Reasons for large annual yield fluctuations in wild arctic bramble (*Rubus arcticus* ssp. *arcticus*) in Finland

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Abstract

Fluctuations in the yield of wild berries are markedly influenced by weather conditions. However, the cause-effect relationship is often poorly understood. Based on data spanning a 20-year period in Finland, we made an effort to elucidate the influence of different weather conditions on the yield of arctic bramble (*Rubus arcticus*). We analyzed the regression coefficients of various weather conditions in several regression models using the elaboration approach. Temperature accumulated in July had a positive effect on yield. Yield was negatively influenced by temperature accumulated during the previous summer, rainfall in the October of the previous year, and temperature accumulated in May of the same year. It is notable that the same weather conditions had a positive influence on yield of the same year whereas these conditions had a negative effect on the yield potential of the following year. Compared to traditional analysis methods, the elaboration approach provided a better understanding of the relationship between weather parameters and yield. The rarity of a good yield could be explained by the particular vulnerability of arctic bramble to the negative effects of weather conditions. Some of these factors could be controlled in field conditions when cultivating arctic bramble.

Keywords: Rubus arcticus, arctic bramble, yield fluctuation, weather, elaboration

Introduction

Arctic bramble (*Rubus arcticus* ssp. *arcticus* L.) is an herbaceous plant native to subarctic Eurasia but it produces berries primarily between 62° and 66° northern latitude (Hultén 1971; Ryynänen 1973). Because of their unique aroma, the fruits are highly desired by consumers and the processing industry. Yields of wild arctic bramble have been decreasing for decades. While in 1941 the estimated yield in Finland was 1 million kg (Raatikainen 1988), the amount harvested in 2011 was only one thousand kg (Mavi 2012). In the past, arctic bramble thrived in woodland fields and open ditches (Saastamoinen 1930). As a pioneer plant, arctic bramble also benefited from slash-and-burn cultivation, which has not been practiced in Finland for over a century (Ervi et al. 1955). Modern farming has destroyed or changed most of the natural habitat. Compared to horse ploughing, tractor ploughing turns the rhizome too deep, resulting in its destruction.

In both cultivation and the wild, large annual yield fluctuations are common in arctic bramble (Mavi 2012). In field conditions, arctic bramble has been reported to produce 1350 flowers/m^2, leading to a yield potential of 10125 kg/ha (Ryynänen 1973). The best-recorded yields have been 6720 kg/ha in 1963 (Ryynänen 1973), and, in the early 1990's, 3300 kg/ha and 2000 kg/ha (Kokko et al. 1993). Flowering is often abundant but only a small proportion of the flowers develops into full aggregate fruits (Saastamoinen 1930; Ryynänen 1973; Kostamo et al. 2015). Similar to many pioneer plants, arctic bramble may produce excess flowers under exceptionally optimal conditions for fruit production, as in cloudberry (*Rubus chamaemorus*; Karst et al. 2008), or the excess flowers may be simply to attract more pollinators (Bell 1985; Burd 1998), and thus, increase pollen dispersal (Sutherland and Delph 1984).

A number of reasons have been proposed for the yield fluctuations (caused by the abortion of flowers or fruits or producing incomplete fruits) in arctic bramble, such as downy mildew (*Peronospora sparsa*) (Lindqvist et al. 1998; Kokko et al. 1999; Kostamo et al. 2015), pests (Kokko et al. 1998; Hartman 2008), pollination problems (Ryynänen 1973) and weather conditions (Saastamoinen 1930; Ervi et al. 1955; Ryynänen 1973; Lindqvist et al. 1998). In blackberry, true bugs and stink bugs misshape the drupelets (Brennan et al. 2013), and redberry mites prevent the drupelets from attaining full maturation (Pye and de Lillo 2010). In loganberry, raspberry and boysenberry, the dryberry mite (*Phyllocoptes gracilis*) causes "dryberry disease" (Pye and de Lillo 2010). Hartman (2008) concluded that in brambles, the poor fruit set resulting from small misshapen berries cannot be explained by a single factor but could be due to fungi, viruses, insects, lack of bees, and/or abiotic factors.

A common explanation for yield fluctuations in arctic bramble is unfavorable weather for bee (*Apis mellifera*) and bumblebee (*Bombus*) flight during the blooming period, and thus, poor pollination. However, there are no studies to support this claim, other than reports on chilling injuries (Saastamoinen 1930; Ryynänen 1973). Moreover, drying of flowers and green berries has also been observed when there is no chilling or downy mildew (Kostamo et al. 2015). Thus the main reason or interaction of reasons for yield fluctuation in arctic bramble has remained unknown.

