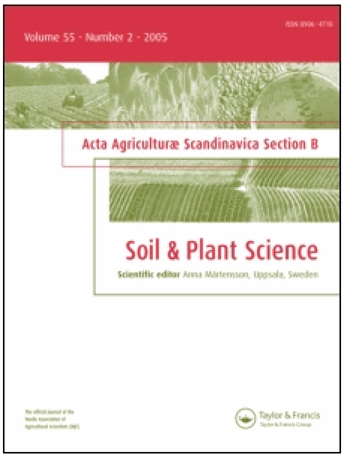

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The productivity and fruit quality of the arctic bramble (Rubus arcticus ssp. Arcticus) and hybrid arctic bramble (Rubus arcticus ssp. arcticus×Rubus arcticus ssp. stellatus)

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ORIGINAL ARTICLE

The productivity and fruit quality of the arctic bramble (*Rubus arcticus* ssp. *Arcticus*) and hybrid arctic bramble (*Rubus arcticus* ssp. *arcticus* × *Rubus arcticus* ssp. *stellatus*)

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Abstract
The fruit biochemical content and productivity of arctic bramble (*Rubus arcticus* ssp. *arcticus*) and hybrid arctic bramble (*R. arcticus* ssp. *arcticus* × *R. arcticus* ssp. *stellatus*) cultivars were investigated during three experimental years (2001–2003) in field conditions. Rows of experimental plants were alternated with rows of raspberry (*Rubus idaeus* L.). Finnish cultivars together with a strain from Estonian nature (E1) and Finnish and Swedish hybrid cultivars were planted in rows that were covered with plastic mulch. The cultivars and strain were planted in rows turning in order to secure the best conditions for pollination. The following combinations were used: E1 + 'Susanna'; E1 + 'Mespi'; E1 + 'Pima'; 'Astra' + 'Aura'; 'Astra' + 'Anna'; 'Anna' + 'Beata'. Yield and biochemical content were different between variants consisting of two cultivars. Significantly higher yield parameters such as fruit weight, number of drupelets, and productivity were observed from the hybrid cultivars 'Astra' + 'Aura'. Combinations with arctic bramble cultivars did not have a significant difference in yield, thus all tested cultivars are suitable for growing in combination with Estonian clone. Hybrid arctic bramble fruits in cultivar combinations of 'Astra' + 'Anna' showed the highest titratable acid (TA) content. E1 and 'Susanna', in combinations with arctic bramble, had higher soluble solids and ascorbic acid content, but TA and SS/TA did not show significant differences. The darkest (L*) and reddest (+a*) juice was found in fruit of hybrid cultivars combinations; those combinations with 'Astra' produced the darker juice colouring.

Keywords: *Ascorbic acid, chromaticity, drupelets, fruit weight, soluble solids, titratable acid, yield.*

Introduction

Arctic bramble (*R. arcticus* ssp. *arcticus*) is found in subarctic Eurasia, mainly between the latitudes of 60° N and 70° N. The growing areas are located in a broader zone in Asia as well as in northern parts of North America, ie. Canada and Alaska. The best Eurasian habitats are located between 62° and 66° latitude (Ryynänen, 1973). Estonia is situated on the southern boundary of the arctic bramble's area of distribution, where the bramble is naturally adapted to growth in the half-shadow of forest undergrowth (Reier, 1982). Another subspecies, *R. arcticus* ssp. *stellatus,* has a narrow distribution range in NW Alaska, the Aleutian Islands, and in NE Asia. The subspecies *stellatus* and *arcticus* can be crossed and vigorous hybrids obtained (Larsson, 1969, 1980; Ryynänen, 1973). In 1999, in Finland, the arctic bramble plantations areas covered 20–25 ha, in Sweden 10–15 ha (Anon., 1999).

