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Effects of cultivar, root weight, storage and boiling on carbohydrate content in carrots (*Daucus carota* L)

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Abstract: The effects of cultivar ($n = 4$), root weight ($n = 4$), storage (5 months) and boiling (7 min) and their interactions on the content of dry matter and carbohydrates were studied and ranked in carrots. Boiling had the greatest effect and had an influence on all variables except the ratio between sucrose and the monosaccharides glucose and fructose. The choice of cultivar was also of great importance as regards glucose, fructose and sucrose content, while dietary fibre and dry matter were much less affected, or even unaffected, by this factor. Root weight and storage were consistently of less significance than boiling and cultivar. Thus dietary fibre solubility, fructose content and the ratio between sucrose and the monosaccharides glucose and fructose were independent of the root weight, while storage had no impact on the dry matter content. After storage the cultivar Lonto had lost more dry matter than the other cultivars (10% versus mean 1% for the others, $P = 0.009$) and the sugar ratio between sucrose and the monosaccharides glucose and fructose had increased in the cultivar Amarant, while it decreased in the other cultivars ($P < 0.001$). Furthermore, Amarant had a lower loss of sugars (35%) following boiling than the other cultivars (mean 39%, $P = 0.002$). Storage and boiling interacted concerning soluble and insoluble dietary fibre, fibre solubility and glucose content. It is concluded that the various factors (especially boiling and cultivar) gave rise to such differences in carbohydrate content and composition that they might be of nutritional importance. The results may thus provide a basis for selecting raw material when studying possible health effects of carrots.

Keywords: *Daucus carota*; carrots; cultivar; storage; root weight; boiling; dietary fibre; insoluble dietary fibre; soluble dietary fibre; carbohydrates; sucrose; fructose; glucose

INTRODUCTION

Food items rich in dietary fibre are usually connected with a number of physiological effects, but for carrots the results are often conflicting. Both glucose and lipid metabolism have been reported to be beneficially affected in some studies,[1–4] whereas others indicate no effect.[5–7] Carrots have also been shown to increase faecal bulk despite the fact that they contain a high level of viscous and soluble fibre, ie fibre that is usually not associated with a high bulking capacity.[4,7,8] Processing may increase the faecal bulk further, but results are ambiguous.[7,9] These contradictory results may be due to cultivar differences, storage conditions or type of process/process conditions, among other factors.

Previous studies on carrots have shown that boiling and storage time strongly influence the composition of individual sugars and dietary fibre components.[10,11] The content at harvest of fibre and soluble sugars as well as the solubility of the fibre probably contribute to these differences. Rapidly growing cultivars are reported to have a higher content of total dietary fibre (TDF) than those with a prolonged growth period, due to a higher content of insoluble dietary fibre (IDF).[11] Furthermore, an increasing ratio between insoluble and soluble fibre has been observed during storage and, in some cultivars, also redistribution of individual sugars. During wet heat treatment, low-molecular-weight carbohydrates leach into the processing water, causing an apparent increase in dietary fibre.[12–14] It

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has been suggested that this loss is mainly dependent on the initial sugar concentration, dry matter content, cell wall resistance and process conditions.[11,15] Results regarding effects of heat treatment on dietary fibre are not clear. However, heat-labile polysaccharides, mainly pectic substances, may be lost through β-eliminative degradation[16] or by cleavage of glycosidic linkages.[17] Furthermore, the number of weak bonds between polysaccharide chains may decrease during heat treatment,[18] and it has been shown that IDF in cabbage can be lost into the boiling water.[14] Growing conditions and the duration of growth may also affect cell wall structure. An ample supply of water and deficiency of phosphorus have been reported to lead to a high TDF content, while soil with a high calcium content yielded high amounts of IDF.[19,20] A delayed harvest generally results in a change in the distribution between individual sugars, and an increasing amount of sucrose in relation to glucose and fructose has been reported.[21]

Alterations in the composition and physicochemical properties of the dietary fibre as well as in the distribution of individual sugars may cause changes in the nutritional effects. Degradation of the cell wall polysaccharides may lead to a reduced viscosity[22] and abolished metabolic effects,[3] while an enhanced amount of insoluble fibre may increase the bulking capacity. Differences in carbohydrate pattern may be of importance for the glucose metabolism. Glucose gives rise to a greater glycaemic response than sucrose, which in turn is higher than that of fructose.[23] By choosing the right cultivar and appropriate process conditions, it should be possible to obtain processed carrots with specific health effects.

