Food Hydrocolloids 170 (2026) 111666

Contents lists available at ScienceDirect

Food Hydrocolloids

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

Isolation and characterisation of cell wall polysaccharides from taewa (Māori potatoes; *Solanum tuberosum* L.)

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ARTICLE INFO

Keywords:
Taewa (Māori potato)
Solanum tuberosum
Cell wall polysaccharides
Sequential extraction
Methylation analysis

ABSTRACT

Taewa are varieties of potato introduced to New Zealand by European explorers in the late 18th century. The aim of this research was to extract and characterise cell wall polysaccharides from three varieties of taewa (Huakaroro, Tutaekuri, Moemoe) and compare their composition and structure with a modern potato variety (Agria). The yield of cell walls ranged from 22.8 mg to 42 mg per gram fresh weight potato and was higher for Tutaekuri than other taewa varieties and Agria. Cell walls of Tutaekuri also contained the highest amounts of galactose and the highest level of pectic polysaccharides compared with other varieties. Sequential fractionation of the cell walls gave two pectic polysaccharides fractions (imidazole + Na_2CO_3 and residue wash), and a hemicellulose fraction (4 M KOH). The residue wash fractions contained higher proportions of rhamnogalacturonan-I than the imidazole + Na_2CO_3 fraction. Constituent sugar and glycosyl linkage compositions indicated that there were differences in the detailed structural features of the pectic polysaccharides among the taewa varieties and Agria. The imidazole + Na_2CO_3 fraction from Moemoe had a lower rhamnogalacturonan-I/homogalacturonan ratio and a lower side-chain/rhamnose ratio than the other varieties. Glycosyl linkage analysis indicated that Moemoe had shorter galactan side-chains than the other varieties. Constituent sugar and glycosyl linkage analysis of the 4 M KOH fractions gave linkages that were typical of solanaceous xyloglucans. This knowledge provides added value to taewa suggesting that as well as their important role as a taonga species for Māori, they could contribute to human health outcomes.

1. Introduction

Taewa (Māori potatoes) are a collection of potato (*Solanum tuberosum* L.) varieties that were introduced to New Zealand by European explorers in the late 18th century and have been cultivated by Māori for more than 200 years (McFarlane, 2007; Wharemate, 2015). They have many features of a *S. tuberosum* subsp. *andigena* type that was introduced into Europe in the sixteenth century, including having deep set eyes and often a knobbly irregular shape. Taewa are considered a taonga (treasure) because of their historical and cultural significance (Harris, 2001). While they have been largely superseded by high yielding commercial varieties, taewa are still grown by the indigenous Māori community in Aotearoa New Zealand as a niche, heirloom crop. Taewa varieties show considerable variation in appearance from Huakaroro with cream-coloured skin and flesh, through Moemoe with multi-coloured skin and cream-coloured patterned flesh, to Tutaekuri with dark purple skin and flesh (Fig. 1). The physicochemical and functional properties of flour prepared from taewa show significant variations and

This article is part of a special issue entitled: 17th IHC published in Food Hydrocolloids.

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https://doi.org/10.1016/j.foodhyd.2025.111666
Received 2 March 2025; Received in revised form 20 April 2025; Accepted 16 June 2025
Available online 17 June 2025

are different from modern potato varieties (Zhu & He, 2020). There is considerable variation in starch granule morphology and differences in thermal, pasting, textural, and retrogradation properties, both among taewa varieties and compared to modern varieties (Singh, McCarthy, & Singh, 2006; Zhu & Hao, 2019).

Taewa generally have higher dietary fibre contents than modern commercial varieties of potato (Wharemate, 2015; Zhu & He, 2020) and, presumably, higher contents of cell wall material which are a major source of dietary fibre. Potato tubers consist of parenchyma tissue with cell walls composed primarily of cellulose, xyloglucan and a large amount (>50 %) of pectic polysaccharides (Klaassen & Trindade, 2020). The pectic polysaccharides contain high proportions of galactose, present mostly as neutral (1→4)-β-D-linked galactan side-chains attached to rhamnose moieties of rhamnogalacturonan-I (RG-I; Ramaswamy Kabel, Schols & Gruppen, 2013; Frost et al., 2016; Klaassen & Trindade, 2020), but is also present as side-chain residues of hemicelluloses, particularly xyloglucan (Ring & Selvendran, 1981; Vincken et al., 1996). Frost et al. (2016) showed that different potato lines yield different amounts of cell wall material, composed mostly of glucose, galactose and uronic acid residues. They found that certain potato lines, with significantly lower levels of rapidly digestible starch, had RG-I with galactan-rich side-chains strongly attached to the cell wall that resisted solubilisation during cooking.

