., 2001). The lowered sugar content probably contribute to the more detectable bitterness in the carrots during storage, (Seljåsen, 2000).

The amount of 6MM increases with temperature in ethylene enriched atmosphere, (Lafuente, Cantwell et.al., 1989) and when stored (Carlton, Peterson et.al., 1961; Sarkar and Phan, 1974; Hoffman, Roebroeck et.al., 1988; Lafuente, Cantwell et.al., 1989; Lafuente, Cantwell et.al., 1991; Willumsen, 1993; Guo and Ohta, 1994; Lafuente, Lopez-Galvez et.al., 1996). The concentration of 6MM reaches its peak a few days after the start of storage and then declines more or less rapidly, (Lafuente, Lopez-Galvez et.al., 1996; Seljåsen, 2000; Czepa and Hoffmann, 2004). The concentration seldom reaches above the detection threshold, (Seljåsen, 2000; Czepa and Hoffmann, 2004), but nevertheless the scores for bitter taste increases when carrots are exposed to ethylene, (Seljåsen, Hoftun et.al., 2001), heavily shaken, (Seljåsen, Bengtsson G. B. et.al., 2001) or washed in a mashine, (Seljåsen, Hoftun et.al., 2004).

The concentration of terpenes is unchanged when carrots are stored in an ethylene-enriched atmosphere, (Simon, 1984; Seljåsen, Hoftun et.al., 2001), but decreases when heavily shaken, (Seljåsen, Bengtsson G. B. et.al., 2001). Refrigerated storage sometimes increases the

concentration of terpenes, (Kjeldsen, Christensen et.al., 2003), 6MM and falcarindiol, (Kidmose, Hansen et.al., 2004)

Low concentration of oxygen, for example in Low Pressure Storage, prevents the effects of acetylene, (McKeown, Lougheed et.al., 1978), but induces higher concentrations of ethanol and acetaldehydes, (Kato Noguchi and Watada, 1997).

The following correlation has been found when storing stressed carrots, (Seljåsen, 2000):

- There is a negative correlation between bitterness and sweetness, and between bitterness and sugar content
- There is a positive correlation between bitterness and terpenes
- There is a negative correlation between bitterness and sickingly sweet taste,
- There is a negative correlation between terpenes and sickingly sweet taste
- There is a positive correlation between ethanol and sickingly sweet taste

Steam blanching reduces the amounts of FaDOH but increases the amount of FaOH and to a certain extent also 6MM, (Kidmose, Hansen et.al., 2004) (Kidmose et al., 2004). By cutting of the peel and the green and dark parts away from the carrot the amount of falcarindiol in the carrot is reduced with 50%, (Czepa and Hoffmann, 2004).

Discussion

Although carrot is a commonly cultivated crop no clear and simple picture has been found neither on the connection between taste and chemical composition nor on the connection between taste and influencing genetic or environmental factors. This paper focuses on sweet and bitter taste in carrot. Concerning sweet taste the connection to sugar seems obvious. But bitter taste seems more likely to be caused by multiplicity of compounds.

One of the reasons for the difficulties in finding connection might be due to the physiology of our taste sense. Bitter and sweet tastes seem to be able to mask each other. Maybe also other tastes can mask the perception of sweet and bitter taste? The experiences collected in this paper encourage to a deeper study of the interaction between different stimulants in our taste perception.

Mostly descriptive methods are used when performing the sensory analysis. At each sensory analysis occasion the carrot samples are screened and the assessors agree on terms to use and "calibrate the scales" according to the present samples. This gives a good resolution when describing the samples but it makes it almost impossible to compare samples analysed at different occasions. This makes it hard to describe the dynamics in the development of the taste profile. If concentrating only on bitter and sweet taste other methods can be developed that also makes it possible to compare the samples over time. It seems so far that such a study still needs to be performed.

Difficulties in finding correlation between taste and chemical composition is probably more due to the physiology of the human taste than to the chemical methods used.

Is bitterness in carrots a bigger problem today than earlier? Due to difficulties in comparing these matters over time probably no simple answer can be given on this question. The recent discussion on bitter taste in carrots has put a lot of focus on stress-induced bitterness. The use of big, mechanical equipment, long transportation, cold and airtight storing seems to play an important role for this induced bitterness. Bitter taste in carrots is also expressed as induced during the defence against pathogens. The opinion that bitter taste is a bigger problem today can find some support in the development towards more stress inducing cultivation measures. The use of pesticides and other pathogen repellents ought to have decreased the pathogen-induced bitterness. At the same time the varieties used has been breeded towards more sugar and less harsh or bitter traits. These two factors ought to have reduced the problem of bitter taste in carrots. The trend of consumers preferring sweeter carrots ought on the other hand to have put more attention on carrots tasting bitter.

Is bitterness in carrots a bigger problem in organic than in conventional farming? Organic farming is also a part of the development towards a more mechanised treatment of carrots and pesticides are used neither on field nor in store. It is possible that the organic farmer to a higher extent uses varieties with a broad genetical resistance against pathogens. Such varieties ought to become bitter tasting more often. The organic farmer more often also sells his produce on the local market directly to the consumers. This probably puts bitter taste under discussion more frequently together with the fact that the consumers buying organic produce has higher expectations on the product. The question of the relation between bitter and sweet taste in organic carrot is complex. Multivariate analysis is probably a useful tool when trying to answer this question.

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