Fruits, 2015, vol. 70(6), p. 377-383
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DOI: 10.1051/fruits/2015040

FRUITS

Available online at:
www.fruits-journal.org

ORIGINAL ARTICLE

Fruit production and polyphenol content of salal (*Gaultheria shallon* Pursh), a potential new fruit for northern maritime regions

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Received 20 February 2015 – Accepted 10 September 2015

Abstract – Introduction. Cool growing seasons, high rainfall, wind and reduced sunshine challenge fruit production in northern maritime regions. Salal (*Gaultheria shallon* Pursh) originates from the Pacific Northwest of North America and our research investigated its fruit production and chemical composition in Orkney, north of mainland Scotland. **Materials and methods.** Fruit production from a 20-plant row was recorded over 3 seasons and fruits were analysed for total polyphenol, anthocyanin content (TPC and TAC) and antioxidant capacity (FRAP). **Results and discussion.** Fruiting occurred from August to October. Although 16−18 pickings were required to harvest the entire crop, about 75% was picked over 4 weeks when maximum production occurred. Annual production varied from 0.7 to 2.3 kg m^{-1} of row, indicating potential yields of 2.7 to 9.1 t ha^{-1} at 10 years for hedgerows 2.5 m apart. In 2014, average fruit weight, height and diameter ranged from 467 to 680 mg, 9.9 to 10.5 mm and 9.2 to 10.2 mm, respectively. The maximum picking rate was about 1.0 kg h^{-1} but was constrained by poor synchronisation of fruit ripening. Variations between years in fruit TPC (658−968 mg 100 g^{-1} fw) were reflected in variations in TAC (121−219 mg 100 g^{-1} fw) and FRAP (63,048−100,815 μM Fe 100 g^{-1} fw). TPC and TAC values were similar to those for blackcurrant (*Ribes nigrum* L.) varieties. **Conclusion.** Salal grew well in Orkney's maritime environment and fruited reliably. This fruit has potential for novel food and drink, but commercialisation will require improved selections, notably for ease of harvest.

Keywords: Scotland / Orkney islands / salal / *Gaultheria shallon* / phenolics / anthocyanins / antioxidant activity

Résumé – Production et teneur en polyphénols des fruits de la gaulthérie shallon (*Gaultheria shallon* Pursh), un nouveau potentiel pour les régions maritimes nordiques. Introduction. Des saisons de culture fraîches, de fortes précipitations, du vent et un ensoleillement réduit rendent difficile toute production de fruits dans les régions maritimes nordiques. La gaulthérie shallon (*Gaultheria shallon* Pursh) provient de la zone Nord-Ouest Pacifique de l'Amérique du Nord et notre objectif était d'étudier la production et la composition chimique de ces fruits dans les Orcades, au nord de l'Ecosse. **Matériel et méthodes.** La production fruitière à partir d'un rang de 20 plantes a été suivie durant plus de trois saisons et les fruits ont été analysés pour leur teneur en polyphénols totaux (TPC), en anthocyanes (TAC) et leur capacité antioxydante (FRAP). **Résultats et discussion.** La fructification s'est déroulée à partir du mois d'août jusqu'au mois d'octobre. Bien que 16 à 18 cueillettes ont été nécessaires pour récolter la totalité des fruits, environ 75 % ont été ramassés sur 4 semaines lors du pic de production. La production annuelle peut varier de 0,7 à 2,3 kg m^{-1} linéaire, selon des rendements potentiels de 2,7 à 9,1 t ha^{-1} pour des haies de 10 ans espacées de 2,5 m. En 2014, le poids moyen, la hauteur moyenne et le diamètre moyen des fruits variait de 467 à 680 mg, de 9,9 à 10,5 mm et de 9,2 à 10,2 mm, respectivement. La meilleure performance de récolte d'environ 1,0 kg h^{-1}, reste limitée par une mauvaise synchronisation de la maturation des fruits. Les variations annuelles de PTC des fruits (658−968 mg 100 g^{-1} pf, poids frais) se sont reflétées dans les variations de TAC (121−219 mg 100 g^{-1} pf) et des valeurs de FRAP (63,048−100,815 μM Fe 100 g^{-1} pf). Les valeurs PTC et TAC étaient semblables à celles des baies de cassis (*Ribes nigrum* L.). **Conclusion.** La gaulthérie shallon a bien poussé dans l'environnement maritime des Orcades et la fructification a été fiable. Ce fruit présente un potentiel pour développer de nouveaux aliments et de nouvelles boissons ; toutefois la commercialisation nécessitera la sélection de variétés améliorées, notamment pour faciliter la récolte.

