Food Chemistry 196 (2016) 228–235

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Growth temperature affects sensory quality and contents of glucosinolates, vitamin C and sugars in swede roots (*Brassica napus* L. ssp. *rapifera* Metzg.)

Tor J. Johansen [a,*], Sidsel F. Hagen [b], Gunnar B. Bengtsson [b], Jørgen A.B. Mølmann [a]

[a] Nibio – Norwegian Institute of Bioeconomy Research, P.O. Box 115, NO-1431 Ås, Norway
[b] Nofima – Norwegian Institute of Food, Fisheries and Aquaculture Research, P.O. Box 210, NO-1431 Ås, Norway

ARTICLE INFO

Article history:
Received 7 April 2015
Received in revised form 14 August 2015
Accepted 14 September 2015
Available online 14 September 2015

Chemical compounds studied in this article:
Ascorbic acid (PubChem CID: 54670067)
Glucoerucin (PubChem CID: 656538)
Progoitrin (PubChem CID: 656566)
Glucoberteroin (PubChem CID: 9548726)
Gluconapoleiferin (PubChem CID: 9548635)
D-Glucose (PubChem CID: 5793)
D-Fructose (PubChem CID: 5984)
Sucrose (PubChem CID: 5988)

Keywords:
Aliphatic GLS
Brassica napus L. ssp. *rapifera* Metzg.
Flavour
Indolic GLS
Odour
Preharvest
Phytochemicals
Taste

ABSTRACT

Swede is a root vegetable grown under a range of growth conditions that may influence the product quality. The objective of this controlled climate study was to find the effect of growth temperature on sensory quality and the contents of glucosinolates, vitamin C and soluble sugars. High temperature (21 °C) enhanced the intensities of sensory attributes like pungent odour, bitterness, astringency and fibrousness, while low temperature (9 °C) was associated with acidic odour, sweet taste, crispiness and juiciness. Ten glucosinolates were quantified, with progoitrin as the dominant component followed by glucoberteroin, both with highest content at 21 °C. Vitamin C also had its highest content at 21 °C, while the total sugar content was lowest at this temperature. In conclusion, the study demonstrated clear effects of growth temperature on sensory quality and some chemical properties of swede and indicated a good eating quality of swedes grown at low temperatures.

1. Introduction

Swede (*Brassica napus* L. ssp. *rapifera* Metzg.), also called rutabaga in North America, is a root vegetable crop. The swede bulb is a swollen part of the hypocotyl and the upper part of the roots and is commonly referred to as swede, swede root or only root. Swedes are grown for fresh and processed food mainly in Northern Europe and North America, but also as a livestock fodder crop around the world (Cornforth, Stephen, Barry, & Baird, 1978; Gowers, 2010). Brassicaceae crops are increasingly studied due to their potential human health benefits, with focus on their content of health-related compounds such as glucosinolates (GLS) and vitamin C (Björkman et al., 2011; Verkerk et al., 2009). There is also an increasing interest in the effect of regional growth conditions on sensory quality traits.

GLS is a class of sulphur-containing glucosides, which may be broken down by enzymes (e.g., myrosinase) to compounds like isothiocyanates, epithioalkanes, nitriles and thiocyanates (Bones & Rossiter, 2006). In addition to potential positive health effects from some of these substances to humans, GLS metabolites may also have negative effects on health, appetite and growth of animals fed large quantities of *Brassica* forage crops (Tripathi & Mishra, 2007; Verhoeven, Verhagen, Goldbohm, vandenBrandt, &

* Corresponding author.
E-mail addresses: tor.johansen@nibio.no (T.J. Johansen), sidsel.hagen@nofima.no (S.F. Hagen), gunnar.bengtsson@nofima.no (G.B. Bengtsson), jorgen.molmann@nibio.no (J.A.B. Mølmann).

http://dx.doi.org/10.1016/j.foodchem.2015.09.049
0308-8146/

vanPoppel, 1997). An example is goitrin, an isothiocyanate metabolite and hydrolysis product of progoitrin, which is known for adverse effect on thyroid metabolism in animal feeding. Intake of normal amounts of such compounds from vegetables by humans, however, is not considered an issue of concern (Han & Kwon, 2009). In swede, progoitrin is one of the dominating glucosinolates (Carlson, Daxenbichler, Vanetten, & Tookey, 1981; Hopkins, Griffiths, Birch, & McKinlay, 1998; Sang, Minchinton, Johnstone, & Truscott, 1984). For the characteristic flavour and taste of *Brassica* species, like pungency and bitterness, there are some reports of correlation with the content of the GLSs progoitrin, sinigrin and glucobrassicin (Drewnowski & Gomez-Carneros, 2000).

In Scandinavia, swede has for a long time been a popular vegetable, and it has been recognised for its high vitamin C content (Gowers, 2010). Production of swede roots is well adapted to a cool temperate climate and in Scandinavia; they are grown up to 70°N. In these northernmost areas, the growth conditions are unique with a short field growth period (June–September) with long periods of 24 h day-lengths. Average daily air temperature is low (11–12 °C) and frost may occur in September. Consumers often state that vegetables grown at such conditions have a better sensory quality (e.g., sweeter taste) than those grown under higher temperatures. Research on this matter is scarce, and the latest comprehensive study of cool climate effects in swede and other vegetable crops was carried out in 1972–1974 in Scandinavia (Hårdh, Persson, & Ottosson, 1977). These authors reported a better taste and higher sugar content of swedes grown in the northern regions compared to southern regions. Other studies have shown increased total sugar content after short periods of low growth temperatures in both swedes and turnips (*Brassica rapa* L. ssp. *rapifera* Metzg.) (Shattuck, Kakuda, & Shelp, 1991a; Shattuck, Kakuda, Shelp, & Kakuda, 1991b). Later, Rosenfeld, Risvik, Samuelsen, and Rødbotten (1997) found that northern low-temperature conditions produced sweeter taste in carrots than warmer southern latitudes. For turnips and cabbages (*Brassica oleracea*), it has been shown that both growth sites (Francisco, Velasco, Romero, Vazquez, & Cartea, 2009) and planting dates (Radovich, Kleinhenz, Streeter, Miller, & Scheerens, 2005) with different temperatures may influence sensory attributes.