In a previous study we saw a weak ($r = 0.76$) correlation between the loss of total dietary fibre during boiling and the average root weight of some carrot cultivars.[11] This prompted us to investigate whether the root weight in carrots had any impact on the content of dietary fibre and low-molecular-weight carbohydrates and if this could be another factor contributing to the diverse nutritional properties reported for carrots in the literature. In this study this variable was therefore also included when studying effects of storage and boiling on various cultivars. Four cultivars (Amaranth, Tourino, Lonto and Kämpe) differing in shape (cylindrical or conical) and growing period (70–80 and 90–100 days) were selected for the study. The content of carbohydrates was studied directly after harvest or following 5 months of storage, either as fresh or after boiling for 7 min. The effects of the different factors (cultivar, root weight, storage and boiling) and their interactions were ranked for the analysed variables (total dietary fibre, insoluble dietary fibre, soluble dietary fibre, fibre solubility, low-molecular-weight sugars, glucose, fructose, sucrose, ratio between sucrose and the monosaccharides glucose and fructose, and loss of dry matter during boiling).

EXPERIMENTAL

Materials

Four carrot cultivars were grown as a commercial crop on the experimental farm at Alnarp in southern Sweden. The soil was a sandy loam rich in potassium and phosphorus. The basal dressing before sowing was 110 kg N, 50 kg P and 180 kg K ha^{-1} (complete fertiliser with micronutrients). The average maximum and minimum temperatures varied in the ranges 13.2–23.3 and 6.0–13.4 °C respectively during the growing period. The monthly precipitation was between 22 mm (June) and 64 mm (May), corresponding to 45–148% of normal precipitation. During dry periods the field was irrigated. Seeds were sown in the middle of May with a row spacing of 45 cm, and each cultivar was grown in two 3.5 m long rows with the seedlings thinned to 50 plants m^{-1} in each row. The experiment comprised the following four cultivars from Svalöv Weibull AB (Hammenhög, Sweden): Amarant, an Amsterdam type; Tourino, a Nantes type; and Lonto and Kämpe, both of the Chantenay type. Amarant and Tourino are rapid growing cultivars (growth period 70–80 days) with a cylindrical form, while Lonto and Kämpe have a growth period of 90–100 days and a conical form.

From each cultivar, 300–350 plants (21–32 kg) were harvested on the same day in mid-September (Table 1). Root and foliage were separated before the roots from each cultivar were sorted according to root weight into four groups: small (S) = 30–59 g, medium (M) = 60–99 g, large (L) = 100–199 g and extra large (XL) >200 g (Table 1). However, only Lonto and Kämpe had a limited number of carrots >200 g. All roots within each group were randomly subdivided into two samples, one of which was used for analyses of fresh carrots while the other was stored for 5 months in a refrigerated store (0–1 °C, relative humidity 95–98%) and subsequently exposed to the same treatment as the fresh carrots before being

Table 1. Root weight (g) and number (*n*) of carrots at harvest

	Total		S		M		L		XL	
Cultivar	Mean	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*
Amarant	61	351	44 ± 8	202	76 ± 11	125	122 ± 17	24	—	—
Tourino	66	351	48 ± 8	172	75 ± 11	144	118 ± 18	35	—	—
Lonto	106	303	48 ± 8	44	81 ± 12	120	133 ± 23	122	238 ± 29	17
Kämpe	91	337	46 ± 9	104	80 ± 10	119	132 ± 27	103	252 ± 52	11

analysed. Approximately half of the total number of harvested plants were stored.

Sample preparation

The total amount of sorted samples (S, M, L and XL) for each cultivar was washed carefully and wiped dry before being cut into cubes ($10 \times 10 \times 10\,mm^3$) (Table 1). The cubes were mixed and subdivided into two groups and treated as independent samples when analysed. Half of each sorted sample was taken for analyses of raw carrots and the other half for analyses of boiled carrots. The design of the experiment resulted in duplicates of 56 different carrot samples, giving a total of 112 independent samples. The sampling schedule is shown in Fig 1.

Samples (250 g) of fresh or stored carrots were placed singly in boiling water (500 ml) for 7 min and drained in a colander for 15 min before being frozen. The boiling water was made up to equal volume, frozen and saved for analysis of the loss of dry matter.

The various prepared carrot samples (fresh or boiled) were frozen (−20 °C), freeze-dried (from −20 to 20 °C during 4 days) and milled to pass through a 0.5 mm mesh before being stored in airtight plastic vials at −20 °C until analysed.