The aim of this study was to better understand the reasons for arctic bramble yield fluctuations, in particular their possible relationships to weather conditions. For this, we used yield data spanning twenty years, offering a unique and reliable basis for the analysis. The yield data have been collected from a rather limited area of natural habitats for arctic bramble, which allowed us to take advantage of the detailed weather recordings of the Finnish Meteorological Institute. This is in contrast with the official Finnish recordings, collected over the country with widely varying weather conditions.

Materials and methods

The yield data from 1991 to 2010 were kindly provided by Lignell & Piispanen Ltd, which is the major processor of arctic bramble in Finland. The local weather data were obtained from the Finnish Meteorological Institute. For confidentiality reasons, the area where most of the fruits were picked and the weather data were derived is referred to as “A.” The yield data were transformed from kg to deviations (in percentages) from the average yield (0 %). The highest and lowest yields were +71.3 % and -24.3 %, respectively.

The weather data consisted of recordings every 3 h from May to July of temperature (ºC), relative humidity (%), and wind speed (m/sec). In addition temperature recordings at 2 m above ground level, daily minimum temperature at ground level measured with a minimum and maximum thermometer, daily rainfall (mm), daily accumulated temperature, and monthly recordings of rainfall were measured. Accumulated temperature was counted as the daily sum counted in degrees by which the actual air temperature rises above 5℃. The weather data were converted into yearly parameters (Table 1), which were used as the basis for the analysis. Yearly recordings of the length (weeks) of snow cover were also included. In considering the weather conditions to be tested, special attention was paid to the lifecycle of arctic bramble, such as periods of flower bud development in the late summer of the previous year and in the early summer of the harvesting year, flowering period, yield development and harvesting period, as well as factors affecting overwintering (Table 1).

Statistical analyses were carried out with IBM SPSS Statistics 21 (IBM, Armonk, NY, USA). Data are shown as means and standard deviations. P-values lower than 0.05 were considered statistically significant. Correlations between arctic bramble yield and weather conditions were characterized using Pearson correlation coefficient.

The data were further analyzed using regression models and elaboration approach (Babbie 2010; Rissanen et al. 2016). Elaboration calls for several regression models with various combinations of weather conditions (explanatory variables), known or hypothesized, being connected with yield development. The modelling starts with a univariate model with weather condition as the only explanatory variable (starting variable) and the yearly yield as the response. After this, the other relevant explanatory variables are added to the model, and the changes in the resulting regression coefficients, are recorded. Even if a variable does not improve the understanding of the phenomenon, it is not removed from the model until the analysis has been taken through the whole process. The focus is in the changes of the effects (regression coefficients) during the process, not in a single final model. Elaboration has been widely used in social sciences to understand the composite effect of several determinants, and to take advantage of their dependency structure. In the elaboration approach, the aim is to observe and compare the effects of the weather conditions on arctic bramble yield across various models that represent different contexts determined by the weather parameters known to modulate the yield. This approach considers multicollinearity more as a source of information rather than as a nuisance. The elaboration aims to reveal the interplay between the different explanatory conditions on yield. For this, we developed models where the weather conditions were included not only by the significance of their p-value but also by their hypothesized potential, based on the knowledge of arctic bramble lifecycle and previous studies, to enhance the whole model’s ability to explain the yield variations.

Results

To better understand the weather conditions that might give rise to the wide fluctuations in arctic bramble yield, we tested all the variables mentioned in Table 2. We will focus on the parameters in the data that reliably improved the understanding of the interaction between yield formation and weather parameters. Weather parameters in Table 2 that are not reported here did not have an effect on arctic bramble yield in our study in correlation analysis, regression analysis or in elaboration approach. All parameters were included in the model building process to avoid the exclusion of a parameter too early in the process. Only after the model was tested with all parameters were the parameters having an effect on the starting variable chosen, and others excluded from the final model displayed in this article.

Interestingly, we found a positive association between the yield and the harvesting year night frosts in correlation analysis (temperature below 0ºC) (Pearson correlation 0.51, $p = 0.021$) and night freezes (temperature below -2ºC) (correlation 0.45, $p = 0.05$) in May. Correspondingly, in the regression analysis the coefficient of the number of night frosts in May influenced the yield positively ($r_S = 2.07$, $p = 0.02$). In simple linear regression, the positive influence on yield increased from 12.42 to 55.89 percentage points when night frosts increased from the minimum value of 6 observations to a maximum of 27 observations. Also, high accumulated temperature in May influenced the yield negatively (correlation -0.448, $p = 0.048$), as also shown by the regression analysis ($r_S = -2.14$, $p = 0.05$). Both results indicate that cool weather conditions in May favor arctic bramble yield.