Mots clés : Écosse / Les Orcades / gaulthérie / *Gaultheria shallon* / composés phénoliques / anthocyanes / activité antioxydante

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1 Introduction

Salal, *Gaultheria shallon* Pursh, is a coarse-leaved, evergreen Ericaceous shrub. The genus *Gaultheria* includes *ca* 134 species native to Asia, North and South America and Australasia, many of which are used in herbal medicine [1]. Salal is native to western North America and occurs from the panhandle of Alaska (56.0° N) to southern California (34.5° N) [2] and is a common understory shrub [3]. Flowers are borne on racemes and develop into purple/black, fleshy fruits [2] which were important in the diet of indigenous coastal people before European settlement [4] and eaten fresh or as a dried cake over the winter [5]. The fruit is now of minor local importance but there is a large market for stems harvested from wild stands for use as cut evergreens in floristry [6]. Salal was introduced to Britain in 1828 by David Douglas [3] as an ornamental shrub and has become naturalised in many areas.

In its native area, salal is a vigorous plant which competes with forestry species like Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*) [2, 7]. There has therefore been considerable forestry research into its competitive effects [8, 9] but few studies on flowering or fruiting. It does not appear to have been planted commercially for fruit production.

Several berry species contain high levels of phenolic compounds [10] important for human diet and health [11]. Anthocyanins are responsible for the red, blue and purple colour of fruit and fruit extracts [12] and also have potential health benefits [13]. Although there are no detailed studies on the chemical composition of salal, dried fruits were reported to have a high ascorbic acid content [4] while fruit extracts have high antioxidant activity [14, 15] and appear to contain anthocyanins [15].

Our research on salal began in 2003 as part of a wider study to identify fruit species suitable for growing in the open in Orkney and adjacent maritime areas. The Orkney archipelago is about 10 km off the north coast of Scotland and has a hyper-oceanic climate with a Conrad index of continentality below 3 [16]. The growing season is cool and wet, with long day length but reduced sunshine hours as a result of cloud or mist. Strong salt-laden winds are common, especially over the winter when high rainfall may result in soil waterlogging. These factors challenge outside fruit production.

The aim of this paper is to describe and quantify salal fruit production and fruit total phenolic content, anthocyanin content and antioxidant capacity over three growing seasons. This is thought to be the first time such detailed information has been reported.

2 Materials and methods

2.1 Trial site and plant material

The trial site was at Orkney College (University of the Highlands and Islands) at 58°59′ N, 2°56′ W on sandy clay soil with a pH of 5.9 and available phosphorus and potassium values of 53 and 74 mg L^{-1} respectively. Meteorological data reported later are for Kirkwall airport (58°57′ N, 2°54′ W; rainfall, temperature and wind) and Loch of Hundland climate station (59°6′ N, 3°13′ W; sunshine hours), about 5 and 22 km, respectively, away from the trial site.

In each of 2003 and 2006, 10 two-year-old salal plants (from Barwinock Herb Nursery, Barrhill, Ayrshire, UK) were planted in a single row, with 0.45 m between plants. The row was in the middle of a 16 × 40 m area bounded by 1.0 m high polyethylene wind break netting.

2.2 Fruit production data and morphological characteristics

At approximately 5-day intervals during the 2012, 2013 and 2014 fruiting seasons, visually ripe fruit (dark blue-black) were picked from the whole row. Fruits were weighed fresh, immediately after picking, and production data are presented per metre of hedgerow, based on a hedge length of 9.0 m. Fresh salal fruit had a moisture content of about 83−85%.