Analytical methods

The dry matter (DM) content of fresh and boiled carrots was determined gravimetrically, by drying samples for 18 h at 105 °C, according to AOAC method 950.01.[24]

The total dietary fibre (TDF) content—separated into fractions of soluble dietary fibre (SDF) and insoluble dietary fibre (IDF)—was determined by the enzymatic, gravimetric method of Asp *et al*[25] with the following two modifications. Owing to the high viscosity of the carrot fibre, the amount of sample was decreased to a quarter, and 250 g of freeze-dried and milled carrots were suspended in 25 ml of phosphate buffer (0.1 M, pH 6.0). Further, since the effects of boiling were studied, the gelatinisation (Termamyl) step at 100 °C was excluded. However, as carrots contain only small amounts of starch ($<1\,g\,kg^{-1}$ DM), the absence of gelatinisation was assumed to have a minor influence on the fibre content.[11]

The amount of low-molecular-weight carbohydrates (LMWCs), ie glucose, fructose and sucrose, was determined enzymatically (manual of Boehringer, Mannheim, Germany, number 716 260). Freeze-dried milled carrot samples (1 g) were suspended in 50 ml of distilled water, boiled for 20 min, diluted to 100 ml and centrifuged. The supernatant was then used for analysis of the content of LMWCs. Glucose and sucrose were quantified as glucose before and after hydrolysis of sucrose with β-fructosidase, while fructose was determined as glucose after treatment with phosphoglucose isomerase.

The weight loss of dry matter during boiling was determined by freeze-drying (from −20 to 20 °C during 5 days) a fraction (150 ml out of 500 ml) of the boiling water. The total dry matter found in the boiling water as a percentage of the total dry matter in the unboiled carrots was the loss of dry matter.

Calculations and statistical analysis

The design of the experiment resulted in 56 different carrots samples, 16 (four root sizes) for the cultivars Lonto and Kämpe and 12 (three root sizes) for the cultivars Amarant and Tourino (Fig 1). Further, as each root weight was subdivided into two groups, there were 112 independent samples in the experiment (Fig 1). All dietary fibre and LMWC analyses of the

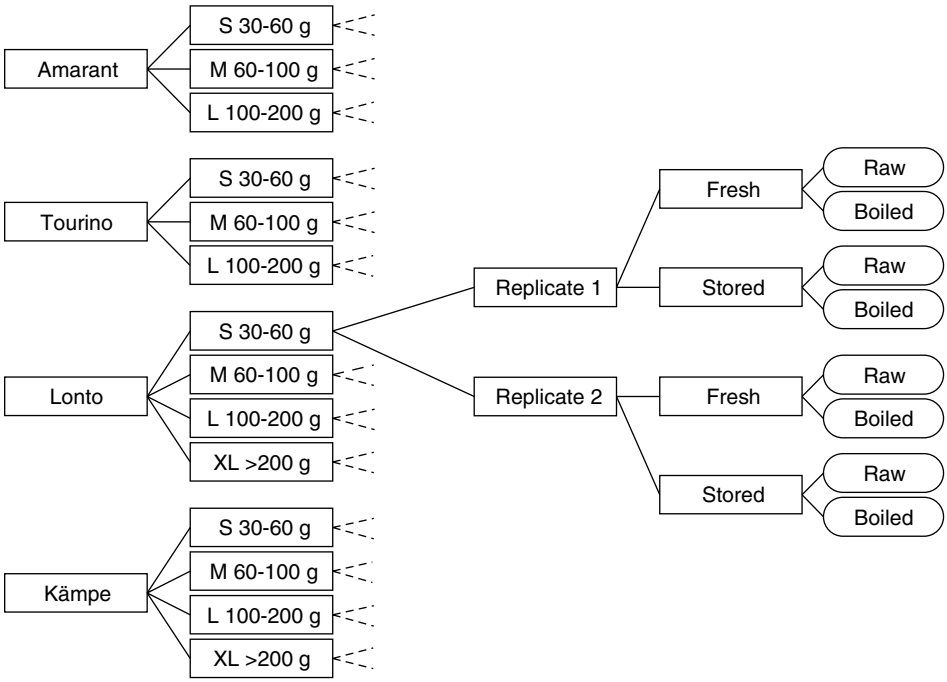

Figure 1. Design of the study showing the carrots used and the treatment to which they were subjected.

independent samples were then performed at least in duplicate. The maximum deviation of the replicates was <5% for both analyses. All carbohydrate analyses were calculated and evaluated on a DM basis. Further, to be able to study real effects of heat treatment, carbohydrate analyses on boiled carrots were corrected for the loss of dry matter into the boiling water during this handling.

