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Journal of Food Engineering 312 (2022) 110754

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Comparison of steaming and boiling of root vegetables for enhancing carbohydrate content and sensory profile

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ARTICLE INFO

Keywords:
Parsnip
Beetroot
Jerusalem artichoke
Dietary fiber
Texture
Sensory

ABSTRACT

Root vegetables have unique techno-functional and nutritional properties however, their use in processed foods is limited to a few species, partially due to a lack of knowledge related to the impact of thermal treatments on the sensory properties. This study investigated the effect of steaming and boiling on the microstructure, mechanical properties, and sensory profile of three model root vegetables with distinct carbohydrate composition: Jerusalem artichoke (*Helianthus tuberosus* L.), parsnip (*Pastinaca sativa*), and beetroot (*Beta vulgaris*). Thermally treated Jerusalem artichoke and parsnip showed higher content of cell wall polysaccharides, particularly β-glucans (e.g. cellulose) and pectic components, compared to raw. Steaming produced more cell shrinkage and loss of cell-cell adhesion than boiling, leading to softer vegetables. Processed beetroot showed loss of cell turgor and drastic softening but not clear changes in overall carbohydrate content. The scores for several flavour and in-mouth attributes were higher for steamed vegetables compared to boiled. Our results give insights on the processability of root vegetables towards products with enhanced sensory and nutritional properties.

1. Introduction

Root vegetables can grow outdoors under different climates, including the harsh conditions of Nordic and tropical countries. From a nutritional point of view, root vegetables are rich in dietary fibre i.e cell wall polysaccharides and antioxidants, which are related to positive effects on human health reducing the risk of cardiovascular diseases and type 2 diabetes (Bach et al., 2015a; Causey et al., 2000; Georgiev et al., 2010; Ninfali and Angelino, 2013; Ninfali et al., 2005; Rubel et al., 2018). Root vegetables are usually consumed worldwide as staple foods however, the use of non-conventional root vegetables (other than carrot and potato) in processed foods i.e particulate soups, ready-to-eat meals, sauces, etc could be enhanced by a better understanding of the impact of thermal treatments on their organoleptic properties. In order to better exploit the techno-functional and nutritional properties of root vegetables the relationship between processing conditions, composition and microstructure must be elucidated.

Boiling in water leads to leakage of soluble cell components to the water, and exposure and degradation of antioxidants. Alternative thermal methods such as steaming, in which the heat transfer is more uniformly distributed compared to boiling in water, could help reduce those losses and retain the full techno-functional and nutritional value of root vegetables.

Jerusalem artichoke (*Helianthus tuberosus L.*), parsnip (*Pastinaca sativa L*) and beetroot (*Beta vulgaris*) are three root vegetables with very different carbohydrate composition, in particular regarding their starch and dietary fibre content. Jerusalem artichoke is high in the storage carbohydrate inulin, a water-soluble polysaccharide formed by β-(2 → 1) linkages of D-fructose with a glucose molecule at the end of the chain, which has been shown to have prebiotic properties (Holscher, 2017; Shoaib et al., 2016). The content and degree of polymerisation of inulin depends on the variety, harvest time (Li et al., 2015), and decreases with storage time, as the polysaccharide is converted to sucrose (Cabezas et al., 2002; Clausen et al., 2012). Furthermore, Jerusalem artichoke is also rich in vitamins, minerals, polyphenols and has a high content of protein compared to other root vegetables (Sawicka et al., 2020).

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https://doi.org/10.1016/j.jfoodeng.2021.110754
Received 5 May 2021; Received in revised form 27 July 2021; Accepted 28 July 2021
Available online 31 July 2021

Parsnip is a starch-rich root vegetable containing approximately 50 % w/w (dry weight) starch (Siddiqui, 1989) and 30% w/w (dry weight) dietary fibre (Castro et al., 2012), of which the main components are cellulose (18.5 % w/w) and hemicelluloses (44.6 % w/w) (Siddiqui, 1989). In contrast beetroot is a non-starchy root vegetable, with pectic polysaccharides and cellulose as the main cell wall components (Waldron et al., 1997a), and it contains ferulic acid as the most abundant phenolic component. Pectins are complex polymers that consist mainly of homogalacturonan (HG), rhamnogalacturonan I (RGI) and rhamnogalacturonan II (RGII) blocks covalently linked to one another (Atmodjo et al., 2013). The ferulic-acid dimers have been proposed to cross-link pectic polymers via the arabinose and galactose neutral side-chains (Ralet et al., 1994) in pectin with implications for cell-cell adhesion (Kato et al., 1994) and texture (Waldron et al., 1997a, 1997b).

Relatively few studies have been performed on the impact of processing methods on root vegetables and tubers other than carrots (Alam et al., 2018; Bach et al., 2013; Greve et al., 1994a; Nayak et al., 2007; Ng and Waldron, 1997; Paciulli et al., 2016; Sila et al., 2005). In this study we investigated the impact of steaming on the carbohydrate composition (starch, inulin and cell wall polysaccharides), mechanical properties and microstructure of three model root vegetables (Jerusalem artichoke, parsnip and beetroot), which are not commonly used in processed foods. The results were compared to those obtained from conventional boiling in water. A multidisciplinary approach was followed, in which physico-chemical properties induced by thermal processing were correlated to the sensory profile evaluated by panellists (n = 18) in terms of flavour and texture attributes. Understanding how carbohydrate composition is related to processability, microstructure and sensory profile of root vegetables could lead to the development of new food products with high dietary fibre content.

2. Material and methods

2.1. Sample preparation and thermal treatments

The root vegetables selected for this study were Jerusalem artichoke (*Helianthus tuberosus* L.), parsnip (*Pastinaca sativa*) and beetroot (*Beta vulgaris*). These vegetables were selected based on their distinct carbohydrate composition, in particular starch and dietary fibre content. The vegetables were grown in Sweden and were purchased at a local grocery store (5 kg). They were placed in plastic bags (1 kg) and stored at 4 °C for 1 day prior to processing. Disk shape samples with a diameter and height of approximately of 1.5 cm were cut with the help of a cork borer. The direction and location of the cut was randomised so that both the vascular and the cortex tissues were included, but not the peel. For each type of vegetable, the cut samples were mixed to ensure randomisation.

Two thermal treatments were compared: steaming and conventional cooking in hot water (which will be referred to as 'boiling' throughout the text). The use of these two processing methods to cook the samples implied differences in heat transfer, contact with water and temperature. Whilst steaming requires 100 °C to generate steam, boiling in water is conventionally performed at approximately 90 °C. For steaming, samples were placed on a tray in the steamer (Air-o-steam Mod. AOS061ETH1, Electrolux, Stockholm, Sweden) at 100 °C for 15, 30, 45, and 60 min. For boiling, the samples were added to hot water and thermally treated at 90 °C for 15, 30, 45, and 60 min. The heating of the pieces was monitored using temperature loggers with a thermocouple inserted in the centre of the vegetable piece, it took approximately 2.5–3.5 min to reach the desired temperature (90 or 100 °C). After the thermal treatments, the samples were immediately cooled down in a cold-water bath and sealed in plastic bags to reduce drying prior to mechanical and microstructural analysis, which were performed within 24 h of processing. A set of processed samples were freeze dried for chemical analysis.