The structure of different dietary fibre carbohydrates has an impact on their use by the human gut microbiota and this can in turn impact health. Earlier work by our research group showed that the short-chain fatty acid propionate, produced by bacterial fermentation of non-digestible carbohydrates in the colon, was associated with longer uninterrupted sleep in infants (Heath et al., 2020). Studies on the extent and preferential order in which plant cell wall derived polysaccharides were consumed by co-cultures of bacterial species typical of weaning infants showed differential production of short-chain fatty acids (Liu et al., 2020). In particular, the utilisation of galactan resulted in increased propionate production which is of particular interest because of its role in hepatic gluconeogenesis and satiety. Thus, the aims of this study were, (1) to determine if varieties of taewa contain greater amounts of cell wall material than commercial European varieties and, (2) to see if a higher cell wall content also results in greater amounts of pectic galactan. The comparative extraction-mediated solubility of the RG-I was examined by sequential fractionation of the cell wall polysaccharides using imidazole as a Ca^{2+} chelator, followed by increasing concentrations of alkali. The constituent sugar compositions, molecular weight profiles and polysaccharide glycosyl linkage structure of the non-cellulosic fractions was determined. The results are discussed in relation to the potential health benefits of taewa.

2. Materials and methods

2.1. Materials

Three varieties of taewa, Huakaroro, Moemoe and Tutaekuri (Fig. 1), were grown in Palmerston North, New Zealand by Tāhuri Whenua (National Māori Vegetable Growers Collective). A modern commercial potato variety (Agria) was grown in Lower Hutt, New Zealand for comparison. Taewa were grown in silty-loam soil and Agria was grown in clay-loam soil; the plants were fertilised following standard agronomic practices. Freshly harvested tubers (harvested April 2022) were stored cool (~5 °C) in the dark to ensure minimal moisture loss, no greening (light response) and no change in sugars.

The tubers were washed to remove soil, drained and left to dry. Half of each variety was peeled and the skins discarded, diced (ca. 2 cm^3), blanched in a microwave (1100 W, 2 min, twice) and stored at −18 °C. The remaining half was diced and microwaved without peeling and stored at −18 °C.

2.2. Isolation cell wall material

Isolation of cell walls was based on the methods of Jardine et al. (2002), but with modifications (Fig. 2). Frozen tubers (unpeeled and peeled) were ground in a mortar and pestle with liquid nitrogen. The powdered material (50 g) was suspended in ethanol (100 mL, 0 °C) and homogenized (15,000 rpm, 5 × 20 s bursts with 1 min between bursts) on ice using a blender (Ultra Turrax, Staufen, Germany). The samples were centrifuged (3234 *g*, 10 min, 4 °C), and the pellets washed four times with aqueous ethanol (100 mL, 70 % v/v, 0 °C), dried in a vacuum oven overnight at 40 °C, weighed and the dried alcohol insoluble residues (AIRs) stored in a desiccator.

To remove starch, the AIRs (~0.5 g) were suspended in 25 mM NaOAc buffer (pH 6.5; 40 mL, containing 1 mM $CaCl_2$, and 0.05 % NaN_3) and incubated with thermostable α-amylase (300 U, *Bacillus subtilis*, Megazyme Ltd.) and amyloglucosidase (650 U, *Aspergillus niger*, Megazyme) at 37 °C, overnight with shaking. The samples were centrifuged (3234 *g*, 20 min, 15 °C) and the insoluble pellets were washed twice with deionised water (10 mL). The enzyme treatment with α-amylase and amyloglucosidase was repeated twice, after which the cell wall materials tested negative for starch with I_2/KI (1 % w/w) staining. However, constituent sugar analysis showed high proportions of glucose (>60 mol %) and therefore the cell wall preparations were enzyme treated a further two times with α-amylase, amyloglucosidase, but with the addition of pullulanase (100 U, *Bacillus licheniformis*, Megazyme). The final pellets, that again tested negative for starch, were suspended in deionised water (10 mL) and freeze-dried to give isolated cell walls.

2.3. Sequential fractionation of cell wall polysaccharides

Due to a limited availability of de-starched cell wall material from unpeeled and peeled tubers, and the similarity in their sugar compositions, the cell walls from each variety were combined for fractionation and subsequent analysis. The cell walls from each variety were sequentially extracted using a calcium chelator, followed by successively stronger alkali solutions (Fig. 2). Freeze-dried cell walls were suspended in 2 M imidazole (pH 7.5) and stirred for 6 h at 20 °C and centrifuged (3234 *g*, 60 min 4 °C). The pellets were resuspended in imidazole and stirred overnight at 20 °C. Following centrifugation, the pellets were extracted at room temperature twice each with 50 mM Na_2CO_3 containing 20 mM $NaBH_4$ (each 16 h), 1 M KOH containing 20 mM $NaBH_4$ (first extraction 3 h; second extraction overnight), 4 M KOH containing 20 mM $NaBH_4$ (first extraction 3 h; second extraction overnight), then deionised water (each 1 h). Each of the fractions was neutralised as required, filtered through borosilicate microfiber filters

Fig. 1. Appearance of taewa tubers from A) Huakaroro, B) Moemoe and C) Tutaekuri.