The first arctic bramble experiments were carried out in Finland at the beginning of the 1970s (Ryynänen, 1973). The first Swedish hybrid cultivars (*R. arcticus* ssp. *arcticus* × *R. arcticus* ssp. *stellatus*) were released in 1980 (Larsson, 1980). In Estonia, the experimental work with arctic bramble began in 1994. The main problem of arctic bramble cultivation in Estonia and Finland is infection with downy mildew (*Peronospora sparsa*). The infection is mainly favoured by low temperature and water deficiency stress in the plant. The second major

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problem, dependent on the prevailing environmental conditions, is the rapid growth of young shoots in the beginning of the spring. The arctic bramble rhizome buds that are located near the soil level begin early growth during the favourable conditions in spring. The young shoots can therefore be damaged by late spring night frost (Tammisalo, 1988; Karp et al., 2000). A third problem in Estonia is too high temperatures in plantations in summer. Partial shading is, therefore, recommended to suppress rapid growth of arctic bramble in early spring and to reduce temperature in summer. Experiments in Finland have been carried out where spruce hedges provide partial shading (Prokkola et al., 2001). An alternative is to cultivate the arctic bramble with other species, for example, raspberries. The first advantage of using raspberries is the uniform height and width of the plants during the vegetation period and consequently uniform shading conditions are achieved during the whole summer. The second is that the raspberry plants give wind protection for the arctic bramble plants, providing the windless conditions favourable for pollinators, especially bees.

Arctic bramble cultivars are self-sterile and, for ensuring yield, different arctic bramble strains should be cultivated together (Hiirsalmi, 1975; Kangasjärvi & Oksanen, 1989). When arctic bramble cultivars are planted alternately in rows and the plant-to-plant spacing is 0.33 m, plants will be grown in combination as a mixture of cultivars by the second year, because arctic bramble rhizomes can grow 0.5 m or more in one year (Ryynänen, 1973). The distance between different arctic bramble cultivars in a row should not exceed 1 m as honeybees make foraging flights along the rows, and this distance is the length of a bee's foraging flight (Vool et al., 2003).

The earliest arctic bramble cultivars are 'Mespi' and 'Pima' (strains of *R. arcticus*), which are recommended for cultivation (Ryynänen, 1972). The most well known and widely distributed cultivars of arctic bramble hybrids in Finland are 'Aura' and 'Astra', of which 'Astra' has been recommended as a pollinator for 'Aura' (Hiirsalmi et al., 1987). Under Estonian conditions, experimentation has shown that cultivars' yield and pollen potential is different each year (Karp & Starast, 1999). A combination of three cultivars was the subject of an Estonian experiment in an attempt to ensure better pollination and increasing yield, but no advantages were found in comparison with the two-cultivars combinations (Karp et al., 2000).

The advantage of the Estonian arctic bramble strain compared with the Finnish cultivars is its significantly vigorous vegetative growth and productivity (Karp & Starast, 1998, 1999); furthermore the Estonian strain grown under Finnish conditions and compared with the Finnish arctic bramble showed good infection resistance (Prokkola et al., 2001). Swedish hybrid cultivars, compared with the arctic bramble cultivars, are thought to be more opulent and productive, but have a weaker aroma (Larsson, 1980); however, they are more resistant to downy mildew fungus (Hellqvist, 2000). Therefore more hybrid cultivars need to be studied under Estonian conditions, since to date experiments only with Finnish cultivars have been conducted.

Arctic bramble fruits are mainly used as raw material in the food and liqueur industry, therefore the biochemical properties of these fruits are of major importance. In Estonia and Finland the fruits of hybrid cultivars contain more acids than do the arctic bramble fruits (Häkkinen et al., 1994; Starast et al., 2000). 'Aura' and 'Astra' among the hybrid cultivars have the lowest sugar content and are less aromatic, but Starast et al. (2000) found that 'Astra' fruits had a significantly redder colour. It is important to note that the fruits of arctic bramble and hybrid cultivars have different biochemical content (Karp, 2001). Since for successful pollination a mixture of different cultivars is grown in the plantations, the food industry gets a mixture of fruit from several cultivars.

The primary aim of the present research was to determine suitable Finnish arctic bramble cultivars for cultivation in combination with the Estonian strain. The secondary aim was to find out the effect of cultivar combinations on yield, biochemical content, and yield colour when analysed as a mixture of two cultivars.