2.2. Mechanical properties

Samples were compressed in an Instron Universal Testing Machine 5542 (Instron, Norwood, MA, USA) equipped with a cylindrical probe of 3 cm in diameter and a 500 N load cell. The compression rate was set to 1 mm/s and the samples were compressed until fracture. For each vegetable, 6 replicates were analysed for each treatment (6 raw, 6 steamed, and 6 boiled). True stress, σ_T, and true strain, ε_T, were calculated using the instrument software Blue Hill as following:

$$\sigma_T = \frac{F(t)(h_{0-}\Delta h(t))}{\pi r_0^2 h_0} \quad (1)$$

$$\varepsilon_T = \ln\left(\frac{h_0}{h_0 - \Delta h(t)}\right) \quad (2)$$

where F is the compression force, is the initial height of the sample, $\Delta h(t)$ is the change in height during compression and r_0 is the initial radius of the sample.

From the trues stress vs true strain curves the maximum trues stress, the true strain at maximum true stress and Young's modulus were obtained.

2.3. Confocal laser scanning microscopy (CLSM)

Samples were examined using a Leica TCS SP2 confocal laser scanning microscope (Leica Microsystems, Heidelberg, Germany) using a 20× (0.7 NA) glycerol objective. A solid-state laser emitting at 543 nm was used for excitation. A slice of approximately 0.25 cm thickness was cut from each sample with the help of a razor blade and placed in a metal cup on a glass sample holder. A droplet of Congo red (0.2% w/w) was added on top of the samples to stain the cell walls. The samples were covered by a cover glass to prevent drying.

2.4. Dry matter

The measurement of dry matter was carried out by drying in an oven at 105 °C for 24 h (UNP 100–800, Memmert, Schawabach, Germany). Three replicates were measured.

2.5. Monosaccharide analysis

Samples were freeze-dried (Alpha 1–2 LDplus freeze dryer, Martin Christ, Osterode, Germany) prior to analysis. Monosaccharide composition analysis was performed by acid hydrolysis followed by high-pH anion exchange chromatography with pulsed amperometric detection (HPAEC-PAD) on an IC-3000 system (Dionex, Sunnyvale, CA, USA). Trifluoroacetic acid (TFA) hydrolysis was carried out by incubating samples with 2 M TFA at 120 °C for 3 h, air-dried afterwards and dissolved in deionized water before injection to the IC. In parallel, two-step sulfuric acid hydrolysis was performed; 1–2 mg of sample was first hydrolysed with 0.125 mL 72 % H_2SO_4 for 3 h at room temperature, and secondly diluted with 1.375 mL of MilliQ water and heated to 100 °C for 3 h (Saeman et al., 1954). The sugar identification and quantification were carried out according to McKee et al. (2016), using separate gradients for neutral sugars and uronic acids. All chemicals and monosaccharide standards were purchased from Sigma-Aldrich (St. Louis, MO, USA). The following monosaccharides and uronic acids were analysed: arabinose (Ara), fucose (Fuc), rhamnose (Rha), xylose (Xyl), mannose (Man), fructose (Fru), galacturonic acid (GalA), galactose (Gal), glucose (Glc), glucuronic acid (GlcA) and 4-*O*-methyl glucuronic acid (meGlcA), abbreviations will be used throughout the text.

2.6. Starch content determination

Analysis of total starch content was done on freeze dried samples

using the Megazyme kit according to AACC Method 76–13.01. In brief, starch was gelatinised in a boiling water bath and simultaneously hydrolysed by the action on thermostable α-amylase, followed by the addition of amyloglucosidase to hydrolyse partly degraded starch to glucose. Using an oxidase/peroxidase reagent (GOPOD), glucose content was determined colorimetrically, and starch content was calculated.

2.7. Soluble protein analysis

The content of soluble protein was determined on freeze dried samples, using Bradford protein assay kit from Bio-rad. The dye solution was added to diluted samples and absorbance was measured at 595 nm. Bovine-γ-globuline standard calibration was used to determine protein content.

2.8. Total phenolic content

The determination of total phenolic content (TPC) was carried out using Folin-Ciocalteu's reagent (Folin and Ciocalteu, 1927). Samples were suspended in water at a concentration of 10 mg/mL under stirring overnight, centrifuged and to an aliquot of 100 μl of the supernatant 100 μl Folin-reagent and 800 μl 5 % (w/v) Na_2CO_3 solution added. The absorbance was measured at 725 nm and results were expressed as mg gallic acid equivalents (GAE) per 100 g dry weight of freeze-dried sample using a gallic acid standard calibration.

2.9. Sensory evaluation

The impact of the steaming and boiling on the sensory properties of the root vegetables was evaluated in three separate sessions, one for each vegetable. The sensory evaluation was performed by 18 semi trained panellists (12 females; 6 males) with ages ranging between 20 and 60 years old (average age 34 years old). The panellists were selected from the database of RISE Research Institutes of Sweden. The research was approved by the funding agency and a specific ethical approval was not required. The participants volunteered for the tasting, they read and signed a consent form. The Rate-All-That-Apply (RATA) method (Reinbach et al., 2014) was used to profile the samples. A list of aroma and flavour descriptors was prepared for each root vegetable based on sensory attributes reported in literature for the specific root vegetables (Bach et al., 2013, 2015b). A preliminary list was firstly discussed internally with food and sensory experts, and then presented to the panellists during a familiarisation session. The list was narrowed down to focus on the interest of the present work, while still covering the different sensory space of the three root vegetables studied. Some Odour (O), flavour (F), in-mouth and texture attributes were used for all three vegetables: overall odour, overall flavour, sweetness, bitterness, cohesiveness, hardness, juiciness, crispiness, chewing resistance, ease to swallow and residues in mouth. Other attributes were specific for the different vegetables, for Jerusalem artichoke: mushroom, raw potato, earthy, Jerusalem artichoke flavour and odour, sweet and asparagus odours; for parsnip: clove and parsnip for both flavour and odour; cooked potato flavour and sweet and raw potato odours; and for beetroot: earthy and beetroot both for flavour and odour and green odour.

Prior to evaluation, the panellist participated in 1 familiarisation session (1 h) in which the protocol and the different sensory attributes were explained and discussed with the panellists, to ensure that they were familiar with the samples, the tasting protocol and the vocabulary used to define the sensory attributes. Steamed and boiled samples were freshly prepared prior to the evaluation. Samples were served as prepared and tasted at room temperature (22 °C). They were presented in opaque plastic cups in randomised order and coded with a three-digits number. Samples were evaluated in duplicate. Sensory evaluations were performed in the sensory laboratory of RISE under ISO standard conditions temperature control (22 °C) and day light equivalent. The sensory attributes were rated on a 5-points categorical scale with 1 = low and 5 = high. The sensory data was collected using EyeQuestion v.3.8.6, Logic 8 BV software. The impact of the thermal treatments on the colour of the samples was also assessed using an unstructured linear scale (from 0 to 100).