The contents of dry matter, dietary fibre and LMWCs of the 28 raw carrot samples are presented in Table 3 in four ways, as means for each cultivar ($n = 4$), means for each root weight group ($n = 4$), means for fresh and stored carrots ($n = 2$) and means for total plant material. The coefficient of variation (CV; ratio between standard deviation and mean value) has been used to give a measure of the variation between the different carrot samples in the experiment. The results of the analyses presented in Tables 3 and 4 were subjected to analysis of variance (ANOVA) using the software package MINITAB (Coventry, UK). All main factors (cultivar, root weight, storage and boiling) and their two-factor interactions were tested by stepwise ANOVA, where all non-significant ($P > 0.05$) interactions were excluded. Comparison of 'treatment means' was performed when the F test in the ANOVA demonstrated significance at $P < 0.05$. In order to avoid the problem that only two cultivars had carrots with weights >200 g, root weight was treated as a covariate and entered as the mean value for each root class and cultivar. The results of the analysis of variance are given in Tables 2 and 5. When significant differences were found in the F test (between several groups, such as cultivars and storage), individual means were analysed by one-way ANOVA, followed by Tukey's procedure for multiple comparisons, or, when possible, differences between paired samples were evaluated by the two-sided Student t test.

RESULTS AND DISCUSSION

Characterisation of carrots

The distribution of carrots according to their root weight varied between the cultivars (Table 1). The mean root weight of the cultivars Amarant and Tourino was similar, 61 and 66 g respectively, compared with 106 g for Lonto and 91 g for Kämpe. The proportion of small and medium roots was also similar for Amarant and Tourino, 93 and 90% respectively, compared with 54% for Lonto and 66% for Kämpe. In these two cultivars the number of XL roots was 17 (6%) and 11 (3%) respectively.

Composition of fresh carrots

Effects of cultivar

The content of dry matter was influenced by cultivar (Table 2). Carrots of the cultivar Amarant had a higher ($P < 0.001$) DM content (130 g kg^{-1} fresh weight, FW) than the other three cultivars (103–107 g kg^{-1} FW) (Table 3).

The cultivar Tourino had the lowest content of TDF, 274 g kg^{-1} DM, versus a mean of 291 ± 4 g kg^{-1} ($P < 0.001$) for the other three cultivars (Tables 2 and 3). No significant differences were observed between the cultivars regarding the SDF content, but the IDF content varied significantly ($P < 0.001$) from 148 g kg^{-1} DM in Tourino to 166 g kg^{-1} DM in Lonto (Table 3). The higher content of IDF in this cultivar therefore resulted in a lower soluble fraction of dietary

Table 2. Analysis of variance of dry matter and carbohydrate content in raw and boiled carrots

		Dry matter		TDF		SDF		IDF		Soluble fraction	
Source of variation	df	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*
Cultivar	3	<0.001	53	<0.001	9	ns		<0.001	9	<0.001	8
Root weight	1	0.014	6	<0.001	23	<0.001	15	0.001	12	ns	
Storage	1	ns		<0.001	54	<0.001	38	<0.001	19	0.023	5
Boiling	1	<0.001	353	<0.001	168	<0.001	154	<0.001	37	<0.001	31
Cultivar* root weight	3	ns		ns		0.042	3	ns		ns	
Cultivar* storage	3	0.009	4	ns		ns		ns		ns	
Cultivar* boiling	3	ns		ns		ns		0.045	3	ns	
Storage* boiling	1	<0.001	15	ns		<0.001	55	<0.001	22	<0.001	67
		LMWCs		Glucose		Fructose		Sucrose		S/(G + F)	
Source of variation	df	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*
Cultivar	3	<0.001	19	<0.001	422	<0.001	208	<0.001	138	<0.001	735
Root weight	1	0.002	11	<0.001	15	ns		0.015	6	ns	
Storage	1	<0.001	25	<0.001	138	<0.001	45	0.013	7	<0.001	27
Boiling	1	<0.001	2727	<0.001	989	<0.001	600	<0.001	1366	ns	
Cultivar* root weight	3	ns		ns		ns		ns		ns	
Cultivar* storage	3	0.042	3	<0.001	13	0.002	6	<0.001	60	<0.001	14
Cultivar* boiling	3	<0.001	7	<0.001	32	<0.001	13	0.010	13	ns	
Storage* boiling	1	ns		0.005	9	ns		ns		ns	

P and *F* values from models with only significant ($P < 0.05$) terms included (ns = not significant).