Materials and methods

Experimental site and soil conditions

The arctic bramble field experiment was established in Tartumaa (58° 15′N, 26° 38′E), in South Estonia on luvisol (IUSS Working GroupWRB, 2006). The soil of the experimental area contained 82 mg P l^{-1}, 267 mg K l^{-1}, 150 mg Mg l^{-1}, 0.79 mg B l^{-1}, 1100 mg Ca l^{-1}, and 2.8 mg Cu l^{-1}. The soil pH_{KCl} was 5.6.

Rows of arctic brambles were grown alternately with raspberries (*R. idaeus* L.). The raspberries were planted in 1999 and the arctic bramble plants in May 2000. The experimental plants were planted on a bed with plastic mulch (black polyethylene with a thickness of 0.06 mm) with width of 60 cm. The plastic mulch was laid out before planting, the holes in the plastic being cut larger every year. A drip-irrigation system was placed under the mulch. The distance between plants in the rows was 33 cm.

The area between the plastic mulch rows of arctic bramble and raspberry plants was covered with sawdust mulch.

Plant material

The arctic bramble has been a protected species in Estonia since 1958. E1 is the first cultivated Estonian arctic bramble ssp. *arcticus* strain originating from Nature. In 1995 the strain was removed, with permission from the Estonian Environment Ministry, from its habitat in Kaansoo for experiments. 'Mespi', 'Pima'. and 'Susanna' are Finnish arctic bramble ssp. *arcticus* cultivars. The hybrid arctic bramble (*Rubus arcticus ssp. stellatus*) cultivars 'Aura' and 'Astra' are from Finland and 'Anna' and 'Beata' from Sweden. There were 72 plants in variant (24 plants in three replications). Because of the self-sterility of arctic brambles, every variant consisted of 2 cultivars (12 + 12 plants in replication), which were planted in rows alternately. The following cultivar combinations were used: E1 + 'Susanna'; E1 + 'Mespi'; E1 + 'Pima'; A'stra' + 'Aura'; 'Astra' + 'Anna'; 'Anna' + 'Beata'.

Measurements

Yield. In the first crop year (2001) the yield was harvested seven times, and three times in 2002 and in 2003. The experiment was carried out until 2005, but in 2004 and 2005 no considerable yield was formed and therefore these years were not included in the current work. The yield was expressed in units of g m^{-2}. Average fruit weight and the number of drupelets per fruit were determined during the harvest. The number of shoots per bush was counted and their length measured (cm) at the same time. The length of shoots was measured from the ground to the shoot tip. The leaf area (mm^2) was also measured (ADC BioScientific Ltd. Area meter AM100).

Biochemical analyses of fruits. Biochemical analyses of the frozen berries of arctic brambles were conducted in January 2002 and 2003. Soluble solids (SS) content was determined as a percentage using a refractometer (ATAGO Pocket Refractometer PAL-1). Titratable acid (TA) content was measured by the titration method with aqueous 0.1 N NaOH, using phenolphthalein as an endpoint indicator. 5 g of material was weighed, ground, and then water at 80 °C was added. The mixture was heated for 30 minutes and set aside for 2 hours. Next the mixture was filtered and three replications of 20 ml each were measured off. The TA content was expressed as citric acid mg per 100 g of fresh fruits. The soluble solids and titratable acids (SS:TA) ratio was calculated based on the content of soluble solids and TA. Ascorbic acid content (AA) was determined with the modified Tillman's method, where 2 g of fruit material was first ground and then 1% HCl was added. Next the mixture was filtered and the filtrate was measured in two 10 ml replications (1 ml of 1% aqueous KI and 1 ml of 1% soluble starch were added).

Colour. The colour of the filtered and heated 5% berry juice was determined. The fruit juice colour was measured using a MINOLTA Chroma meter CR-400. The index numbers used were lightness (L^*) and the chromaticity coordinates. The letter a^* indicates colour directions: $+a^*$ is the red direction, $-a^*$ is the green direction.

Meteorological conditions of experimental years

All three experimental years had different climatic conditions. Precipitation during 2001 was significantly higher than the long-term average (1960–1999) (Table I). Abundant precipitation also occurred in May, July, and August 2003. 2002 was significantly warmer and dryer than the long-term average. The warmest month during the experimental years was July. In 2001, the warmest months, when compared with the long-term average, were April and July.