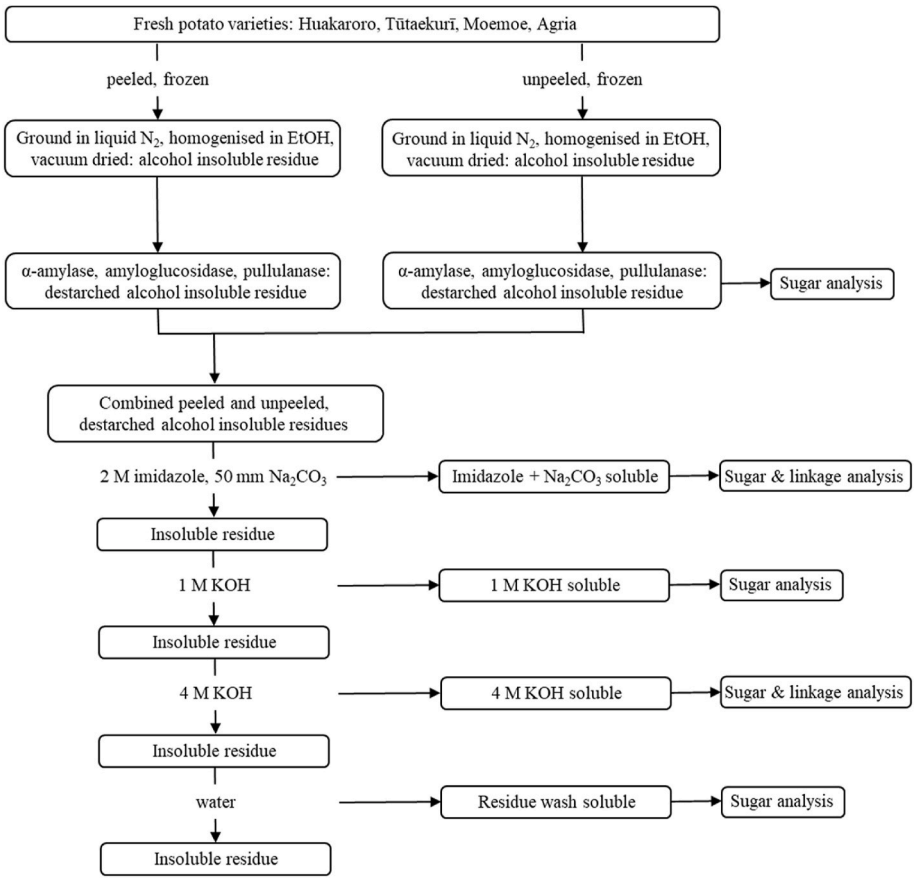

Fig. 2. Preparation of de-starched cell walls from peeled and unpeeled potatoes and sequential fractionation of isolated cell wall material.

(GD120, 0.9 μm, Advantec), dialysed exhaustively against distilled water (MWCO 12–14 kDa) and freeze-dried.

For constituent sugar and glycosyl linkage analysis, the imidazole and Na_2CO_3 fractions were combined to give a pectic polysaccharide fraction.

2.4. Constituent sugar analysis

Constituent sugar compositions were determined by high-performance anion-exchange chromatography (HPAEC; Dionex ICS 5000$^+$, Thermo Fisher Scientific, Sunnyvale, CA, USA) as described by Kidgell et al. (2021), but with modifications. Samples (0.25 mg in duplicate) were hydrolysed with methanolic HCl (3 N, 80 °C, 18 h) followed by aqueous TFA (2.5 M, 120 °C, 1 h). The resulting hydrolysates were dried, diluted to 50 μg/mL and separated on a CarboPac PA-1 (4 × 250 mm) column equilibrated in 20 mM sodium hydroxide (NaOH) and eluted with simultaneous gradients of NaOH and NaOAc (1 mL/min, 35 °C). The sugars were detected by pulsed amperometric detection (PAD), identified from their elution times relative to standard sugar mixes (hydrolysed at the same time as the samples) and quantified using calibration curves of individual sugars.

2.5. Glycosyl linkage analysis

Glycosyl linkage compositions were determined by methylation analysis. Where constituent sugar analysis showed the presence of more than 5 % uronic acid, prior to glycosyl linkage analysis, uronic acid residues were reduced to their dideuterio-labelled neutral sugars using a modification of Sims and Bacic (1995) as described by Kidgell et al. (2024). Samples (0.5 mg, in duplicate) were methylated with the method of Ciucanu and Kerek (1984). The methylated polysaccharides were then hydrolysed (2.5 M TFA, 1 h, 120 °C), reduced (1 M $NaBD_4$, 18 h, 25 °C) and acetylated. The partially methylated alditol acetate derivatives produced were analysed on an Agilent 8890 GC system coupled with a 5977B mass selective detector. Samples were separated by GC on a BPX90 fused silica capillary column (SGE Analytical Science, Australia; 30 m × 0.25 mm i.d., 0.25 μm film thickness) with the GC oven programmed from 80 °C (1 min hold) to 130 °C at a rate of 50 °C/min, then to 230 °C at a rate of 3 °C/min. Additional analyses were completed on an Agilent HP5MS capillary column (30 m × 0.25 mm i.d., 0.25 μm film thickness) as some partially methylated alditol acetate sugar derivatives were observed to co-elute on the BPX90 column. The separated derivatives were identified based on peak retention times and electron impact mass spectra compared with partially methylated alditol acetate standards made by the method of Doares et al. (1991).