The content of GLS in brassicas is strongly affected by genotype and varies widely between different organs and developmental stages. Nevertheless, preharvest climatic conditions like temperature, light intensity and photoperiod may influence GLS synthesis and levels (Björkman et al., 2011; Verkerk et al., 2009). Most studies indicate that high or low, rather than optimal intermediate growth temperatures (21–22 °C), produce the highest levels of GLS. For light conditions, there seem to be complex interactions with temperature giving less predictable effects (Charron & Sams, 2004; Schonhof, Kläring, Krumbein, Clauβen, & Schreiner, 2007). For vitamin C, a limited number of studies indicate that low growth temperature and high light intensity may be associated with high vitamin C levels in vegetable plants (Lee & Kader, 2000; Lo Scalzo, Bianchi, Genna, & Summa, 2007; Schonhof et al., 2007). There is, however, little specific information with regard to root vegetables, except for Dragland (1968) and Hårdh et al. (1977) who found only minor differences in vitamin C levels in swede roots grown in northern and southern regions within Scandinavia.

In controlled climates, studies of preharvest temperature effects on sensory quality and contents of health and sensory related metabolites of swedes are missing in the scientific literature. Therefore, the objectives of the current study on swede are (1) to find how varying growth temperature may affect sensory attributes, (2) to find how growth temperature may affect the contents of GLS, vitamin C and soluble sugars, and (3) to discuss any correlation between selected plant metabolites and sensory attributes.

2. Materials and methods

2.1. Experimental conditions

The experiments were conducted in climate regulated chambers under natural long-day light conditions in the phytotron at the University of Tromsø (69° 39′N, 18° 55′E) in 2010 and 2011. Irradiance reached 300–400 $\mu mol\ m^{-2}\ s^{-1}$ on the plant surfaces on sunny days at noon. Humidity was standardised to give a water vapour pressure deficit of 0.5 kPa. Swede seeds 'Vigod' were sown in a mixture of standard fertilised peat soil (Floralux®, Nittedal Torvindustri, Arneberg, Norway) and perlite (70/30 volume) at 21 °C and moved to 15 °C from start of sprouting. After 4–6 weeks, plants were transplanted to a similar soil mixture in 7.5 litre pots. Each pot was supplied with an additional 9 g NPK mineral fertilizer (Fullgjødsel® 11-5-18 micro, Yara Norge AS, Oslo, Norway) giving 1, 0.4 and 1.6 g NPK/plant, respectively. In addition, 0.1 g Borax/plant (Searles Valley Minerals, Trona, California, USA) was supplied.

Plants were exposed to different growth temperatures (±0.5 °C) according to Table 1. Some treatments included stepwise-reduced temperatures during the growth period. Changes were done after three weeks (from 21 to 15 °C), after 6 weeks (from 15 to 9 °C) and after nine weeks (from 9 to 6 °C) for the appropriate temperature combinations. At 6 °C plants were kept in chambers with artificial light (Philips TLD 840, about 150 $\mu mol\ m^{-2}\ s^{-1}$).

The targeted root weights at harvest were between 0.5 and 1 kg. Therefore, the harvest dates for plants grown at high, intermediate and low temperature were different (see Table 1). These three dates were chosen based on root diameter measurements (about 12 cm). At harvest, leaves were cut and weighed fresh and dry. The roots were cleaned, weighed, marked individually, and packed in perforated vegetable bags (polyethylene) and stored at 0.5 °C. About two months after the last harvest date, they were transported at low temperature (0–4 °C) to Nofima at Ås for analyses. Upon arrival, the roots were stored at 2 °C until sample preparation (October 27–28th in 2010 and December 1st in 2011).

2.2. Preparation for sensory and chemical analyses

The swede roots were hand-washed and brushed in cold tap water, divided vertically into four similar pieces, and peeled. Two diagonal pieces/root were cut in 1 cm cubes with a cutting

Table 1
Root properties of swede (*Brassica napus* L. ssp. *rapifera* Metzg.) grown at different controlled temperatures at 24 h natural light. Planted 28th April (2010) and 27th May (2011). DAP = days after planting. Temperature changes: 21 DAP (21–15 °C), 42 DAP (15–9 °C) and 63 DAP (9–6 °C). Average values,[a] n = 6–8 roots/treatment.

	Growth temperatures (°C)	Harvest (DAP)	Root shape index[b]	Root FM (g)	Root DM[c] (%)
2010	21	54	1.6 a	632 c	10.4
	15	78	1.6 a	833 a	12.8
	9	117	1.1 c	789 ab	13.7
	21/15/9	78	1.6 a	838 a	13.7
	15/9	78	1.5 ab	675 bc	14.9
	15/9/6	78	1.4 b	643 c	15.1
2011	21	62	1.6 a	720 b	10.4 c
	15	80	1.5 a	899 a	11.3 bc
	9	119	1.2 b	758 b	12.4 a
	21/15/9	80	1.5 a	790 b	13.2 a
	15/9	80	1.4 a	810 ab	12.3 ab
	15/9/6	80	1.5 a	774 b	12.2 ab

[a] Values within each column for each year not having any letters in common within columns are significantly different by Tukey's multiple comparisons test (α = 0.05).
[b] Root diameter/root height.
[c] 2010 results are from pooled samples (no replicates).