Statistical analysis

The average results of the three years (2001–2003) were used to study the influence of cultivars and strain combination on the arctic bramble fruit biochemical composition and yield. A two-way analysis of variance (ANOVA) was used for data analysis; the factors were A – cultivars combination, and B – years. The mean values to be compared are followed by the same letter if they are not significantly different at $P < 0.05$. Linear correlation coefficients between variables were calculated; the significance of coefficients being $P < 0.05^*$, $P < 0.01^{**}$.

Results

Yield

The fruit weight ranged from 0.6 to 1.2 g, depending on the cultivars combination (Figure 1A). The fruit size was not dependent on the year, but the cultivars' properties had a significant effect. All hybrid

Table I. Meteorological conditions of experimental years in 2001–2003 and long-term averages 1960–1999.

	Temperature (°C)				Precipitations (mm)			
Month	2001	2002	2003	Long-term averages	2001	2002	2003	Long-term averages
April	7.5	6.5	3.3	4.3	52	20	37	35
May	10.8	13.9	11.6	11.0	49	15	105	55
June	14.6	16.5	13.1	15.1	86	81	59	66
July	21.3	21.1	19.6	16.7	112	45	88	72
August	16.6	19.2	15.1	15.2	127	22	109	79

cultivars had heavier fruits than did arctic bramble cultivars. Lighter fruits were found in arctic bramble combinations E1 + 'Pima', heavier fruits in hybrid cultivar combinations 'Astra' + 'Aura' and 'Anna' + 'Beata'.

The number of drupelets differed between variants, from 10 to 26 per fruit (Figure 1B). The hybrids 'Astra' and 'Aura' had the highest number of drupelets. When compared with the arctic bramble cultivars the hybrids had a higher number of drupelets. E1 and 'Susanna' fruit mix had the lowest number of drupelets. In 2001, there were significantly more drupelets compared with other years.

The duration of the harvest period varied during the experimental years. The fruiting period of the arctic bramble was 26 June to 7 August in 2001, 22 June to 8 July in 2002, and 27 June to 11 July in 2003. In all three experimental years the main yield ripened at the end of June to the beginning of July. In 2004, the yield was harvested only twice and in 2005 a considerable yield was not obtained. The productivity of experimental plants was highly variable – the yield ranged from 17 to 91 g m^{-2} (Figure 1C). There were no significant differences between arctic bramble variants. The hybrid cultivars 'Astra' and 'Aura' had significantly higher productivity than did other cultivars. In 2003, the productivity was significantly lower than in the rest of the experimental years.

Correlation analysis showed a positive relationship between yield and fruit weight ($r = 0.82^{**}$), yield and drupelets number ($r = 0.76^{**}$), also between the fruit weight and drupelets number ($r = 0.74^{**}$). Similarly, a positive correlation was found between