2.6. High performance size-exclusion chromatography

Relative molecular weight distributions were determined using size-exclusion chromatography. The imidazole + Na_2CO_3 and 4 M KOH fractions were dissolved in 0.1 M $NaNO_3$ (1 mg/mL) and centrifuged (14,000×*g*, 10 min) to clarify. The soluble material (100 μL) was injected and eluted with 0.1 M $NaNO_3$ (0.5 mL/min, 60 °C) from three columns (TSK-Gel $G5000_{PWXL}$, $G4000_{PWXL}$ and $G3000_{PWXL}$, 300 × 7.8 mm, Tosoh Corp., Tokyo, Japan) connected in series. The eluted material was detected using a variable wavelength detector (280 nm) and a refractive index monitor. The system was calibrated with a series of pullulan molecular weight standards (1–1220 kDa; Agilent Technologies, Inc., Santa Clara, CA).

3. Results and discussion

3.1. Characterisation of cell wall preparations

The yield of AIR (% on a fresh weight basis) from taewa varieties ranged from 28 to 36 %, compared with 23 % for Agria. This is consistent with the higher dry matter content observed for taewa compared to the modern variety, Nadine (Wharemate, 2016). Following enzyme treatment, the mass of the AIRs decreased by about 90 % and the de-starched preparations tested negative for starch upon iodine staining. The yields of cell walls ranged from 22.8 mg to 42 mg per gram fresh weight, with the three taewa varieties generally showing higher yields than Agria (Table 1). In particular, Tutaekuri not only gave much higher yields of cell walls than Agria, but also higher yields compared with Moemoe and Huakaroro. Similarly, Wharemate (2016) showed that the dietary fibre content (comprising mostly plant cell walls) of Tutaekuri was highest compared with other varieties of taewa and Nadine. Whilst potato skins have higher dietary fibre contents than the flesh, whole unpeeled tubers have similar dietary fibre contents to the flesh (Wharemate, 2016). Therefore, unsurprisingly, the yield of cell walls was generally similar for both unpeeled and peeled tubers, with only Huakaroro giving a higher yield of cell walls for unpeeled than peeled tubers.

Constituent sugar analyses of the non-cellulosic polysaccharides, expressed per gram fresh weight of tuber, showed that the cell walls contained mostly glucose, galactose and galacturonic acid, accounting for 86–90 % of the sugars detected (Table 2). Despite extensive enzyme treatment to remove starch, the high levels of glucose indicated that residual starch was present in the preparations, and subsequent fractionation and analysis suggested that starch was the major component of the 1 M KOH fraction (Fig. 3).

GalA, Rha, Gal and Ara together comprised 42.8–57.4 % of the sugars detected, suggesting that pectic polysaccharides accounted for a high proportion of the polysaccharides present. Unpeeled Moemoe and Huakaroro contained higher amounts of pectic polysaccharide sugars compared with peeled (6522 vs. 4576 and 6963 vs. 5114 μg/g fresh weight (FW) for Moemoe and Huakaroro, respectively). However, Tutaekuri (unpeeled and peeled) contained the highest amount of pectic polysaccharide sugars, 7287 and 7505 μg/g FW, respectively. Pectic polysaccharide sugars were lower in unpeeled Agria, compared with unpeeled taewa varieties, but pectic polysaccharides in peeled Agria were similar to peeled Moemoe and Huakaroro. Due to limited availability of cell wall material and the similarity in sugar composition between unpeeled and peeled tubers, for subsequent fractionation and analysis the cell walls from unpeeled and peeled tubers were combined.

3.2. Sequential extraction and constituent sugar analysis of cell wall polysaccharides

Sequential extraction of the combined unpeeled and peeled cell walls gave five fractions (Table S1). The imidazole + Na_2CO_3 (pectic) and 1 M KOH fractions accounted for 21.3–23.9 and 40.4–46.4 % of the recovered cell walls, respectively. The 4 M KOH (4.6–6.0 %) and residue wash (5.5–9.7 %) fractions accounted for a low proportion of the cell walls; the final insoluble residue, assumed to be mostly cellulose, accounted for 21–26 % of the recovered cell walls.

Table 1
Yields of destarched cell walls isolated from fresh, blanched taewa and Agria potatoes.