2.10. Statistical analysis

Statistical analysis was performed with XLSTAT Basic (version 2019.3.2, Addinsoft) with ANOVA and pairwise comparison using Tukey's HSD test. For the sensory evaluation, two-way ANOVA analysis (including the judge as a random factor) was performed for assessment of each individual vegetable, significant differences were analysed by post-hoc Tukey's HSD test.

3. Results and discussion

3.1. Impact of steaming and boiling on the mechanical properties of the root vegetables

Fig. 1 illustrates the maximum true stress, which is related to the strength of the vegetable pieces, as function of steaming and boiling time. Time 0 refers to the raw vegetables i.e without any thermal treatment. The dry matter content of the raw vegetables was 23.4 ± 1.8% w/w, 21 ± 2.2% w/w and 14.7 ± 1.3% w/w for Jerusalem artichoke, parsnip and beetroot, respectively. As raw material, parsnip was softer than Jerusalem artichoke, despite having similar dry matter, the maximum true stress was 893.6 ± 152.5 kPa for parsnip and 1484.0 ± 120.3 kPa for Jerusalem artichoke (Table 1). Beetroot had the lowest dry matter and was the strongest vegetable, 1419.3 ± 114.7 kPa for beetroot (Table 1), indicating that dry matter is not the main parameter determining vegetable strength. The Young's modulus can be obtained from the linear region of the trues stress vs true strain curves and is related to stiffness/elasticity of the vegetable pieces. The values of the Young's modulus for the raw materials were 7.12 ± 0.81 MPa for Jerusalem artichoke, 3.30 ± 0.18 MPa for parsnip and 4.60 ± 0.34 MPa for beetroot (Table 1), this indicates that parsnip was also more elastic than Jerusalem artichoke and beetroot.

After 15 min processing time all three vegetables were significantly softer compared to raw. The trends in Fig. 1 indicated that boiled samples were slightly stronger than steamed samples, although the differences were only significant for Jerusalem artichoke after 15 min treatment.

From these experiments, the duration of the thermal treatments was selected to investigate how processing impacts carbohydrate and sensory properties. For parsnip and Jerusalem artichoke the thermal treatments were applied for 15 min whilst for beetroot 30 min was chosen, as after 15 min they were still undercooked, in agreement with previous studies (Waldron et al., 1997a). Fig. 2 shows that the compression profile was different for raw and thermally treated vegetables. Raw vegetables had a fast increase in stress and a sharp maximum true stress peak, after which the structure collapsed. For steamed and boiled samples, the stress increased slower than for raw vegetables, no clear peak was observed and instead a broadening of the curve profile was obtained. The shape of the curves was very similar independently of the type of vegetable. The average maximum true stress, Young's modulus and true strain at maximum true stress are presented in Table 1. The large variation between samples was expected due to their biological nature and the fact that not specific tissues were analysed. All vegetables showed a decrease in true stress and Young's modulus after the thermal treatments. Steamed Jerusalem artichoke showed a significant decreased in maximum true stress and young modulus compared to boiled i.e steamed samples were softer and more elastic than boiled samples. For parsnip and beetroot both thermal treatments led to similar loss of strength and increase in elasticity compared to the raw vegetables, although for parsnip the true stress of boiled samples were larger than for steamed samples the differences were not statistically

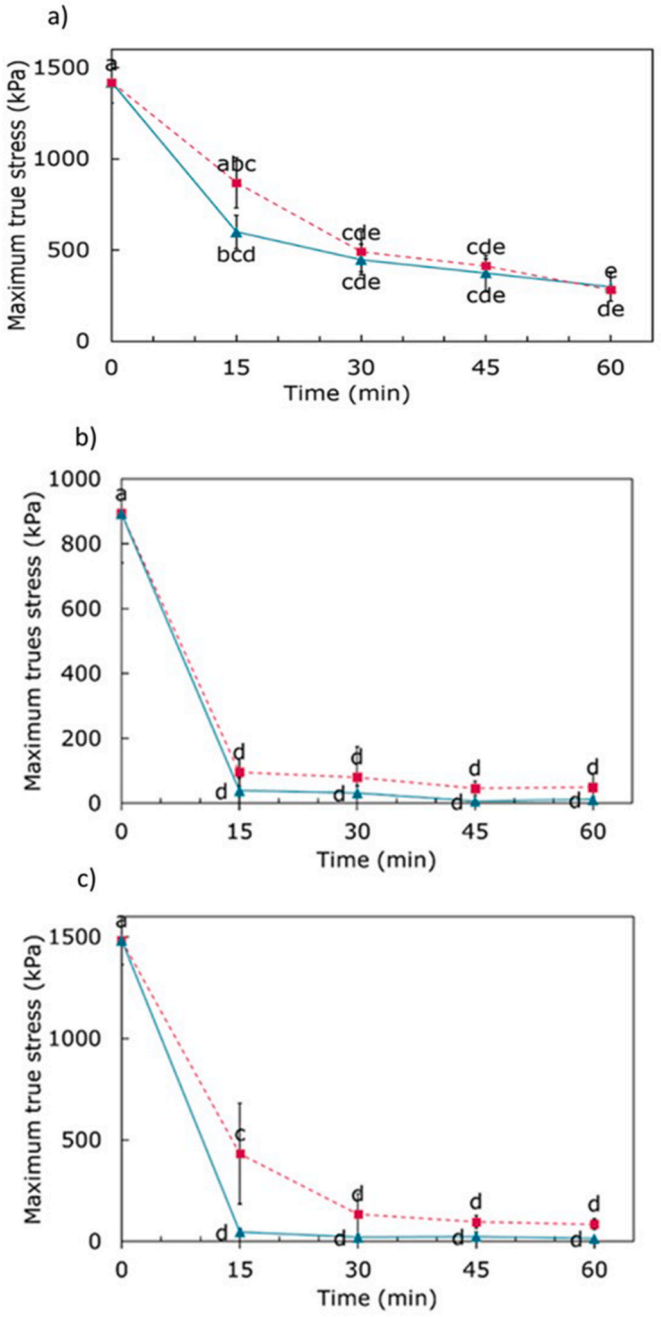

Fig. 1. Evolution of the maximum trues stress as function of time for steamed (blue solid line) and boiled vegetables (red dashed line). Jerusalem artichoke (a), parsnip (b) and beetroot (c). Average and standard deviation of 6 measurements is presented. Significant differences ($p < 0.05$) are indicated by different letters. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

significant. It has been reported that steamed carrots were softer than boiled carrots when cooked for similar times (Paciulli et al., 2016). The strain at maximum trues stress, i.e. the deformation at break, is related to sample brittleness. For all three vegetables the true strain decreased from raw to heated, indicating that they became less brittle, however not significantly ($p < 0.05$) in the case of beetroot. No significant difference ($p < 0.05$) in true strain was observed between steamed and boiled vegetables.

Table 1
Maximum true stress, Young's modulus and true strain at maximum true stress obtained from compression curves for raw, steamed and boiled vegetables. Jerusalem artichoke and parsnip were boiled or steamed for 15 min, beetroot was boiled or steamed for 30 min. Values represent the average and standard deviation of six replicates. Different letters represent significant differences between the treatments.