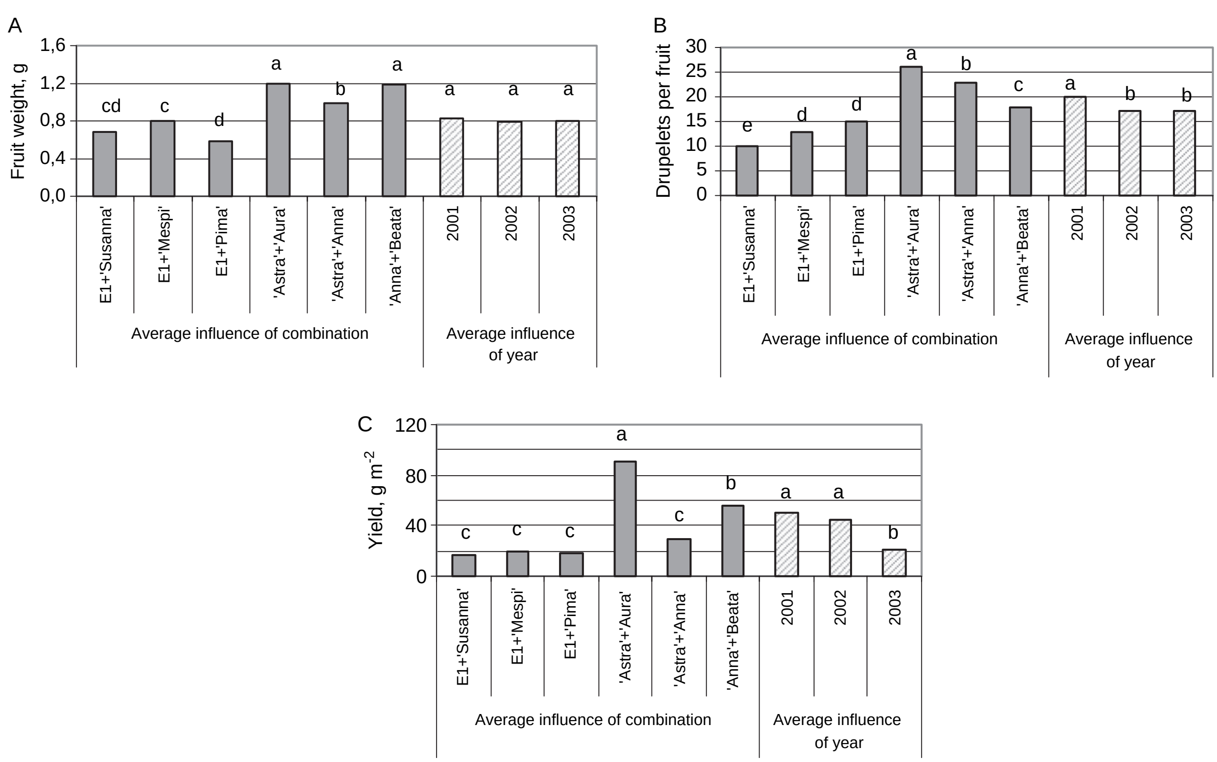

Figure 1. The influence of cultivar and strain combinations on the arctic bramble. A- fruit weight (g), B- number of drupelets (per fruit), and C-yield (g/m^{-2}) as an average of three experimental years (2001–2003).