	Yield (mg/g fresh weight potato)	
Variety	**Unpeeled**	**Peeled**
Moemoe	33.1	31.3
Huakaroro	32.1	22.8
Tutaekuri	42.0	40.9
Agria	24.4	25.8

Table 2
Non-cellulosic constituent sugar compositions of cell wall material isolated from taewa and Agria potatoes. Data are means of duplicate analyses.

	Constituent sugars (μg/g fresh weight potato)							
Variety	Fuc	Rha	Ara	Xyl	Gal	Glc	Man	GalA
Unpeeled								
Moemoe	45	349	672	396	3538	6759	418	1963
Huakaroro	38	293	657	428	3911	4653	320	2102
Tutaekuri	46	402	888	452	3965	8661	532	2032
Agria	24	216	417	246	2888	3129	210	1345
Peeled								
Moemoe	38	240	429	248	2559	5370	303	1347
Huakaroro	23	203	373	210	3105	4372	264	1433
Tutaekuri	50	353	682	331	4429	9130	527	2040
Agria	35	233	406	238	3293	6172	286	1270

Fuc = fucose, Rha = rhamnose, Ara = arabinose, Xyl = xylose, Gal = galactose, Glc = glucose, Man = mannose, GalA = galacturonic acid.

Constituent sugar analysis of the imidazole + Na_2CO_3 and residue wash fractions contained high proportions of Gal and GalA, together with Rha and Ara, consistent with the presence of mostly pectic polysaccharides (Fig. 3A and C). The residue wash fraction contained particularly high proportions of RG-I side-chain residues (Gal + Ara = 66.7–73.5 mol%). Whilst most RG-I is extracted with a chelator and Na_2CO_3, a portion of RG-I that was rich in galactan and arabinan side-chains was the major component of the residue wash fraction of raw and cooked taro (*Colocasia esculenta*; Quach, Melton, Harris, Burdon, & Smith, 2001) and buttercup squash (*Cucurbita maxima*; Ratnayake et al., 1999; Ratnayake et al., 2003). The 1 M KOH fraction contained high proportions of glucose (Fig. 3B) and subsequent glycosyl linkage analysis (data not shown) showed mostly 4-linked glucopyranosyl residues consistent with this fraction being mostly residual starch that was not removed by the extensive enzyme treatment. The 4 M KOH fraction contained Glc, Xyl, Gal and Ara, consistent with the presence of arabinosylated xyloglucan typical of solanaceous species (Fig. 2D; Ring & Selvendran, 1981; Vincken et al., 1996).

The ratios of constituent sugars in the imidazole + Na_2CO_3 and residue wash fractions were used in order to examine the structure of the extracted pectins (Table 3; Alba et al., 2015). Both fractions contained high proportions of RG-I, with the imidazole + Na_2CO_3 fractions containing about two times as much RG-I as HG, while the proportion of RG-I in the residue wash fractions was considerably higher. The molar ratio of (Ara + Gal)/Rha, indicative of the degree of branching of RG-I segments, was higher in the residue wash fractions suggesting a higher degree of branching. Tutaekuri showed the highest proportion of RG-I in the imidazole + Na_2CO_3 fraction but the lowest proportion in the residue wash fraction. Moemoe showed the lowest proportion of both RG-I and (Ara + Gal)/Rha in the imidazole + Na_2CO_3 fractions when compared to the other varieties.

3.3. Glycosyl linkage analysis of cell wall polysaccharides

Glycosyl linkage analysis of the carboxyl reduced imidazole + Na_2CO_3 fractions showed partially methylated alditol acetate derivatives that corresponded to linkages typical of homogalacturonan (HG) and rhamnogalacturonan-I (RG-I) backbones with neutral pectic side-chains. The linkages were grouped into different pectic polysaccharide classes based on knowledge of typical plant cell wall polysaccharide structures (Table 4; Pettolino et al., 2012). The data agreed with the constituent sugar analysis data (Fig. 2) and provided further insight on differences among the cell walls of taewa varieties and Agria. The four varieties showed similar proportions of HG, but Moemoe had a higher proportion of RG-I backbone and arabinan, and a lower proportion of galactan, than the other varieties.