	Max True stress (kPa)	Young's modulus (MPa)	True strain at max true stress
Jerusalem artichoke_Raw	1484.0 ± 120.3^{a}	7.12 ± 0.81^{a}	0.32 ± 0.02^{a}
Jerusalem artichoke_Steamed	47.3 ± 16.6^{c}	0.39 ± 0.16^{c}	0.23 ± 0.04^{b}
Jerusalem artichoke_Boiled	433.0 ± 247.8^{b}	2.53 ± 1.20^{b}	0.23 ± 0.05^{b}
Parsnip_Raw	893.6 ± 152.5^{a}	3.30 ± 0.18^{a}	0.40 ± 0.06^{a}
Parsnip_Steamed	39.3 ± 39.1^{b}	0.23 ± 0.20^{b}	0.25 ± 0.10^{b}
Parsnip_Boiled	96.0 ± 42.8^{b}	0.45 ± 0.16^{b}	0.30 ± 0.03^{ab}
Beetroot_Raw	1419.3 ± 114.7^{a}	4.60 ± 0.34^{a}	0.41 ± 0.07^{a}
Beetroot_Steamed	446.8 ± 84.0^{b}	2.83 ± 0.52^{b}	0.34 ± 0.06^{a}
Beetroot_Boiled	491.4 ± 111.4^{b}	2.38 ± 0.59^{b}	0.36 ± 0.06^{a}

3.2. Microstructural changes after steaming and boiling

Fig. 3 illustrates the parenchyma tissues of raw, boiled, and steamed Jerusalem artichoke, parsnip and beetroot. In the raw materials (Fig. 3a, d, 3g), cells were turgid and the cell walls were sharp, intercellular spaces were visible mainly in parsnip. The microstructure of the raw vegetables, visualised by confocal laser scanning microscopy, was similar to those reported in previous studies for beetroot (Dalmau et al., 2019; Nayak et al., 2007), parsnip (Alam et al., 2018) and Jerusalem artichoke (Rubel et al., 2018) using light microscopy and scanning electron microscopy techniques. Microstructural observations revealed that, at the observed length scale, the impact of thermal treatments on tissue integrity was different for the three vegetables. Jerusalem artichoke showed more cell shrinkage, more cell-cell separation, and a larger increase in intercellular spaces when it was steamed (Fig. 3b) compared to boiled (Fig. 3c). These differences agreed well with the measured mechanical properties (Table 1), showing that steamed samples were approximately ten times softer than boiled samples. Steamed parsnip (Fig. 3e) also showed a higher loss of cell-cell adhesion compared to boiled parsnip (Fig. 3f), with cells that were deformed and shrank to a larger extent and an increase in cell-cell separation, a loss of strength compared to boiled was also observed but the differences were not significant (Table 1). It has been shown that starch granules in parsnip occupy a large fraction of cell volume (Alam et al., 2018), moisture penetration and heat lead to starch gelatinisation, the starch granules lose their integrity and α-amylose is leaked from the cells, which could explain why the parsnip cells appeared drastically deformed and shrank compared to the other two vegetables. Steamed beetroot (Fig. 3h) presented cells with swollen walls and some cells showed the evidence of the onset of separation in the middle lamella compared to raw and boiled (Fig. 3i) however, not cell-cell separation or cell shrinkage was observed.

Steaming leads to a more homogenous distribution of heat in the vegetables, and consequently to an increase in cell-cell separation throughout the tissues. Thermal treatments have been shown to induce cell separation of vegetable tissues due to the pectin depolymerisation in the middle lamella via β-elimination (Keijbets and Pilnik, 1974; Waldron et al., 1997b), as well as hydrolysis of cell wall components and loss of turgor pressure due to membrane denaturation (Greve et al., 1994a, 1994b). The above mechanisms have been proposed for carrots (Greve et al., 1994a; Sila et al., 2005). Furthermore, softening of water chestnuts and carrots has been correlated to cell-cell separation an ease of fluid flow (Ormerod et al., 2004; Waldron et al., 1997b). The higher

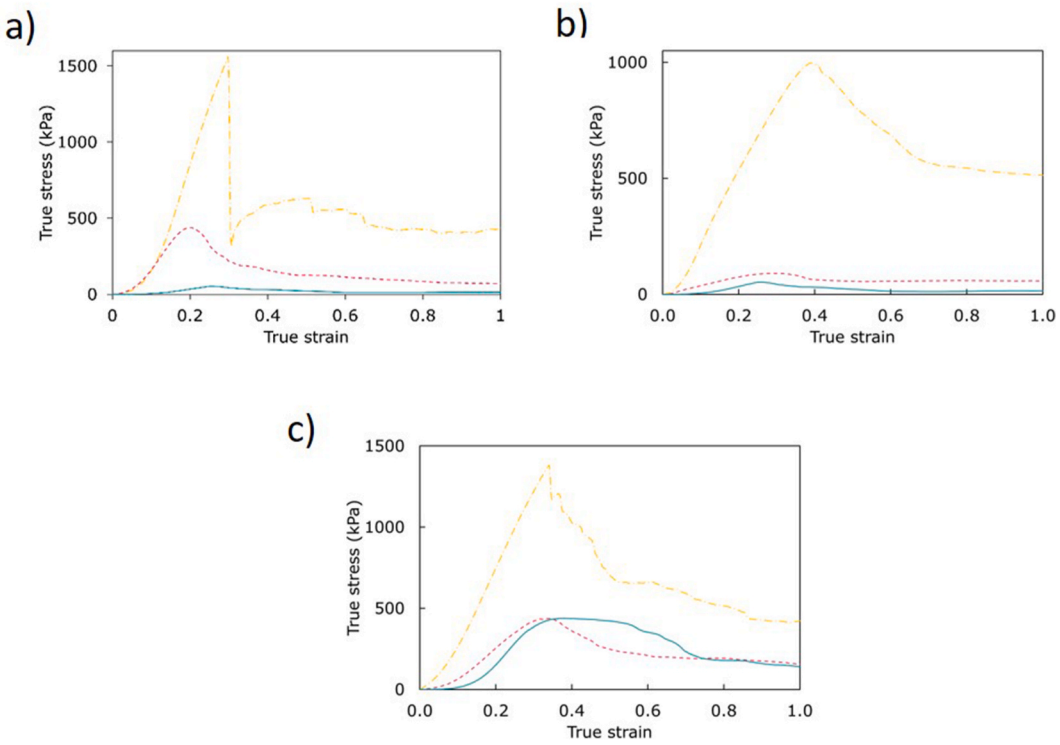

Fig. 2. Representative compression curves for each vegetable and thermal treatment. Raw vegetables (dashed-line), boiled (dotted line) and steamed vegetables (solid line). Jerusalem artichoke (a), parsnip (b) and beetroot (c). Jerusalem artichoke and parsnip were treated for 15 min. Beetroot was treated for 30 min. Notice different scale on Y axes.

degree of cell-cell separation and intercellular spaces in steamed Jerusalem artichoke could explained why they were softer compared to boiled. In beetroots the decrease in strength compared to raw has been previously related to hydrolysis of cell wall components leading to softening and increase porosity of the cell walls, rather than a decrease in intercellular adhesion (Waldron et al., 1997a), in agreement with our microstructural results.