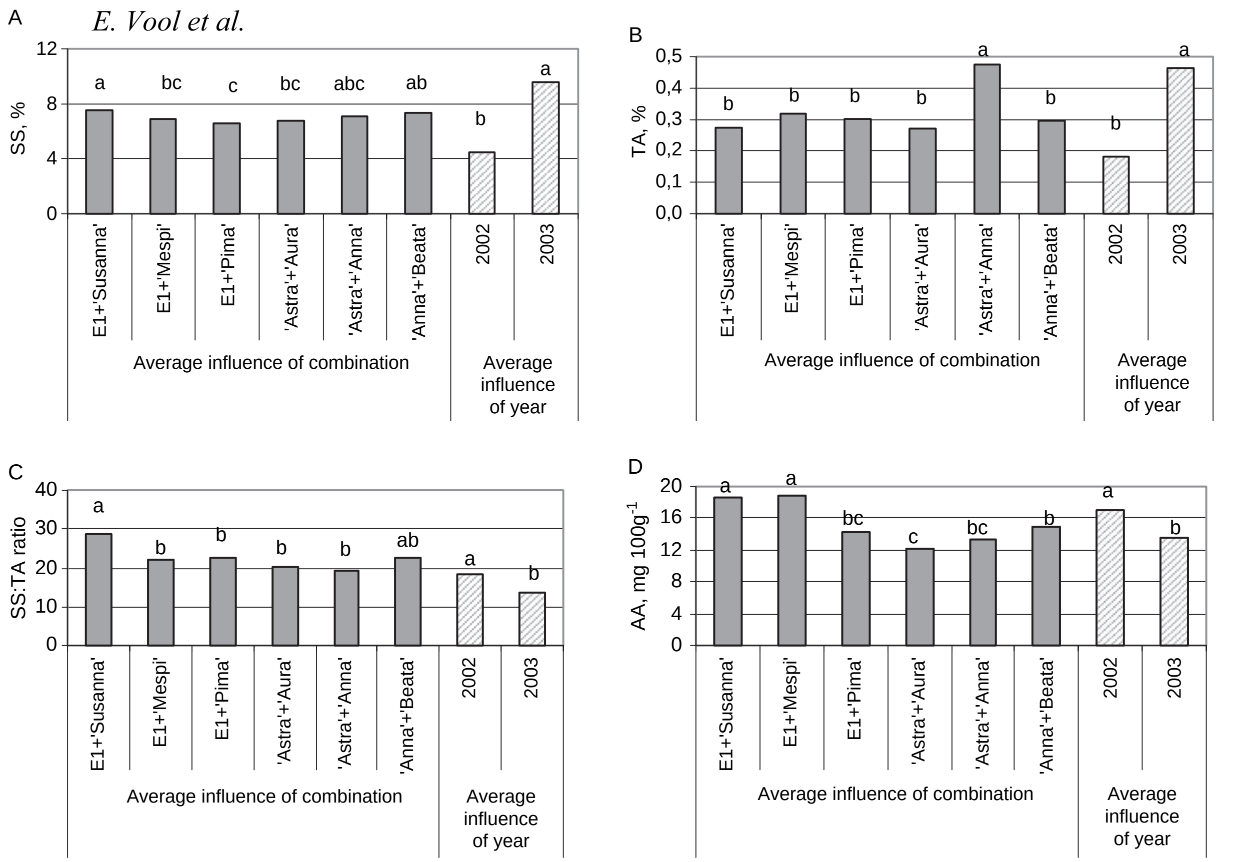

Figure 2. The influence of cultivar and strain combinations on the arctic bramble fruit biochemical composition over two experimental years (2002–2003). A – Soluble solids (%), B – titratable acids (%), C – ratio of soluble solids and titratable acids, D – ascorbic acid (mg per 100 g).

drupelets number and shoot number ($r = 0.60^{\star}$). The size of leaves did not influence the productivity.

Biochemical indicators

SS content of the fruit was 6.6–7.5% and was significantly dependent on the cultivars and year: E1 + 'Pima' had significantly less SS than did E1 + 'Susanna' (Figure 2A). There were no differences between SS content of hybrid cultivars. In 2002, the fruits contained less SS than in other years.

The TA content of the fruits ranged from 0.27 to 0.48% during the experimental years (Figure 2B). The 'Astra' + 'Anna' fruit mix contained more acids, but there was no significant difference between other cultivars. The TA content was lowest in 2002.

The SS:TA ratio was influenced by cultivars. The ratio was significantly higher in strain E1 and 'Susanna' when compared with the hybrid cultivar combinations containing cultivar 'Astra' (Figure 2C). Comparing experimental years, in 2002 the fruits had a significantly higher SS:TA ratio than in the second year.

The AA content of arctic bramble ranged from 12 to 19 mg (100 g)$^{-1}$ (Figure 2D). E1 combinations with 'Susanna' and 'Mespi' had significantly higher AA content than did other combinations. Correlation analysis showed a negative correlation between fruit weight and AA ($r = -0.67^{\star\star}$), shoot number and AA ($r = -0.65^{\star}$), and between the TA and shoot length ($r = -0.58^{\star}$).

Colour

The cultivars' properties influenced the juice colour. Significantly higher $L^{\star}$ values of fruit juice were found in the E1 combination with 'Mespi' or 'Pima' (Figure 3A). Significantly lower $+a^{\star}$ values were found in E1 and 'Pima' mixes (Figure 3B). Darker juice was obtained from hybrid cultivar combinations where 'Astra' was used. The correlation between drupelets number and $L^{\star}$ ($r = -0.56^{\star\star}$) was negative. A positive correlation was found between the drupelets number and $a^{\star}$ values ($r = 0.55^{\star\star}$), also between AA content and $L^{\star}$ ($r = 0.57^{\star\star}$). A positive correlation was found between the leaf area and $a^{\star}$ values ($r = 0.56^{\star}$), but there was a negative correlation between the shoot number and $L^{\star}$ ($r = -0.57^{\star}$).