The ratio of neutral side-chain (galactan, arabinan and

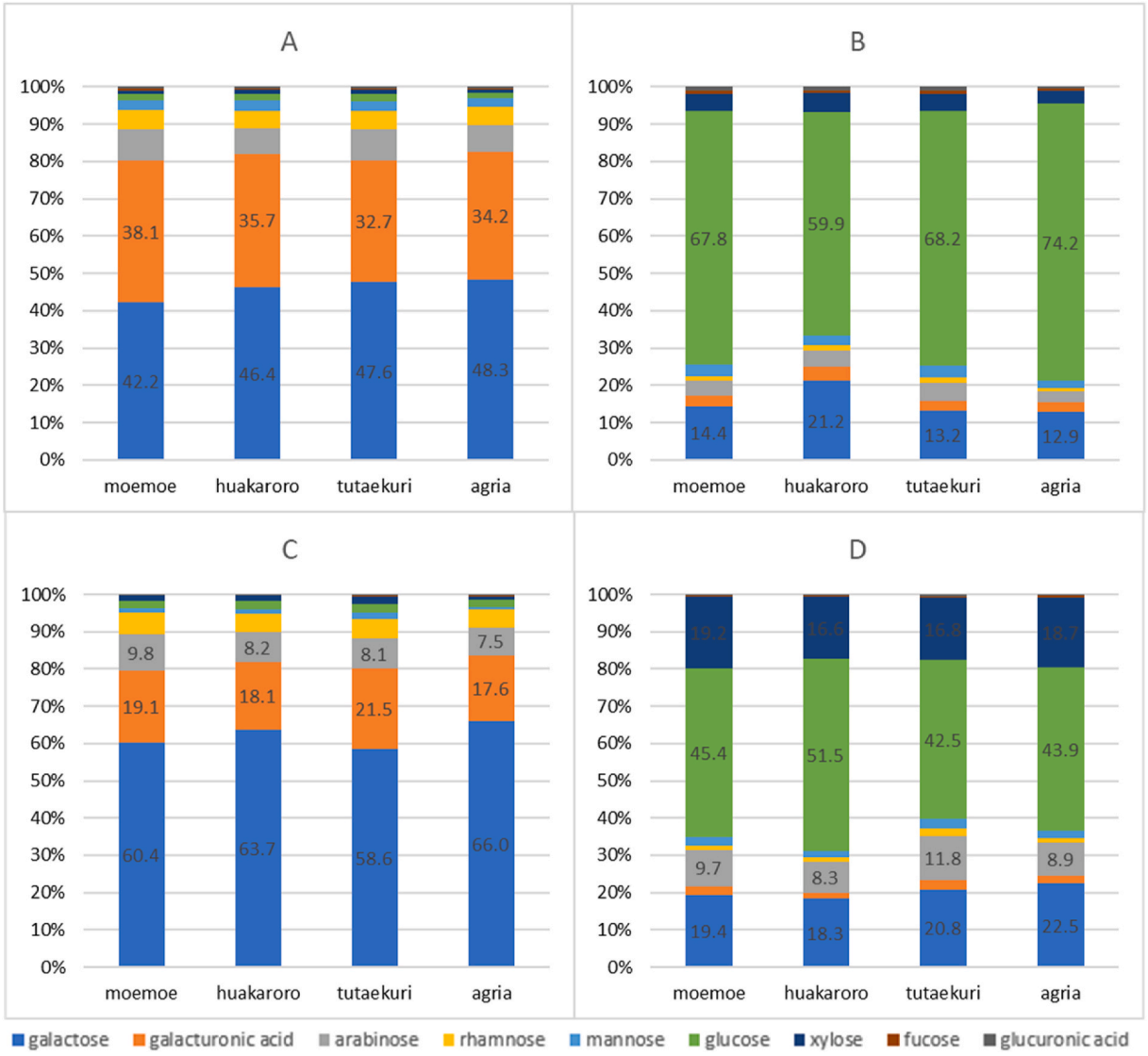

Fig. 3. Constituent sugar compositions (mol%) of fractions obtained from cell wall material of taewa and Agria potatoes. A, imidazole + Na_2CO_3; B, 1 M KOH; C, residue wash; D, 4 M KOH. Data are means of duplicate analyses.

Table 3
Structural features of pectic fractions obtained from cell wall material of taewa and Agria potatoes. Data are means of duplicate analyses.

Variety	(Ara + Gal)/Rha	RG-I	HG	RG-I/HG
Imidazole + Na_2CO_3				
Moemoe	9.51	61.0	32.8	1.86
Huakaroro	11.84	62.3	31.2	2.00
Tutaekuri	11.65	65.5	27.9	2.35
Agria	11.83	65.0	29.5	2.20
Residue wash				
Moemoe	12.10	81.8	13.3	6.15
Huakaroro	14.67	81.7	13.2	6.19
Tutaekuri	12.35	77.5	16.1	4.81
Agria	15.64	82.9	12.9	6.43

arabinogalactan) residues to RG-I branches (2,4-Rha*p*) indicated that the average side-chain length was 12.5 sugar residues for Moemoe, whereas the average side-chain length for the other varieties ranged from 16.2 (Tutaekuri) to 20.5 (Agria). There were no clear differences in the composition and structure of the pectic polysaccharides of Huakaroro and Tutaekuri, compared with Agria.