In 2014, more detailed measurements were collected on fruit characteristics. At the start of the harvest, the numbers of fruits per raceme were recorded on a sample of 63 racemes composed of 7 randomly selected racemes from each 1.0 m section of row. On each picking date, average fresh fruit weight was calculated from a random sample of 100 fruits. On 5 of these occasions, individual fruit weights were recorded for a sample of 20 fruits together with measurements of fruit height and diameter using digital calipers (Camlab).

2.3 Berry extraction, total phenol, total anthocyanin and FRAP assay

For compositional analysis of the fruit from each year, a composite sample was collected over the harvest season, consisting of 30 g fruit from each picking occasion which was stored in a freezer at −18 °C. This sample was transported frozen to the James Hutton Institute. After the sample was thawed and thoroughly mixed, a representative sub-sample was selected for extraction. Fruit were weighed then extracted with an equal volume to weight of acetonitrile containing 0.2% formic acid. Samples were homogenized by hand using a hand held glass tissue homogenizer with a PTFE pestle then centrifuged at 13,000 rpm for 5 min. The centrifugation was repeated and the supernatant taken as the extract. Total phenol, anthocyanin and ferric reducing antioxidant power (FRAP) assays were carried out on the same day as extraction but these values were stable after storage at −80 °C.

Total phenolic content (TPC) was measured using the Folin-Ciocalteu's method [17], as modified by Deighton *et al.* [18], and estimated from a standard curve of gallic acid. The total anthocyanin concentration (TAC) was estimated by a pH differential absorbance method as described previously [18]. The absorbance value was related to anthocyanin content using the molar extinction coefficient calculated for cyanidin-3-*O*-glucoside (purchased from ExtraSynthese Ltd., Genay, France).

A manual FRAP assay was used based on the method described previously [18]. FRAP reagent was freshly prepared (1 mM 2,4,6-tripyridyl-2-triazine (TPTZ) and 2 mM ferric

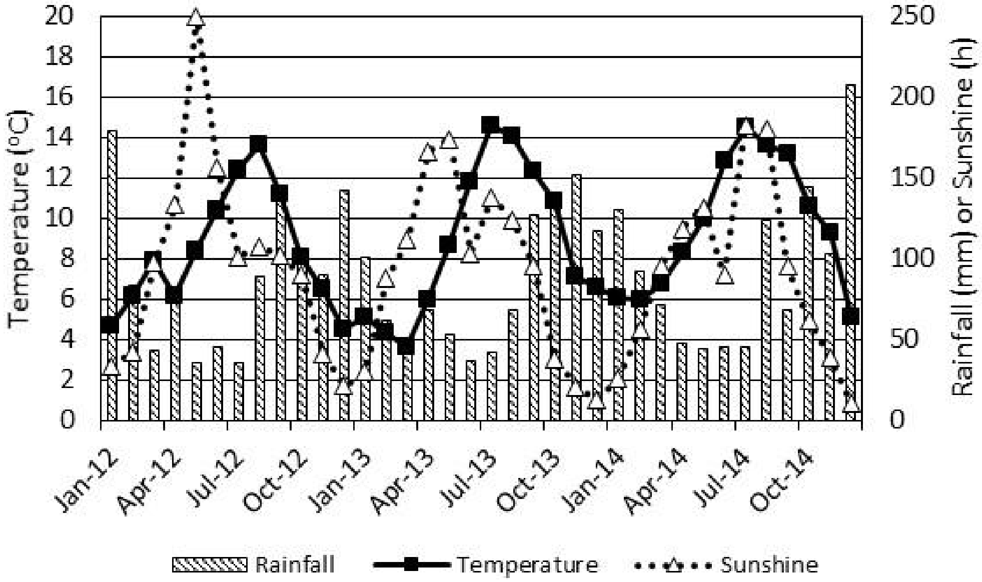

Figure 1. Average monthly temperature and rainfall at Kirkwall airport and sunshine at Hundland climate station from January 2012 to December 2014.

chloride in 0.25 M sodium acetate, pH 3.6). A 100 μL aliquot of extract (at 1% v/v in distilled water) was added to 900 μL of FRAP reagent and mixed. After standing at ambient temperature (~20 °C) for 4 min, absorbance at 593 nm was determined against a water blank. Calibration was against a standard curve (50–1000 μM ferrous ion) produced by the addition of freshly prepared ammonium ferrous sulphate. FRAP values obtained are presented as micromolar ferrous ion (ferric reducing power) of the extracts, from three determinations.