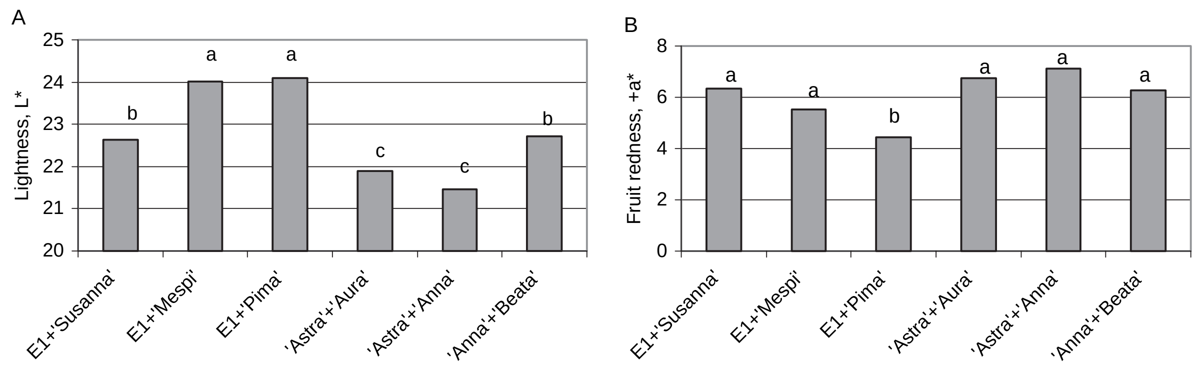

Figure 3. The influence of cultivar and strain combinations on the arctic bramble. A – Fruit lightness (L*), B – fruit redness (+a*) in 2003.

Discussion

Yield parameters

Arctic bramble fruits contained 10–15 drupelets, but hybrid fruits had 17–27 drupelets and that was dependent on the year. Better results (averaging 20 drupelets) were obtained in 2001. In arctic brambles, which are insect-pollinated, drupelets number depends on pollination success (Kangasjärvi & Oksanen, 1989). The data of Reier (1982) showed that well pollinated flowers would develop fruits with 15–30 drupelets. Thus, the conclusion can be made that pollination in the current experiment was not very successful and that hybrid cultivars were better pollinated. In addition to cultivars' characteristics, pollination success and the presence of pollinators is greatly dependent on yearly climatic conditions. The reason for the greater number of drupelets in 2001 was possibly due to a larger amount of precipitation in summer that increased the moisture content in air (Table I). Air moisture is an important factor for the pollen-grain development inside a flower. In the third year diseases negatively influenced the drupelets number.

The yields of arctic bramble were shown to be significantly lower than those of the hybrid cultivars. In the current experiment, the highest yield of the three experimental years was in arctic bramble hybrid cultivar combinations 'Astra' + 'Aura' and 'Anna' + 'Beata'. 'Aura' has also shown high productivity in Finnish experiments and has been recommended for growing in combination with 'Astra' (Hiirsalmi et al., 1987). At the same time the current experiment indicated that 'Astra' is not the best combination for 'Anna', because the yield was lower than in the combination 'Anna' + 'Beata'. In Finnish experiments 'Anna' has been one of the most productive cultivars among Swedish hybrids (Prokkola et al., 2001). Based on our results, the conclusion can be made that hybrid cultivars originating from the same country are more suitable for growing together. In arctic bramble variants, E1 was used in combination with Finnish cultivars. Although the number of drupelets and fruit weight differed between variants, there were no significant differences in yield. Cultivar 'Susanna' had not been used in experiments in Estonia before, but based on the current research results 'Susanna' can give the same amount of yield as 'Pima' and 'Mespi'. Thus, if we want to choose a pollinator for the Estonian local clone, none of the Finnish cultivars from the current experiment can be preferred based on yield.

Biochemical indicators

The averages of the three experimental years showed that the SS content in arctic bramble fruits varies, even if the fruits are picked from a two-cultivar mixture. The highest SS content was found from fruits in combinations E1 + 'Susanna' compared with E1 + 'Pima'. No significant differences in SS content were found comparing arctic bramble cultivars with hybrid cultivars. These results are different from those of previous experiments, where lower SS content occurred in fruits of hybrid cultivars (Häkkinen et al., 1994), with significant differences between the cultivars (Karp, 2001). Previous experiments showed that a lower SS content is found in fruits of 'Aura' and 'Astra'; the average SS content in fruits was 3.8–6.1% (Häkkinen et al., 1994; Starast et al., 2000). In the current experiments it was around 7%. The significant effect here could be the habitat as well as microclimatic conditions. In other words, the arctic bramble plants were surrounded with raspberries and they offer partial shadow, moreover they reduced the temperature fluctuations during the fruit-ripening period.