Glycosyl linkage analysis of the 4 M KOH fractions gave linkages (4-Glc*p*, 4,6-Glc*p*, t-Xyl*p*, 2-Xyl*p*, t-Ara*f* and t-Gal*p*) that were typical of solanaceous xyloglucans and agreed with analyses of potato xyloglucan (Table 5; Ring & Selvendran, 1981; Vincken et al., 1996). The backbone showed less branching than typical of many xyloglucans and showed the presence of both terminal Ara*f* and Gal*p* residues. The ratio of 4-Glc*p*/4, 6-Glc*p* observed ranged from 1.85 (Agria) to 3.30 (Huakaroro). These differences may represent differences in the branching of xyloglucans between these varieties, but more likely reflects the presence of residual starch in the cell wall preparations. In addition to xyloglucan, detection of 4-Gal*p*, 4-Xyl*p* and 4-Man*p* indicated the presence of pectic galactan, xylan and mannan.

3.4. Size-exclusion chromatography of cell wall polysaccharides

Size-exclusion chromatography of the imidazole + Na_2CO_3 fractions showed differences in the elution profiles among the three varieties of taewa and Agria (Fig. 4). The chromatograms showed a high molecular weight region (17–19.5 mL; relative weight average molecular weight ~500 kDa) that was more prevalent in Tutaekuri, a medium molecular weight region (19.5–23 mL; relative weight average molecular weight ~130 kDa) that was more prevalent in Moemoe, and a lower molecular

Table 4
Glycosyl linkage composition of the carboxyl reduced imidazole + Na_2CO_3 fractions. Data are means of duplicate analyses.

Polysaccharide[a]	Glycosyl linkages	Mol % (≥0.5 %)			
		Moemoe	Huakaroro	Tutaekuri	Agria
Homogalacturonan	4-Gal*p*A	**26.7**	**28.5**	**26.4**	**28.5**
Rhamnogalacturonan-I	2-Rha*p*	1.8	0.9	0.7	0.9
	2,4-Rha*p*	4.5	3.1	3.7	3.0
	4-Gal*p*A	6.3	3.5	4.4	3.4
	3,4-Gal*p*A	–	0.5	–	0.5
		12.6	**8.0**	**8.8**	**7.8**
Galactan (type I)	t-Gal*p*	0.7	1.2	1.0	1.8
	4-Gal*p*	45.1	51.5	51.8	51.9
	2,4-Gal*p*	–	–	–	0.6
	4,6-Gal*p*	0.7	1.2	1.0	1.2
		46.5	**53.9**	**53.8**	**55.5**
Arabinan	5-Ara*f*	**8.9**	**5.9**	**6.0**	**5.5**
Arabinogalactan (type II)	3-Gal*p*	**0.7**	-	-	**0.5**
Minor linkages (≤0.5 mol%)		**4.6**	**3.7**	**5.0**	**2.2**

[a] Based on known structures of plant cell wall polysaccharides (Pettolino et al., 2012).

Table 5
Glycosyl linkage composition of 4M KOH fractions. Data are means of duplicate analyses.

Derivative	Glycosyl linkages	Mol % (≥0.5 %)			
		Moemoe	Huakaroro	Tutaekuri	Agria
2,3,5-Me_3-Ara	t-Ara*f*	3.7	3.3	4.2	4.2
3,5-Me_2-Ara	2-Ara*f*	1.1	1.0	2.1	0.7
2,3-Me_2-Ara	5-Ara*f*	0.9	0.6	0.8	–
2,3,4-Me_3-Xyl	t-Xyl*p*	6.2	4.2	3.9	5.2
3,4-Me_2-Xyl	2-Xyl*p*	8.2	7.5	8.7	10.7
2,3-Me_2-Xyl	4-Xyl*p*	2.7	2.8	3.5	3.1
2,3,4,6-Me_4-Gal	t-Gal*p*	4.4	4.1	5.1	5.8
2,3,6-Me_3-Gal	4-Gal*p*	10.0	8.7	10.6	8.4
2,3,6-Me_3-Glc	4-Glc*p*	41.0	50.3	40.5	39.6
2,3-Me_2-Glc	4,6-Glc*p*	20.3	15.2	17.1	21.4
2,3,6-Me_3-Man	4-Man*p*	1.3	1.1	1.8	0.8
	Minor linkages	0.2	1.2	1.7	0.1

weight region (23–30 mL; relative weight average molecular weight ~15 kDa). Size-exclusion chromatography of the 4 M KOH fractions showed similar elution profiles, with a large peak at an elution volume range of 17.5–26 mL that was assumed to be due to xyloglucan (Table 5), together with several smaller later-eluting peaks (27–32 mL). The relative weight average molecular weight for the major peak was determined to be ~101–107 kDa for Moemoe, Huakaroro and Agria, but ~83 kDa for Tutaekuri.