3.3. Impact of steaming and boiling on the carbohydrate composition of Jerusalem artichoke, parsnip and beet root

Carbohydrates are major components in the studied root vegetables, with a total composition that ranges between 200 and 500 mg/g (Table 2). The general monosaccharide composition is somehow similar for the studied root vegetables, with Glc being the major carbohydrate component, mainly attributed to starch and structural β-glucans such as cellulose and mixed-linkage β-glucans (Buchanan et al., 2015). The content of hemicellulosic components such as Xyl and Man is very low for all the studied root vegetables, always below 1 % of the total sugar composition. However, there are interesting differences between the three root vegetables.

The major monosaccharide in Jerusalem artichoke was Glc (78.2 wt %) followed by Ara (7.6 wt%) and Fru (6.3 wt%). The composition of Jerusalem artichoke has been previously reported in terms on dietary fibre and total sugars (Bach et al., 2013; Cerniauskiene et al., 2018) however, no detailed monosaccharide analysis has been previously shown. The presence of Fru in Jerusalem artichoke is mainly attributed to inulin, but could also arise from the hydrolysis of saccharose (Barta and Patkai, 2007). Similar inulin contents of 70–100 mg/g have been previously reported for several Jerusalem artichoke varieties (Bach et al., 2013).

Parsnip also contains a slight amount of Fru (10 mg/g) that may be attributed to inulin, but in much lower amounts that in Jerusalem artichoke. On the other hand, raw parsnip is rich in starch (around 90 mg/g), whose content was negligible in Jerusalem artichoke. Contents of 5.6 wt% starch have been previously reported for parsnip (Siddiqui, 1989). Furthermore the content of starch in just-harvested parsnip has been shown to be as high as ca. 35 wt % and it decreased to 2.2 wt% during cold storage (Bufler and Horneburg, 2013). The main monosaccharides in parsnip are glucose (80.7 wt %, starch and β-glucans), arabinose (6.7 wt %), galacturonic acid (5.2 wt %) and galactose (4.9 wt %), in agreement with previous studies (Castro et al., 2012; Siddiqui, 1989). Parsnip shows a rich content of pectic monosaccharides such as GalA, Gal and Ara, which could be attributed to domains of homogalacturonan, galactans and arabinans (Siddiqui, 1989).

Beetroot, conversely, shows no presence of inulin and a low starch content in its composition. The main monosaccharides in beetroot were glucose (70. 8 wt%, mainly β-glucans), arabinose (9.9 wt%), galacturonic acid (12.8 wt %) and galactose (4.7 wt %). Similar monosaccharide composition in beetroot cell walls has been previously reported (Ng et al., 1998). In particular, the content of galacturonic acid in beetroot, was almost double compared to parsnip and eight times higher than in Jerusalem artichoke. This confirms that the cell walls of beetroot and parsnip are rich in pectin, whereas the pectin content in the cell wall of Jerusalem artichoke is low. Arabinan has been shown to be responsible for the interactions of pectin with cellulose in the cell wall (Fry and Miller, 1987).

The thermal treatments showed interesting effects on the chemical composition of the different root vegetables (Table 2). In general, both steaming and boiling increased the total carbohydrate content of Jerusalem artichoke and parsnip, probably due to the leaching of soluble metabolites that increased the content of the insoluble cell wall polysaccharides upon thermal processing. For beetroot, the increase in total carbohydrate content after the thermal treatments was not significant compared to raw. Indeed, the content of β-glucans (e.g. cellulose), increased for all three vegetables, especially for parsnip. In Jerusalem artichoke, the inulin content was not largely affected by the treatments. Steaming, on the other hand, seemed to increase the inulin content

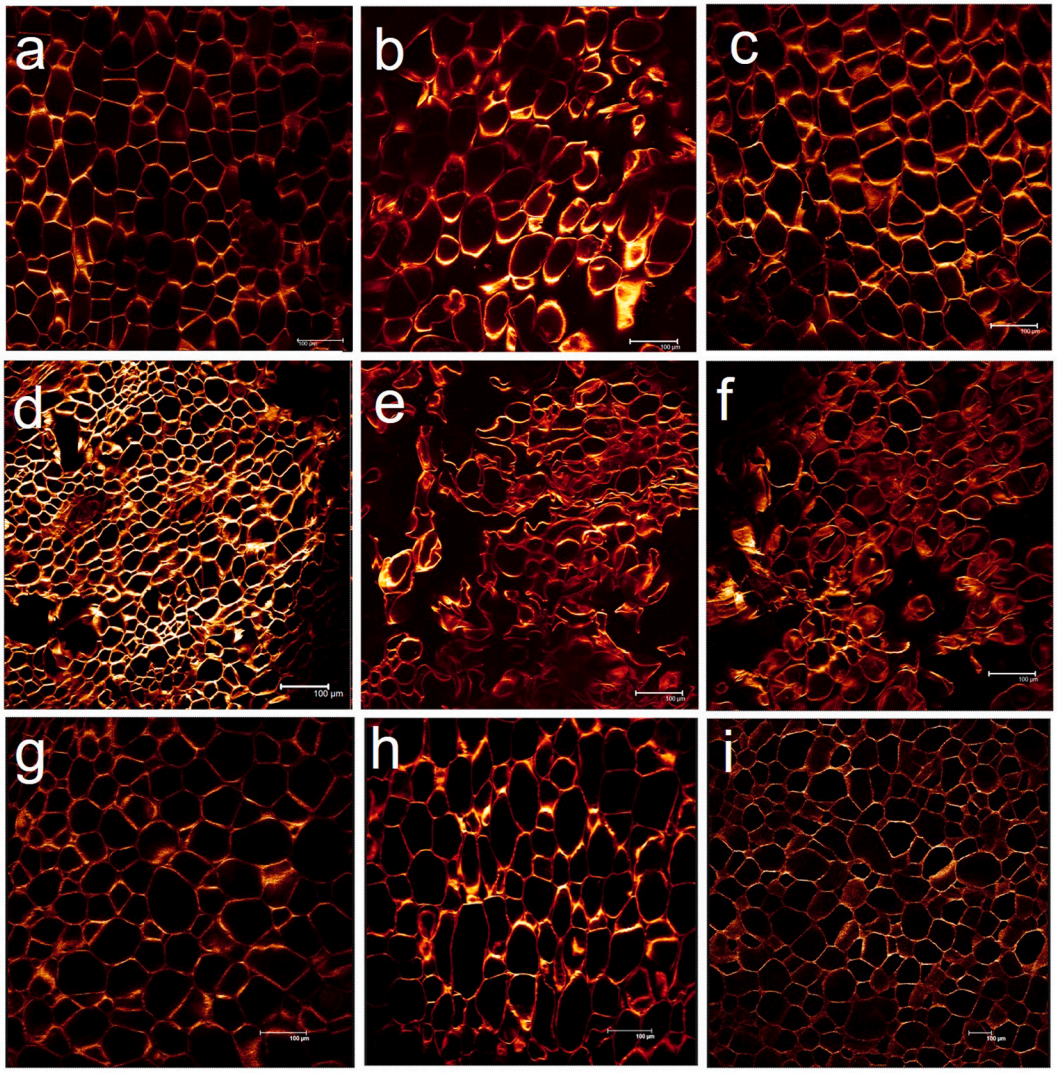

Fig. 3. Confocal Laser Scanning micrographs of the vegetables where the cellulosic cell walls are stained with Congo red 0.2% (w/w). Jerusalem artichoke (a–c), parsnip (d–f), and beetroot (g–i), raw (first column), steamed (second column), and boiled (third column). Scale bar represents 100 µm. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