Table 3. Dry matter (g kg^{-1} FW) and carbohydrate content (g kg^{-1} DM) in raw carrots according to cultivar, root weight and storage

	Cultivar				Root weight[a]				Storage		Total	
	Amarant	Tourino	Lonto	Kämpe	S	M	L	XL[b]	Fresh	Stored	Mean	CV (%)
Dry matter	130	103	107	103	114	111	111	100	109	111	110	12
Total dietary fibre	293	274	294	286	281	285	293	294	294	281	287	4
Soluble dietary fibre	137	126	128	131	126	131	135	129	130	131	130	5
Insoluble dietary fibre	156	148	166	155	154	154	158	165	164	149	157	8
Soluble fraction (%)[c]	47	46	44	46	45	46	46	44	44	47	45	5
LMWCs[d]	490	553	522	532	533	531	516	512	514	535	525	5
Glucose	57	137	115	139	115	114	111	119	103	125	114	31
Fructose	60	125	100	124	100	103	104	110	97	110	104	27
Sucrose	374	292	307	268	318	314	300	283	313	300	307	14
S/(G + F)[e]	3.2	1.1	1.5	1.0	1.7	1.7	1.7	1.3	1.8	1.5	1.6	54

[a] Root weight: S = 30–60 g, M = 60–100 g, L = 100–200 g, XL > 200 g.
[b] Mean values of cultivars Lonto and Kämpe.
[c] Soluble fraction: (SDF/TDF) × 100.
[d] Total content of low-molecular-weight carbohydrates (glucose, fructose and sucrose).
[e] Ratio between sucrose and the monosaccharides glucose and fructose.

fibre ($P < 0.001$). However, owing to the higher dry matter content in the cultivar Amarant, the contents of SDF, IDF and TDF were, when expressed on a fresh weight basis, higher in this cultivar than in the others ($P < 0.001$). TDF amounted to 38 g kg^{-1} FW compared with 28–31 g kg^{-1} FW in the other cultivars (data not shown).

The content of LMWCs varied significantly ($P < 0.001$) between the cultivars (Tables 2 and 3). The cultivar Amarant had the lowest content and also exhibited a completely different composition of individual sugars in comparison with the other cultivars. The contents of glucose and fructose were lower (57 and 60 g kg^{-1} respectively) and the content of sucrose higher (374 g kg^{-1}) than in the other cultivars (Table 3). As a consequence, the ratio S/(G + F) for this cultivar was considerably higher (3.2) than for the other cultivars (1.0–1.5).

When the contents of dietary fibre and LMWCs in the cultivars are considered, two cultivars are clearly distinguished. The distribution of dietary fibre was different in the cultivar Lonto and the composition of LMWCs was different in the cultivar Amarant. In addition, the cultivar Amarant also diverges from the others with a significantly higher dry matter content. Interestingly, these cultivar differences were also seen in a previous study[11] where the same four cultivars as in this investigation were analysed.

The higher amount of dry matter in roots of the cultivar Amarant was mainly caused by an enhanced content of TDF (+8.4 g kg^{-1} FW) and LMWCs (+8.0 g kg^{-1} FW) when compared with the average contents in the other cultivars (data not shown). However, the fraction of IDF did not deviate from that in the cultivars Tourino and Kämpe (Table 3). A possible explanation may be that, in the rapidly growing Amarant, cell division continues at the expense of cell expansion or that the proportion between outer cortex and vascular tissue is different in this cultivar. The lower proportion of SDF in the cultivar Lonto was unexpected, since both Lonto and Kämpe belong to the conical Chantenay type and thus deviate in shape from the cylindrical cultivars Amarant and Tourino. Obviously, the root shape does not influence the composition of dietary fibre. Sucrose is the main carbohydrate transported from carrot foliage to the root. During root growth, acid invertase activity disappears, with a remaining low activity of alkaline invertase resulting in an accumulation of sucrose and a concomitant decrease in glucose and fructose.[10] According to Freeman and Simon,[26] the ratio between sucrose and the monosaccharides glucose and fructose is under genetic control and thus can vary between different cultivars. Whether or not this ratio is correlated with the composition of dietary fibre is unknown.