2.4 Statistical analysis

GenStat version 9 (VSN International Ltd) was used to produce descriptive statistics of the data and for analysis of variance of fruit measurements on different picking dates in 2014. Significant differences between picking dates were identified by the F-test and when this was significant ($P < 0.05$), a least significant difference test (at $P < 0.05$) was used to separate significantly different treatment means Unless otherwise specified, mean values are presented ± the sample standard deviation Statistical significance between the TPC, TAC and FRAP measurements was assessed using two-tailed t-Tests (Microsoft Excel 2010).

3 Results and discussion

3.1 Early growth and fruit production

Although detailed yield data were not collected until 2012, salal plants started flowering and fruiting from the second year in the field and harvest data from the third and fourth years indicated fruit production of about 0.3–0.4 kg m^{-1} of row. Shoots from rhizomes filled in the space between plants to form a hedgerow in which individual plants could no longer be identified. The hedgerow was very uniform and in July 2014 its average height and spread were 0.96 m (±0.08) and 1.81 m (±0.17) respectively.

3.2 Meteorological data from 2012 to 2014

From 2012 to 2014, average annual temperature and rainfall ranged from 8.3–9.7 °C and 1001–1125 mm, respectively. Average monthly wind speed for the windiest (October to March) and least windy (April to September) months varied from 21.5–26.3 km h^{-1} and 17.6–19.0 km h^{-1}. Monthly rainfall patterns were similar over the 3 years (*figure 1*) with most summer and winter months having at least 40 and 80 mm of rain, respectively. Considering Orkney's latitude, winter temperatures were mild (*figure 1*) and the lowest monthly average was 3.6 °C. This would be very suitable for salal which is restricted in North America, to mild coastal areas with little snow [2]. Monthly temperatures from November 2013 to July 2014 (*figure 1*) were all between 0.6 and 1.3 °C above the average for 2003–2014 and the average temperature for this period was 7.8 °C for 2013/14 compared with 7.1 °C for 2003–2014. Sunshine hours in July and August 2014 (*figure 1*) were also exceptionally high.

3.3 Fruit production from 2012 to 2014

The flowering period of salal occurred from late May to early July in both 2012 and 2013, but in 2014 it started about two weeks earlier, lasting from 8 May until 3 July. The first fruits were ready for picking about 11 weeks after the start of flowering which was equivalent to 990 day degrees (0 °C base temperature) in 2014. In July 2014, the mean number of fruits on racemes was 7.8 (±1.8), with 80% having from 6 to 9 fruits. Only 5% of racemes had less than 6 fruits.

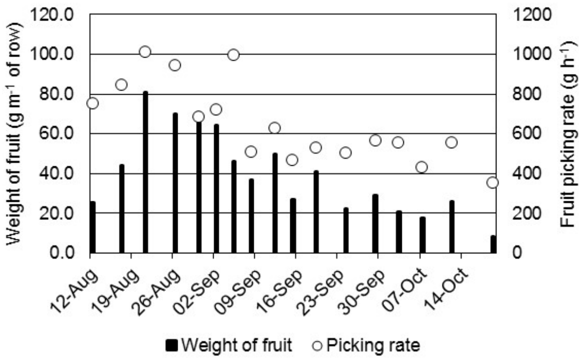

Figure 2. Weight of salal fruit harvested m^{-1} of row and the fruit picking rate on each picking occasion in 2012.