specifically in parsnip. The starch content in parsnip was largely affected by type of thermal treatment, only slightly decreasing during steaming but almost disappearing during boiling. This could be attributed to the gelatinisation and leaking of the starch granules in parsnip upon boiling. This decrease in the starch content was not observed for Jerusalem artichoke and beetroot, probably due to their lower amounts and accessibility. The micrographs and chemical analysis showed that the cell walls of beetroot are more resistant to thermal degradation, this could lead to a reduced leakage of starch from cells during cooking. In the case of Jerusalem artichoke, no literature was found on starch content, the main storage carbohydrate in Jerusalem artichoke is inulin, nevertheless minor amounts of starch were found on raw and processed samples.

In general, the content of pectic monosaccharides (Ara, Gal and GalA) increased upon thermal treatments for all three root vegetables, which can be related to the tight interactions with the structural cellulose components in the cell walls. The results suggest that although soluble compounds could be lost during boiling in water, a fraction of the pectin, likely with arabinose as neutral sugar chains, remained in the cells after the boiling treatment. Considering Jerusalem artichoke, there were not significant differences in the GalA content of steamed and boiled samples, suggesting that the larger degree of cell-cell separation in steamed samples compared to boiled (Fig. 3) could be due to changes in the molecular structure of the pectin in the middle lamella, rather than loss of soluble pectin, as previously shown for other vegetables (Waldron et al., 1997b). In parsnip, the differences between steaming and boiling were more significant with regards of the relative amounts of pectic monosaccharides. Indeed, boiled parsnip showed a marked increase in the content of Ara, Gal and GalA compared to the raw and steamed vegetable. This indicates that solubilisation of sugars and leakage in the boiling water changed the sugar composition of the boiled parsnip to a larger extent than when parsnip was steamed. Finally, beetroot showed similar trends in the monosaccharide composition with a slight increase of β-glucans and pectic sugars upon steaming and cooking, albeit not as marked as in parsnip. The content of galacturonic acid in beetroot (12.8 wt %) is similar to previously reported values (Schafer et al., 2020). Interestingly, beetroot contains ferulic acid (Fissore et al., 2013), and the degree of thermal stability of cell-cell adhesion in *Beta vulgaris* tissues is related to the degree of FA-cross linking between pectic polysaccharides (Waldron et al., 1997a). The higher content of ferulic compounds and distinct pectin molecular structure in beetroot could explain the higher integrity of the tissues after thermal treatments compared to parsnip (Fissore et al., 2013; Waldron et al., 1997a).

Table 2
Chemical composition (in mg/g) of Jerusalem artichoke, parsnip, and beetroot. Steamed and boiled samples were treated for 15 min in the case of Jerusalem artichoke and parsnip, and for 30 min in the case of beetroot. Fucose (Fuc) and 4-*O*-methyl glucuronic acid (meGlcA) were not detected. Standard error is presented between brackets. Statistically significant differences between treatments (Tukey's test, confidence interval 95 %) are represented by different letters.

	Jerusalem artichoke			Parsnip			Beetroot		
	Raw	Steamed	Boiled	Raw	Steamed	Boiled	Raw	Steamed	Boiled
Total carbohydrate[a]	177.0 (32.8)[a]	201.8 (21.4)[a,b]	260.9 (29.7)[b]	292.7 (25.9)[a]	518.5 (49.6)[b]	425.2 (36.6)[b]	379.2 (47.1)[a]	428.9 (43.8)[a]	485.1 (113.3)[a]
Ara[b]	8.9 (1.2)[a]	13.3 (1.7)[b]	23.4 (0.2)[c]	17.1 (1.5)[a]	34.2 (4.0)[b]	42.2 (2.4)[c]	34.0 (4.5)[a]	37.2 (6.3)[a]	46.1 (18.8)[a]
Rha[c]	3.8 (0.8)[a]	2.2 (0.7)[a]	2.7 (0.6)[a]	3.2 (0.8)[a,b]	4.6 (1.0)[b]	2.5 (0.5)[a]	1.3 (0.2)[a]	3.0 (0.4)[b]	1.5 (0.2)[a]
Gal[b]	3.6 (0.2)[a]	8.4 (2.4)[b]	8.9 (0.4)[b]	11.2 (1.0)[a]	18.7 (4.8)[b]	29.0 (1.5)[c]	18.3 (4.0)[a]	20.2 (3.1)[a]	23.8 (4.4)[a]
Glc[b]	96.5 (17.5)[a]	127.8 (15.5)[a,b]	145.4 (15.9)[b]	229.3 (10.2)[a]	381.3 (27.4)[c]	285.9 (19.7)[b]	293.3 (38.7)[a]	315.0 (34.8)[a]	373.2 (96.5)[a]
Xyl[b]	0.8 (0.1)[a]	1.3 (0.6)[a]	2.0 (0.6)[a]	3.0 (1.0)[a]	3.6 (2.2)[a,b]	6.9 (0.3)[b]	n.d.	n.d.	3.4 (1.2)
Man[b]	0.6 (0.0)[a]	0.8 (0.2)[a]	1.4 (0.1)[a]	2.3 (0.2)[a]	3.9 (0.6)[b]	7.2 (0.1)[c]	2.3 (0.1)[a]	3.0 (0.3)[a]	4.3 (1.4)[a]
GalA[c]	3.6 (0.7)[a]	6.0 (0.9)[a]	4.1 (0.9)[a]	18.4 (5.4)[a]	31.8 (5.1)[a,b]	41.8 (7.6)[b]	29.6 (5.6)[a]	51.2 (5.0)[b]	32.6 (1.8)[a]
GlcA[c]	n.d.	n.d.	n.d.	0.1 (0.1)[a]	0.4 (0.1)[a,b]	0.8 (0.3)[b]	1.7 (0.2)[a]	2.4 (0.2)[b]	1.8 (0.0)[a]
Fru[b]	63.1 (13.0)[a,b]	44.2 (0.0)[a]	75.7 (11.6)[b]	11.2 (3.4)[a]	44.5 (4.9)[b]	11.5 (3.3)[a]	n.d.	n.d.	n.d.
Starch[d]	2.9 (0.8)[a]	4.5 (0.3)[a]	3.4 (0.4)[a]	90.9 (27.7)[b]	63.9 (3.4)[b]	16.6 (1.4)[a]	18.2 (1.1)[a]	14.9 (3.0)[a]	19.5 (6.1)[a]
β-glucans[e]	93.6	123.3	142.0	138.3	317.4	269.3	275.2	300.1	353.6
Inulin[f]	63.1 (13.0)[a,b]	44.2 (0.0)[a]	75.7 (11.6)[b]	11.2 (3.4)[a]	44.5 (4.9)[b]	11.5 (3.3)[a]	n.d.	n.d.	n.d.
Other polysaccharides[g]	17.5 (2.3)[a]	29.7 (5.9)[b]	39.8 (2.2)[c]	52.2 (9.1)[a]	92.6 (16.7)[b]	127.8 (12.1)[c]	85.8 (14.3)[a]	113.9 (14.9)[a]	111.9 (27.6)[a]
Soluble proteins [h]	12.0 (4.4)[b]	3.8 (1.1)[a]	5.8 (2.7)[b]	5.5 (2.0)[a]	2.7 (0.4)[a]	3.4 (0.8)[a]	4.1 (0.7)[a]	8.2 (4.7)[a]	7.2 (1.8)[a]
Total phenolic content[i]	2.7 (1.0)[b]	1.6 (0.3)[a,b]	1.1 (0.1)[a]	3.1 (1.2)[a]	1.7 (4.0)[a]	3.7 (2.4)[a]	4.1 (0.3)[a]	6.4 (1.9)[a]	8.3 (4.5)[a]