The differences in carbohydrate pattern between various cultivars may cause differences in postprandial glucose response. However, as the ratio between glucose and fructose was close to one (0.95–1.15) in all cultivars, the glycaemic index will be close to that of sucrose. It must be questioned whether the glucose/fructose ratio is close to one in all carrot cultivars. If this is the case, the differences reported in the literature in postprandial glucose response with carrots[1–3,6] may be due to other factors, eg the permeability of the cell walls, which can be considerably affected by processing. Blanched and microwaved carrots have also been shown to elicit higher glucose and insulin responses in healthy subjects than raw carrots, when included in a lunch containing creamed potatoes and white wheat bread.[3]

Effects of root weight

Averaged over all cultivars, root weight up to 200 g had no significant effect on the dry matter content, while it was significantly lower ($P = 0.014$) in those with a weight >200 g (100 versus 111–114 g kg^{-1} FW for the other weight classes) (Tables 2 and 3). However, these values must be interpreted with care, as mean

values of the root weight XL are only based on two of the cultivars (Lonto and Kämpe) and thus cannot be directly compared with mean values of the other root weight classes (S, M and L).

The content of TDF increased independently of cultivar by ~5% ($P < 0.001$) up to class L owing to increasing amounts of both SDF and IDF ($P < 0.001$). Concerning TDF and SDF, all cultivars behaved in a similar way, as judged by the non-significant interaction between root weight and cultivar (Table 2). XL roots did not deviate from L roots as far as TDF was concerned, but the fraction of SDF was somewhat lower in these roots (44 versus 46%) owing to a lower amount of SDF and a higher amount of IDF compared with the L roots (Tables 2 and 3).

The content of LMWCs was somewhat lower in larger carrots (L and XL) ($P = 0.002$) than in the smaller ones (S and M) (mean 514 versus 532 g kg^{-1} DM in smaller carrots) owing to a lower content of sucrose in these carrots ($P = 0.015$). The same pattern was present in all cultivars.

A major conclusion regarding the effects of root weight is that small carrots (<60 g) had the highest and XL carrots (>200 g) the lowest dry matter content, while roots between 60 and 200 g had similar contents. Small carrots had the lowest amount of TDF and the highest content of LMWCs, but increasing root weight had no evident influence on either the fraction of SDF or the amounts of glucose, fructose and sucrose. Compared with the other factors tested, the effect of root weight was therefore rather small. The growth of the carrot root normally results in an increased ratio between the outer parenchymatic cortex and the inner stele of vascular tissue, but the presence of roots >200 g can be a result of either more rapid growth due to a lower plant density or a longer period of growth (rapid germination). The higher amount of IDF in XL carrots could therefore be expected owing to an expanded secondary thickening of the cell walls. This may result in the onset of cell wall lignification and/or development of phenolic crosslinks between polysaccharides.[17,27] As the degree of lignification is small in vegetables, crosslinking between phenolic acids seems to be a more likely explanation. The accumulation of phenols in carrots after long periods of storage has also been reported.[28,29] A possible explanation of the lower content of sucrose in larger carrots than in smaller ones could be that the higher growth rate of the larger carrots results in a lower concentration of sucrose. Similar results have been seen in relation to the time of sowing and harvest of carrots.[21]

Effects of storage

Storage had no significant effect on the average dry matter content (Tables 2 and 3). However, one of the cultivars (Lonto) behaved differently from the others and lost about 10% dry matter during storage, while the other cultivars were only slightly affected and lost about 1% dry matter ($P = 0.009$) (data not shown).

The TDF content decreased (from 294 to 281 g kg^{-1} DM, $P < 0.001$) while the soluble fraction increased (from 44 to 47%) during storage ($P = 0.023$). All cultivars behaved in a similar way, as indicated by the non-significant interaction between storage and cultivar (Table 2). The increased solubility was due to a reduction in the content of IDF ($P < 0.001$) (Table 3).

The average content of LMWCs (Table 3) increased from 514 to 535 g kg^{-1} DM following storage ($P < 0.001$) (Table 3). There was also a redistribution between individual sugars. The content of glucose and fructose increased ($P < 0.001$) while the content of sucrose decreased ($P = 0.013$), resulting in a lower ratio between sucrose and the monosaccharides ($P < 0.001$), which is in agreement with earlier findings.[10] The cultivar Amarant, however, behaved differently from the other cultivars, with an increase in the sugar ratio S/(G + F) from 3.2 to 3.4, while the ratios in the other cultivars decreased from a mean of 1.4 to 1.1 ($P < 0.001$) (data not shown).