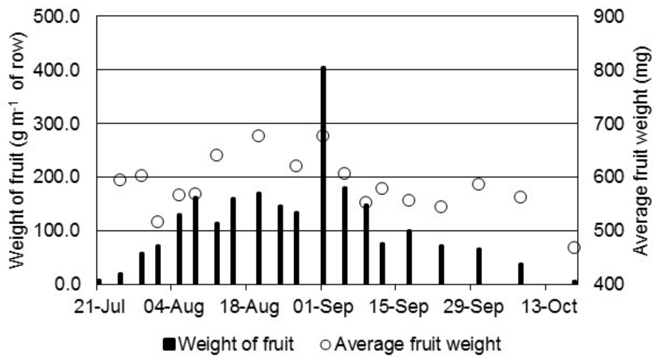

Figure 3. Weight of salal fruit harvested m^{-1} of row and average fruit weight on each picking occasion in 2014.

Table I. Harvesting period of salal (*Gaultheria shallon*) and fruit production from 2012 to 2014 (NA: not available).

Year	Harvest period	Number of picking occasions	Fruit production (kg m^{-1} of row)
2012	12 Aug-19 Oct	17	0.68
2013	15 Aug-24 Oct	NA	0.84
2014	21 Jul-18 Oct	20	2.27

The salal fruit harvest lasted 2−3 months (*table I*), from about mid-August to late-October in 2012 and 2013, but in 2014 it started about 3 weeks earlier. Since fruits were ready for harvesting at about 5−7-day intervals, there were many picking occasions each year – 17 in 2012 and 20 in 2014. Over the 3 years, fruit production in 2014 (2.27 kg m^{-1} of row) was about three times that of the two preceding years (0.68 and 0.84 kg m^{-1} of row). These data suggest that fruit yields of 2.7 to 9.1 t ha^{-1} could be achieved by year 10 in Orkney if salal is grown in hedgerows 2.5 m apart. These yields are comparable with those (2.2 to 12.0 t ha^{-1}) reported for lowbush blueberry (*Vaccinium angustifolium*) [19], a relatively unimproved species which is important for fruit production in northeastern North America. They are much higher than yields recorded for wild stands of bilberry (*Vaccinium myrtillus;* 0−130 kg ha^{-1}) and cowberry (*V. vitis-idaea;* 0−95 kg ha^{-1}) in Finland [20] and for *V. myrtillus* (0−450 kg ha^{-1}) in Sweden [21]. Large variations in fruit production, as seen with salal from 2013 to 2014, are common in northern species. In Finland, for example, the mean annual national yields between 1997 and 2008 of wild bilberry and cowberry were estimated to vary from 12.0 to 37.9 kg ha^{-1} and 12.4 to 34.0 kg ha^{-1}, respectively [22]. Climatic factors affecting flower development or pollination are often reported to have an important effect on yield fluctuations [22,23]. It is not obvious what stimulated early flowering and greater fruit yield of salal in Orkney in 2014, but lowbush blueberry, elder (*Sambucus nigra*) and saskatoon (*Amelanchier alnifolia*) grown at the same location were similarly affected. One possibility is the above average temperatures from November 2013 to July 2014 described earlier. Wind speed during flowering in May-June 2014 was also lower than average and may have provided better pollination conditions than in previous years.

During the 2012 and 2014 harvests (*figures 2 and 3*), the maximum weight of fruit harvested on a single occasion in each year was 80 and 400 g m^{-1}, respectively. With small amounts of fruit being harvested in the early and late pickings of each season, 72% of the 2012 crop was harvested in 9 pickings from 21 August to 19 September and 77% of the 2014 crop in 10 pickings from 5 August to 9 September. Manual fruit picking rates were recorded for each picking in 2012 (*figure 2*) and averaged 680 g h^{-1}, with a minimum and maximum of 350 and 1,010 g h^{-1}, respectively. The highest rates were at the time of peak fruit production. In 2013 and 2014 picking rates of about 1,000 g h^{-1} were also recorded around this time. A harvesting efficiency of 250 mL of fruit in 8 min was reported [24] for salal growing in the wild. Using fruit volume data from Orkney, this converts to a picking rate of ~870 g h^{-1} which is within the range of the data for 2012. Picking costs could be reduced by concentrating on harvesting fruit during the approximately 4 weeks of the harvest period when maximum fruit production occurs and the highest picking rates can be achieved. The picking rates for salal are low compared with more conventional berry crops like highbush blueberry (2.7 kg h^{-1}) [25] and aronia (*Aronia melanocarpa*; 7.3 kg h^{-1}) [26]. Part of the reason for the lower rate is the poor synchronisation of fruit ripening, so that ripe fruit usually need to be selected on each raceme and can seldom be stripped off all together. Under Orkney's wet conditions, extending the interval between pickings to allow more fruit to ripen together often resulted in soft fruit prone to abscission. Greater synchronization of fruit maturity might be obtained by using sprays of ethephon, which has been used successfully for this purpose in other fruit crops, including cherry [27] and saskatoon (*Amelanchier alnifolia*) [28].