[a] Total carbohydrate content calculated as the sum of the neutral sugars (after sulfuric hydrolysis) and uronic acids (after TFA hydrolysis).
[b] Neutral sugars quantified after sulfuric hydrolysis and HPAEC-PAD analysis.
[c] Uronic acids quantified after TFA hydrolysis and HPAEC-PAD analysis.
[d] Starch content quantified by enzymatic hydrolysis (total starch kit).
[e] β-glucan content (including cellulose and mixed-linkage b-glucans) quantified by subtracting starch content from the total Glc content.
[f] Inulin content quantified from the Fru content (after sulfurig hydrolysis).
[g] Other polysaccharides (including hemicelluloses and pectins) quantified from Ara + Gal + Xyl + Man + GalA + GlcA.
[h] Soluble protein quantified using the Bradford colorimetric method.
[i] Total phenolic content (TPC) quantified using the Folin – Ciocalteu method.

In addition to carbohydrate changes, thermal treatment could also affect the content of soluble proteins. Root vegetables have distinct protein compositions, Jerusalem artichoke has the higher amount (2 % wt.) of total proteins including a rich variety of essential amino acids, compared to parsnip (1.2 % wt.) and beetroot (0.7 % wt.) (Butnariua and Butu, 2014; Cieslik et al., 2011). The chemical analysis showed that soluble protein contents were 12 mg/g in Jerusalem artichoke, 5.5 mg/g in parsnip and 4.1 mg/g in beetroot. The soluble protein content was similar in raw and thermally treated parsnip and beetroot. For parsnip the values were 5.53 mg/g in raw, 2.73 mg/g in steamed and 3.37 mg/in boiled samples. For beetroot, the values were 4.12 mg/g in raw, 8.25 mg/g in steamed and 7.17 mg/g in cooked samples. These results indicate that solubilisation of proteins during the thermal treatments of parsnip and beetroot were minimum. In contrast, steaming and boiling decreased the content of soluble protein of Jerusalem artichoke, both from 12.01 mg/g in raw to 5.84 mg/g in boiled and 3.75 mg/g in steamed samples. The different ways that the thermal treatments affected the soluble protein content of the vegetables could be related to the location and linkage of protein to the carbohydrates in the cell wall.

The total phenolic content (TPC) is related to the antioxidant activity of the root vegetables with potential health benefits, the TPC was determined to be 2.7 mg GAE/g for Jerusalem artichoke, similar values have been reported for Jerusalem artichoke flours (Diaz et al., 2019). For parsnip the TPC was 3.1 mg GAE/g and 4.1 mg GAE/g for beetroot. For beetroot TPC contents of 1.4–3.7 mg GAE/g have been reported for different red beetroot cultivars (Barta et al., 2020; Slosar et al., 2020). The TPC of the thermally treated samples was similar to the raw materials for all three vegetable, indicating that neither steaming or boiling led to significant losses in total phenolics.

3.4. Impact of thermal treatments on the sensory profile of Jerusalem artichoke, parsnip and beetroot

The impact of steaming and boiling on the sensory profile of the three root vegetables is reported in Fig. 4. Discussion of the results will firstly approach the impact of these thermal treatments on the aroma (O) and in-mouth flavour (F) attributes (Fig. 4 a, c, e), followed by their impact on the texture and mouthfeel properties (Fig. 4 b, d, f). From a flavour perspective, and as a general overview, steaming seemed to have a better preservation of the aroma and flavour properties for Jerusalem artichoke and parsnip. For Jerusalem artichoke, the intensity of "Jerusalem artichoke O″, "mushroom O″ and "earthy F″ was found to be significantly higher on steamed samples than on boiled samples. No differences in sweetness were observed between samples, with the exception of Jerusalem artichoke which was significantly sweeter when steamed compared to boiled. This could be counterintuitive as the inulin content was higher in boiled samples however, sweetness of the samples will depend not only on inulin content but inulin molecular weight, which could be affected by the thermal treatment (Gonzalez-Tomas et al., 2009). In parsnip, the perception of "cooked potato F″ was also significantly higher on steamed samples, whereas for beetroot no significant differences were found for any of the evaluated Odour and Flavour attributes, independently of the type of thermal treatment. The impact of some conventional cooking techniques on the sensory profile of different root vegetables have been previously explored (Bach et al., 2013, 2015b; Nunn et al., 2006) however, most of these works have been mainly driven by a focus of reaching a better understanding on the relationship between the processability and consumer's acceptability.

The different thermal treatments also had an influence on the mouthfeel properties of the Jerusalem artichoke and parsnip. As it occurred with the aroma and flavour, no significant differences were detected between the mouthfeel attributes of cooked and steamed