The increased solubility of the fibre after storage was unexpected (Table 3) and is in contrast to that found in other studies.[11,30] The reason for this discrepancy is not known, but it might be due to the activation of polygalacturonanases, enzymes cleaving glycosidic linkages in the pectin molecule.[31] However, to become a substrate for polygalacturonanases, pectic substances must first be de-esterified by the enzyme pectin esterase or pectin methylesterase. Other endogenous enzymes of importance that may be activated during storage and thus may be responsible for the lower TDF content are arabinases, galactosidases and glucanases,[32] which degrade polysaccharides associated with or linked to the interior chain of the pectin molecule. The lower TDF and IDF values after storage indicate that the polysaccharides were degraded/modified to such an extent that they were also soluble in the ethanol concentration (80%) used to recover the fibre.

The decrease in the sugar ratio S/(G + F), evident in all cultivars except Amarant, implies that there is an increased invertase activity in most cultivars during storage. Similar changes during long-term storage of carrots have previously been reported by others.[10,29] The impact of storage was, however, comparatively small (Table 2), with glucose being the most affected variable.

Composition of boiled carrots

Boiling exerted the strongest effect on all variables analysed with the exception of S/(G + F) (Table 2).

Effects on dry matter

The dry matter content was reduced by a mean of 24% when the carrots were boiled ($P < 0.001$) (Table 4). A similar decrease could be seen in all cultivars (22–25%) (Table 5). The loss of dry matter content was more pronounced in stored carrots (28%) than in fresh ones (19%) ($P < 0.001$) (Tables 4 and 5). Root

Table 4. Carbohydrate content (g kg^{-1} DM) in boiled carrots and loss of carbohydrate and dry matter into the boiling water (%) according to cultivar, root weight and storage

	Cultivar				Root weight[a]				Storage		Total	
	Amarant	Tourino	Lonto	Kämpe	S	M	L	XL[b]	Fresh	Stored	Mean	CV (%)
Carbohydrate content												
Total dietary fibre	259	245	262	263	248	257	262	273	268	248	258	7
Soluble dietary fibre	117	104	110	112	105	112	113	117	122	100	111	13
Insoluble dietary fibre	142	141	151	151	143	145	149	156	147	147	147	5
Soluble fraction (%)[c]	45	42	42	43	42	43	43	43	45	41	43	7
LMWCs[d]	321	337	306	329	323	332	319	309	314	330	322	7
Glucose	37	81	67	85	68	69	67	72	62	75	69	30
Fructose	38	77	58	76	60	63	64	67	59	68	63	27
Sucrose	246	178	181	168	194	200	188	170	194	187	191	18
S/(G + F)[e]	3.3	1.1	1.5	1.1	1.7	1.8	1.7	1.3	1.8	1.6	1.7	54
Loss into the boiling water												
Dry matter	24	25	23	22	25	23	24	21	19	28	24	23
Total dietary fibre	11	11	11	8	12	10	10	7	9	12	10	39
Soluble dietary fibre	14	18	13	15	17	15	16	9	6	24	15	73
Insoluble dietary fibre	8	5	9	2	7	5	5	5	10	1	6	121
LMWCs[d]	35	39	41	38	39	37	38	40	39	38	38	10
Glucose	35	41	42	39	40	39	39	40	40	39	39	11
Fructose	36	38	41	39	39	39	38	40	39	38	39	13
Sucrose	34	39	41	37	39	37	38	40	38	38	38	10

[a–e] See Table 3 for details.

Table 5. Analysis of variance of dry matter and carbohydrate loss following boiling

		Dry matter		TDF		SDF		IDF	
Source of variation	df	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*
Cultivar	3	ns		ns		ns		ns	
Root weight	1	0.026	6	0.053	4	0.017	7	ns	
Storage	1	<0.001	77	0.023	6	0.030	5	<0.001	18
Cultivar* storage	3	ns		ns		ns		ns	
Storage* root weight	1	ns		ns		0.006	9	ns	
		LMWCs		Glucose		Fructose		Sucrose	
Source of variation	df	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*
Cultivar	3	0.002	7	0.033	3	ns		0.001	8
Root weight	1	ns		ns		ns		ns	
Storage	1	0.525	<1	ns		ns		0.644	<1
Cultivar* storage	3	0.030	4	ns		ns		0.009	5
Storage* root weight	1	ns		ns		ns		ns	

P and *F* values from models with only significant ($P < 0.05$) terms included (ns = not significant).

weight also had a significant effect ($P = 0.026$), and in the heaviest (XL) carrots (ie cultivars Lonto and Kämpe) the loss of dry matter was less (21%) than in carrots with root weights <200 g (S, M and L), which averaged 24% (Tables 4 and 5).