The average fruit weight determined from 100-fruit samples at each harvest during 2014 (*figure 3*) ranged from 467 to 677 mg and averaged 583 mg over the season. It tended to be highest in the middle of the harvest, when most fruit were picked. Measurements on samples of 20 individual fruits on 5 occasions (*table II*) had a similar range of average fruit weights and showed that the ranges of average diameters and heights were 9.2 to 10.2 mm and 9.7 to 10.5 mm, respectively. There were significant differences in fruit weight and fruit diameter between picking dates ($P < 0.05$). Fruit weight

Table II. Average fruit weight, diameter and height for samples of salal during the 2014 harvesting season. Values expressed as mean ± standard deviation (n = 20).

Picking date	Fruit weight (mg) [y]	Fruit diameter (mm)[y]	Fruit height (mm)[y]
25-Jul-14	585 ± 164 b	10.2 ± 0.1 a	9.9 ± 0.1 a
29-Jul-14	602 ± 117 b	9.9 ± 0.1 ab	10.1 ± 0.1 a
01-Aug-14	554 ± 145 b	9.7 ± 0.2 abc	9.9 ± 0.1 a
01-Sep-14	707 ± 220 a	9.8 ± 0.1 abc	10.5 ± 0.2 a
05-Sep-14	558 ± 122 b	9.2 ± 0.1 c	9.7 ± 0.1 a

[y] For each variable, sample date means followed by the same letter are not significantly different at $P < 0.05$

was significantly higher in the sample of 1 September than at any other date while the diameter of the sample on 5 September was significantly less than that of the two earliest samples. Fruit height was not significantly affected by picking date, although it was largest on 1 September when fruit weight was also largest. Fruit shape varied from spherical to oblong and appeared specific to certain parts of the row, suggesting that fruit shape may be a characteristic of individual plants. In all years, it was noticed that the same end of the row, probably an individual bush, produced smaller fruit than other parts of the row. For example, a sample of 15 fruits on 25 July 2014 from this area had an average fruit weight of 391 mg (±54 mg), a diameter of 8.6 mm (±0.03 mm) and height of 8.5 mm (±0.04 mm). This suggests that fruit size is a characteristic which could be improved by plant selection.

3.4 Total phenolic content, anthocyanin content and antioxidant capacity

The total phenolic content (TPC) of salal fruit differed between harvests and ranged between 658 mg 100 g^{-1} fw in 2014 to 968 mg 100 g^{-1} fw in 2012 (*table III*). The total anthocyanin content (TAC) reflects the content of red pigments and is a subset of the TPC. TAC ranged between 121 and 219 mg 100 g^{-1} fw which represented between 0.14 to 0.23 of the TPC. The antioxidant capacity (FRAP value) of the fruit also varied between harvests but it was essentially correlated with the TPC, as reported for other species [18]. Allowing for possible variations due to differences inherent in the sampling routine, it is possible that the growing season influenced both TPC and TAC. Larger berry size in 2014 may have reduced TPC as phenolics in small currant-like berries are often concentrated in the skin [29] which makes up a smaller proportion in larger, fleshier berries. The relatively higher proportion of anthocyanins in 2014 may reflect the better growing season with more incident sunlight and warmer temperatures.