4. Conclusions

These results show that, while the general polysaccharide composition of each of the potato varieties was similar, there were variations in the amounts and detailed structure of the different polysaccharides. The three varieties of taewa generally gave higher yields of cell wall material compared with Agria and, in particular, Tutaekuri yielded over 1.5 times the amount of cell wall material on a fresh weight basis. The work focused on whether taewa contained greater amounts of galactose, as β-(1→4)-D-galactan side-chains of RG-I, than Agria. One variety, Tutaekuri, contained considerably more galactose than Agria, most of it as galactan side-chains. The research was motivated by results from a human study which showed that greater proportional faecal propionate was correlated with longer uninterrupted sleep in infants (Heath et al., 2020), and an *in vitro* study that showed when polysaccharide mixtures containing potato galactan were provided as a substrate for co-culture of five bacterial species, the amount of propionate, as a proportion of total short chain fatty acids, increased (Liu et al., 2020). Therefore, galactan-rich foods such as taewa have the potential to alter substrate metabolism by the gut microbiota, increasing propionate production (Larsen et al., 2019; Liu et al., 2020). This in turn could modify human energy metabolism by glucose synthesis via gluconeogenesis (den Besten et al., 2013; Byrne et al., 2015).

This research contributes to our knowledge of varieties of taewa that were introduced to New Zealand in the late 18th century, and were prized by Māori, becoming a staple food crop and important commercial crop by the 19th century (Harris, 2001). More recently, Tāhuri Whenua, the National Māori Vegetable Growers Collective, has played an important role in the revitalisation of the growing of these taonga (treasures), providing expertise around appropriate and effective practices for their growth, harvesting and storage. This knowledge provides added value to taewa suggesting that, as well as their important role as a taonga species for Māori, they could contribute to human health in ways additional to those offered by modern European potato varieties.

CRediT authorship contribution statement

Cara.A. Luiten: Writing – review & editing, Methodology, Investigation, Formal analysis. **Simon F.R. Hinkley:** Writing – review & editing, Supervision, Resources. **Nick R. Roskruge:** Writing – review & editing, Supervision, Resources. **Saii A. Semese:** Resources, Investigation. **Anne-Louise M. Heath:** Writing – review & editing, Conceptualization. **Tracy L. Perry:** Writing – review & editing, Conceptualization. **Nancy J. Rehrer:** Writing – review & editing, Resources, Project administration, Funding acquisition, Conceptualization. **Ian M. Sims:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Investigation, Funding acquisition, Data curation, Conceptualization.

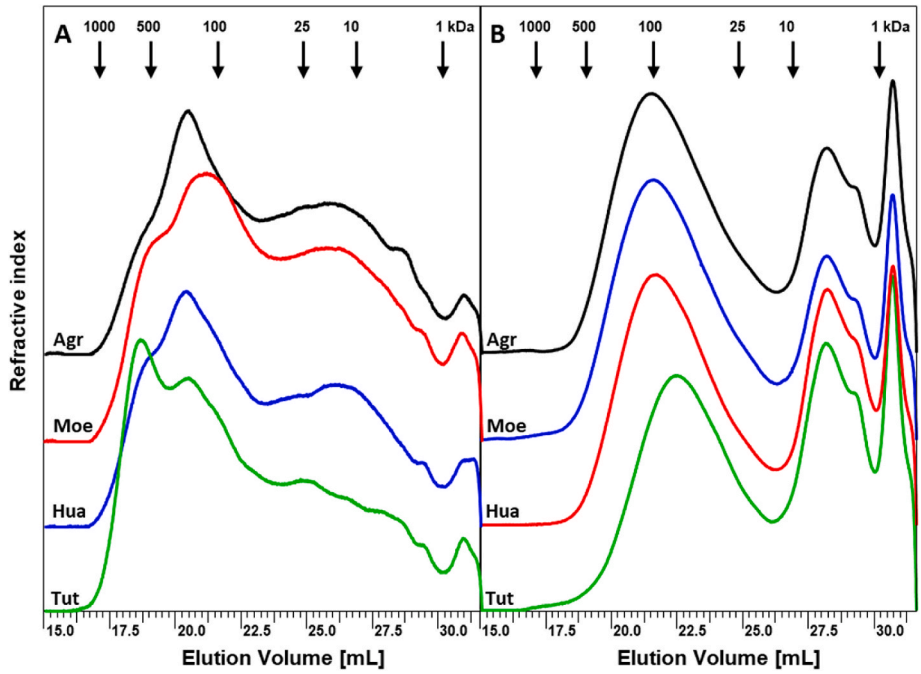

Fig. 4. SEC-RI chromatograms of (A) imidazole + Na_2CO_3 fractions and (B) 4 M KOH fractions. Arrows show elution volumes at different molecular weights, based calibration with pullulan standards (1–1220 kDa). Agria = Agr (——); Moemoe = Moe (——); Huakaroro = Hua (——); Tutaekuri = Tut (——).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was supported a Victoria University of Wellington, Faculty Strategic Research Grant (No. 410689) and by University of Otago Research Grants (Nos. 119579 and 120576). We gratefully acknowledge the sharing of knowledge and taewa by Tāhuri Whenua (Indigenous Growers' Collective of New Zealand).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodhyd.2025.111666.

Data availability

Data will be made available on request.

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