The TA content was high in fruits of 'Astra' and 'Anna, whereas Hiirsalmi et al. (1987) recorded that 'Astra' had more acidic fruit. TA content in other hybrid variants was similar to that of arctic bramble cultivars. Previously conducted experiments have shown that hybrid cultivars produce more acidic fruits (Häkkinen et al., 1994; Starast et al., 2000;

Karp, 2001). The average TA content in fruits in the current experiment was 0.33%, which is relatively low yet similar to results presented from Finland, showing citric acid content to be 0.3–1.9% (Häkkinen et al., 1994). In addition to partial shadow, the results were influenced by plant growth. Plant height has a considerable effect on TA content. The highest TA content was found in fruits of plants with a lower, shrub-type growth. The proposition could be that the effect on results obtained here is due to different light conditions. Based on the SS:TA ratio the sweetest fruits in the current experiment were in variants E1 + 'Susanna' compared with the hybrid cultivar combinations containing 'Astra'. The important indicator here is the consumers' sense of taste; the higher the SS:TA ratio the sweeter the taste, while the lower the ratio the sourer the taste of the fruits (Haffner et al., 2002).

In the current experiment a higher AA content was found in Estonian strain fruits with 'Susanna' and 'Mespi'. The average AA content in arctic bramble fruits over the experimental years was 16 mg (100 g)$^{-1}$. This is lower than that found in previous experiments conducted in Estonia, which showed AA content to be 19–25 mg (100 g)$^{-1}$ (Starast et al., 2000). Differences could be caused by partial shading by raspberries or by different annual climatic conditions. Since July was the warmest month during all three experimental years it could have caused the decrease of AA in fruits (Table I). The AA content in the current experiment was also dependent on the fruit weight and the shoot number; the AA content was higher in the case of lower fruit weight and shoots number.

The presence of an intense red colour is important in arctic bramble, which is a valuable raw material resource for liqueur production. In the current experiment cultivars' properties had a significant effect on juice colour. The darker juice was produced from combinations 'Astra' with 'Anna' or 'Aura'. The current results showed that cultivar 'Astra' improves the colour of cultivars mixture fruits. 'Astra' has also had good colour in previous experiments in Estonia (Starast et al., 2000). Among arctic bramble cultivar combinations with the Estonian clone, the juice was darker when 'Susanna' was used in combination. Thus 'Susanna' had the best colour among Finnish cultivars. In the current experiment erratic fruit colouring influenced the arctic bramble fruit juice colour. Most of the fruit was dark red and soft, but 1–3 drupelets remained yellow. Pirinen et al. (1998) also noticed this kind of erratic colouring. In the current experiment, however, the erratic fruit colouring did not occur on hybrid cultivars. Moreover, correlation analysis showed that arctic bramble drupelets number significantly influenced the colour; the more drupelets present, the darker and redder the fruit.

The experimental result showed that average yield of arctic brambles in different years is the same. Biochemical content of fruits from two-cultivar combinations is different in most characteristics.

Content of TA was similar in combinations, but SS content and SS:TA ratio were higher in combination where the Estonian clone was grown together with 'Susanna'; this combination also produced the darkest juice. Therefore the Estonian clone + 'Susanna' combination can be recommended.

Hybrid cultivar combinations showed that cultivars originating from the same country should be grown together for ensuring higher yields – good combinations were 'Astra' + 'Aura' and 'Anna' + 'Beata'. The biochemical content of a mixture of two hybrid cultivars was different only in TA and AA content. The colour of the mixture was improved when 'Astra' was used.

It is important to continue the research in order to examine disease resistance of cultivars, since in the current experiment yield could only be harvested during the first three years. After these three years the plants were infected and no significant yield was obtained.

Acknowledgements

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