Effects on dietary fibre

The reduction in TDF during boiling averaged 10% (from 287 to 258 g kg^{-1} DM, $P < 0.001$), with a higher reduction in SDF than in IDF (mean 15 versus 6%) (Tables 2 and 4). All cultivars responded in the same way (Table 4). However, the loss of dietary fibre was different depending on whether or not the carrots had been stored before boiling. The decrease in SDF during boiling was greater ($P = 0.030$) in stored carrots (from 131 to 100 g kg^{-1} DM, corresponding to a loss of 24%) than in fresh carrots (from 130 to 122 g kg^{-1} DM, corresponding to a loss of 6%), while the loss of IDF in stored carrots was small (1%, from 149 to 147 g kg^{-1} DM) compared with that in fresh carrots (10%, from 164 to 147 g kg^{-1} DM) ($P < 0.001$) (Tables 4 and 5). As a consequence, the soluble fraction of the fibre was similar before and after boiling in fresh carrots (44 versus 45%), compared

with a decrease from 47 to 41% in stored carrots (Tables 3 and 4). Also, the size of the carrots seemed to have some effect, and the heavier the carrots, the lower was the loss of TDF ($P = 0.053$) (Table 5). The loss was only 7% in XL carrots and as high as 12% in small carrots (Table 4). The lower loss of TDF was mainly due to a lower loss of SDF in XL carrots ($P = 0.017$) (Table 4).

Effects on LMWCs

The loss of LMWCs was as high as 38% (from 525 to 322 g kg^{-1} DM, $P < 0.001$), and all three sugars (glucose, fructose and sucrose) showed a similar behaviour (39, 39 and 38% loss respectively) (Tables 2 and 4). Thus the ratio between sucrose and the monosaccharides glucose and fructose was not altered as a result of boiling. The weight of the carrots was of no importance for the loss of any of the LMWCs (Table 5). However, the cultivars behaved differently ($P = 0.002$). The cultivar Amarant deviated with a lower loss (35%) following boiling than the other cultivars, where the average loss amounted to 39% (Table 4).

The higher loss of dry matter in stored carrots than in fresh carrots may be due to a modified cell wall structure. During storage, endogenous cell wall hydrolases such as pectin methylesterase, polygalacturonanases, cellulase and arabinase break up the cell wall, and pectic substances, mainly in the middle lamella, may be degraded and partly solubilised.[32] Furthermore, there is a breakage of weaker bonds between polysaccharide chains during boiling, as demonstrated in plant material at different degrees of maturation.[18] Pectin methylesterase, on the other hand, which demethoxylates pectin and catalyses the Ca^{2+} crosslinking between various pectin molecules, decreases the possibility of insoluble pectin being solubilised and lost into the boiling water. These events will lead to an open but compact structure of the plant tissue after storage, and consequently an increased leakage of nutrients through the cell wall, and possibly loss of cell wall polysaccharides into the boiling water.[33] The root weight was also of significance, and larger carrots lost less dry matter than smaller ones. It may therefore be speculated whether or not the cell walls in heavy carrots are more lignified, and/or phenolic crosslinks are more frequent in carrots when the conditions of growth have allowed the development of heavy roots.

The sugar ratio S/(G + F) was the only variable that remained unchanged when the carrots were boiled before and after storage. Similar diffusion of sugars into the boiling water was also expected, as fresh and stored carrots had very similar dry matter contents.[15] The diffusion of sugars is known to be mainly dependent on the initial concentration and the process conditions used. The cultivar Amarant had the lowest loss of sugars compared with the other cultivars. This cultivar also had the highest dry matter content ($P < 0.001$). This is in accordance with results obtained by others, where a high dry matter content of the material was found to be related to a lower diffusion of LMWCs into the boiling water.[11,15]

CONCLUSIONS

- The dry matter content in fresh carrots depended on cultivar and root weight, while storage had no effects. During boiling there were considerable losses of dry matter, mainly LMWCs but to some extent also dietary fibre, into the processing water.
- The different dietary fibre variables were most affected by boiling. The other factors had fewer effects on most variables. However, the choice of cultivar was of no importance for the SDF, and the root weight had no effect on the solubility of the fibre.
- The content of LMWCs, as well as the contents of individual sugars, was affected by most factors tested. An exception was the ratio between sucrose and the monosaccharides glucose and sucrose, which was not affected by boiling, as the loss of all LMWCs was similar during this handling. Root weight also had no influence on this ratio or on the fructose content. Boiling was the factor that was of most importance, followed by the choice of cultivar.

The results may provide a basis for selecting raw material when studying possible health effects of carrots.

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