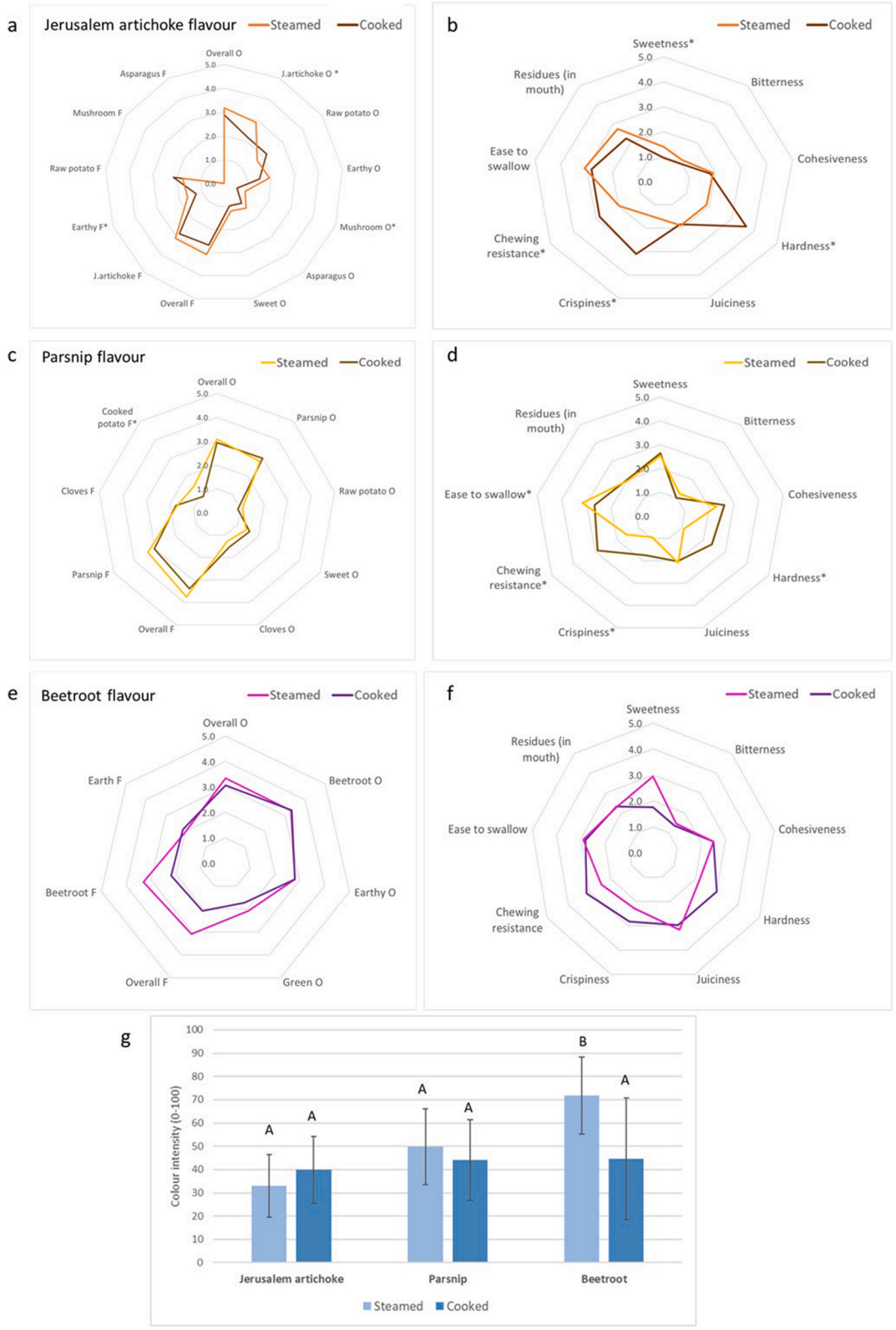

Fig. 4. Spider plots illustrating the impact of different cooking techniques (steamed and boiled) on the flavour and mouthfeel attributes of Jerusalem artichoke (a–b), parsnip (c–d) and beetroot (e–f). Bar charts illustrating the impact of thermal treatments on the colour of the samples (g). Significant attributes ($p < 0.005$) are marked with an *. Different letters are obtained from Turkey's post-hoc HSD test and represent significant differences within the same root vegetable. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

beetroot. Regarding Jerusalem artichoke and parsnip, boiled samples were described with a significantly higher chewing resistance, crispiness and hardness than steamed samples, the different effect of the thermal treatments is especially significant for Jerusalem artichoke as displayed on the spider plots of Fig. 4b. A similar trend was also observed for these attributes in beetroot however, the differences in intensity were not significant.

In addition to mouthfeel the panellists were also asked to evaluate the ease-to-swallow of the different vegetables. Food hardness has been shown to influence the particle size of the formed bolus during swallowing (Chen et al., 2013). The harder the food product, the smaller the particle size, and the smaller particle size consequently the easier to swallow (Tobin et al., 2017). In the present study, even though boiled Jerusalem artichoke and parsnip samples were perceived as harder than steamed samples, the ease-to-swallow was only significant for parsnip, showing that steamed 'softer' parsnip was easier to swallow that boiled 'harder' parsnip. This indicates that not only the hardness, but the chemical composition of the vegetables influences the formation of an ease-to-swallow bolus (Tobin et al., 2020). For instance a higher content of starch, which is traditionally used as a thickener to aid swallowability (Martinez et al., 2019), could help form an easier-to-swallow bolus when parsnip is steamed compared to boiled.

For Jerusalem artichoke the results of the sensory profiling agreed well with the results of mechanical testing (Fig. 2 and Table 1), in which boiled samples were harder i.e higher maximum true stress, and they were perceived as crispier and harder compared to steamed samples. Bach et al. (2013) also found a positive correlation between instrumental hardness and crispiness of boiled Jerusalem artichoke. For parsnip, the mechanical testing showed not significant differences in hardness compared to steamed samples, although the trend showed that boiled samples were harder, and the panellist described boiled parsnips samples as significantly harder than steamed samples.

Other attributes such as juiciness, cohesiveness of the sample and residues in mouth were similar independently of the thermal treatment for any of the evaluated root vegetables.

The impact of the thermal treatments on the colour of the samples was also assessed (Fig. 4g). No significant differences in colour were observed for steamed and boiled Jerusalem artichoke and parsnip. Steamed beetroot samples showed a significantly greater colour intensity than boiled beetroot samples. This can be related to the polarity of anthocyanins, extracted and solubilised when beetroot is boiled in water (Guldiken et al., 2016). Bach et al. (2015b) also investigated the impact of processing conditions on beetroot showing that preparation method (boiled vs pan fried) influenced the colour.

4. Conclusions

For parsnip, boiling in water was the preferred cooking method to optimise the carbohydrate profile because i) it enhanced the content of insoluble cell wall polysaccharides i.e dietary fibre, particularly β-glucans (e.g cellulose) and pectic components; and ii) reduced starch content, which was attributed to gelatinisation and leaching of the starch in the cooking water. A high consumption of dietary fibre is related to a reduce risk of suffering cardiovascular diseases and type 2 diabetes, whilst high intake of non-resistant starch could have the opposite effect. Furthermore, boiling in water retained texture to a larger extent than steaming, this was measured by mechanical and sensory evaluations and was related to a larger cell-cell separation and loss of cell integrity, due to a more homogeneous heat penetration in the steaming process. In the case of Jerusalem artichoke, both steaming and boiling showed a positive effect on the carbohydrate composition since they increased insoluble cell wall polysaccharides and retained inulin, which has been attributed probiotic effects. Boiling was preferred from a textural point of view, owing to similar microstructural effects than parsnip. Beetroot behaved differently to parsnip and Jerusalem artichoke, the softening effect observed after cooking was not related to changes in the total carbohydrate content, and no significant differences were observed in the microstructure or texture profile between steamed and boiled beetroot. It has been previously shown that the presence of cross-link pectic polymers in beetroot cell walls are related to a strong cell-cell adhesion in this vegetable.

We may conclude that the thermal process required to optimise dietary fibre composition and sensory properties depends on the type of root vegetable. We showed that this is due to their distinct carbohydrate composition, which in turn determines cell wall integrity and solubilisation of cell components during thermal treatments. The insights of the present study contribute to an increase utilisation of root vegetables in processed foods.

Author contributions

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Funding

The study was funded by Jordbruksverket 2018-2132.

Declaration of conflict of interest

The authors have declared that no competing interests exist.

Acknowledgements

The authors would like to thank Marie Hildenbrand, Ana Miljkovic and Lisa-Maria Oberrauter for assistance with the sensory evaluations.

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