These TPC data approach those achieved by blackcurrant (*Ribes nigrum*) varieties (600–1,000 mg 100 g^{-1} fw) but exceed the range noted for strawberry (*Fragaria x ananassa*) and raspberry (*Rubus idaeus*) varieties (~200 mg 100 g^{-1} fw, exceptionally up to 400 mg 100 g^{-1} fw) [18, 30] and also blueberry varieties (around 100 to 190 mg 100 g^{-1} fw) [31, 32]. The TAC values were similar to those for blackcurrants and were higher than those usually reported for raspberry or strawberry [30]. The antioxidant potential as measured in FRAP values were also relatively high (63,048–100,815 μM Fe 100 g^{-1} fw) but seemed to be in proportion with the TPC, as noted previously [18]. However comparisons between varieties and species must be treated with caution as the variety, agronomic conditions, and environmental conditions at each growing location often have substantial influence on these parameters [32, 33].

3.5 Further development of salal

As a completely unimproved species, it is likely that selection, crossing and vegetative propagation of elite plants could be used to develop salal clones more suitable for fruit production. This would be helped by variation which has been reported in the wild population [2] and by salal's ease of propagation from rhizome cuttings, producing plants which flower earlier than from seed [34]. The potential benefits of clonal selection have been demonstrated for lowbush blueberry [35]. The main characteristics requiring improvement are those which would facilitate both manual and mechanical harvesting, like greater synchronisation of fruit maturity, larger fruit size and yield stability.

With salal's reputation as an aggressive forestry weed [2] which has also colonised heathland habitats in Britain [36], it might be difficult for it to be accepted as a cultivated fruit species. But, in Orkney, it has been easy to restrict the spread of plants by regular cutting of grass and the lack of volunteer plants in the vicinity of the hedgerow suggests it establishes poorly from seed in the open as was also found under forestry conditions [37]. Our experience suggests it should be planted in the open, within a grass sward away from woodland, and preferably surrounded by agricultural fields.

Fresh salal fruit in Orkney are juicy but do not have a strong flavour. In Canada, the fruit is thought to vary in flavour from area to area [5] and so it may be possible to breed and select for more flavoursome clones. Nevertheless, the juice has an attractive deep red colour which could be valuable if used in products like juices, jams, wines or coloured spirits. For food and drink producers in northern maritime areas, an attraction of using salal is that it is an uncommon fruit which would not be readily available to competitors and could be used to develop unique local products.

4 Conclusion

Salal grew well in Orkney's maritime environment and produced large numbers of new shoots from rhizomes, making it very suitable for cultivating as a hedgerow. Although only quantified for 5 years, it produced fruit annually from the second to twelfth year from planting. It had a protracted fruiting period (August to October) but about 75% of the crop was produced in 4 weeks when most fruit matured. Picking costs would be reduced, if harvesting is restricted to this period, as this is when the highest picking rates can be achieved. Fruits have been shown to have a reasonable TPC, TAC and FRAP,

Table III. Total phenolic and anthocyanin contents and FRAP values of salal fruit from the 2012 to 2014 harvesting seasons. Values expressed as mean ± standard deviation ($n = 3$).

Season	Total phenolic content - TPC (mg 100 g^{-1} fw) [y]	Total anthocyanin content - TAC (mg 100 g^{-1} fw) [y]	Ratio of TAC/TPC	FRAP (μM Fe 100 g^{-1} fw) [y]
2012	968 ± 24 a	219 ± 10 a	0.226	100815 ± 438 a
2013	827 ± 12 b	121 ± 9 b	0.146	95932 ± 719 b
2014	658 ± 16 c	134 ± 10 b	0.204	63048 ± 516 c

[y] Values in each column followed by the same letter are not statistically different at $P < 0.05$.

with levels comparable to those in blackcurrants. Significant commercial growing of salal will require plant improvement, especially to make harvesting less labour intensive.

Acknowledgements. We are grateful for funding assistance from the Scottish Government's Interface programme and UK Government's Technology Strategy Board which supported some of this work. We would also like to thank the Orkney Wine Company for their help and collaboration in collecting some of the salal data and Keith Johnson for providing meteorological data for Loch of Hundland climate station.

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Cite this article as: Peter Martin, John Wishart, Gordon McDougall, Rex Brennan. Fruit production and polyphenol content of salal (*Gaultheria shallon* Pursh), a potential new fruit for northern maritime regions. *Fruits* 70 (2015) 377–383.