High accumulated temperatures from May to June in the previous year influenced arctic bramble yield negatively (Pearson correlation = -0.53, $p = 0.02$) (Figure 1), which was corroborated by the regression analysis (r= -1.62, p=0.02). The accumulated temperature combines several single weather parameters: temperature, rainfall and evaporation. When the accumulated temperature is higher it is more probable that evaporation is also higher, and the occurrence of rain is less probable.

To elucidate the associations among the weather conditions, and their relationship to yield formation, the data were further analyzed using elaboration. Our initial observation was that only a few of the individual weather parameters appeared to influence yield, and none of them was a strong determinant. However, different weather parameters together are known to influence yield. We thus chose the elaboration approach to evaluate the effects of different weather conditions as a whole on the yield. This resulted in four weather conditions that were examined more closely: previous year accumulated temperature from May to July; previous year rainfall in October; accumulated temperature in May; and accumulated temperature in July. Table 3 displays the relationships between arctic bramble yield and the previous year accumulated temperature as the starting variable, with rain and temperature conditions as added variables.

In the elaboration, we studied how the regression coefficients of weather variables changes when additional variables are included in the model. Elaboration was built around the first weather condition in the lifecycle of arctic bramble, i.e., the “accumulated temperature in the previous year from May to July” (starting variable; Table 3). Since this variable influenced the yield negatively at -1.62 regression coefficient (p = 0.02) (in 10^{o}C units), we further analyzed the three months individually and in all combinations. July had the greatest influence as a single month, however, all the three summer months together better explained the negative effect of increasing accumulated temperature on the following year’s yield. The starting variable explained 28.5% of the variation in the yield data. When this variable changed from the observed minimum to the maximum, the effect on yield changed from -90.20 (-1.62 x 55.68) to -133.55 (-1.62 x 82.44) representing a 43% negative effect on yield during the warmest summer compared to the coldest one. The other three weather variables were then added to the model in chronological order of their occurrence in the lifespan of arctic bramble.

In a univariate model, the “previous year rainfall in October” did not correlate significantly with the yield ($p = 0.44$), but when included in the model as the first added variable it turned out as significant ($p = 0.01$). The two variables together explained 51.6% of the yield variability, which was a marked increase compared to the 28.5% for the starting variable alone in the univariate model. Although the two weather variables are not linked in nature, in our data they showed a negative correlation ($r = -0.44$, $p = 0.06$). By including the first added variable in the model, the negative effect of the starting variable on the yield changed from -1.62 to -2.34 (in 10^{o}C units). By excluding the effect of the first added variable from the starting variable, the negative effect of accumulated temperature in May to July of the previous year was increased because the model was able to better describe the interactions of different weather parameters on yield. By using the minimum accumulated temperature, the effect changed from -90.20 (-1.62 x 55.68; univariate analysis) to -130.29 (-2.34 x 55.68; bivariate analysis). By using the maximum accumulated temperature, the influence on yield changed from -133.55 to -192.91, representing a 63 % difference in influence [-2.34 x (82.44-55.68)] on yield. Previous year rainfall in October associated with previous year accumulated temperature from May to July decreased the yield by a regression coefficient of -5.14 (in 1 cm rain). The previous year October rainfall observations in our data varied from 0.61 cm to 9.40 cm. By using the maximum October rainfall, the influence on yield had a 45% difference compared to the minimum value [-5.14 x (9.40 – 0.61)].

When “accumulated temperature in May” of the harvesting year (p = 0.03) was included in the trivariate model as the second added variable, the R^2 value increased from 51.6% in the bivariate model to 64.7%. The regression coefficient of the starting variable changed only slightly from –2.34 to -2.11 (in 10^{o}C units). By using minimum accumulated temperature, the effect on yield changed from -130.29% (bivariate analysis) to 117.48% (trivariate analysis). By using the maximum accumulated temperature, the effect on yield changed from 192.91% to 173.95%. The correlation coefficient decreased slightly because of the positive correlation between these two variables, both having a negative effect on the yield. Hence the previous year accumulated temperature from May to July partly carried the influence of accumulated temperature in May. The values of these two weather conditions change in the same direction in the data, so when this second added variable was included in the model, the previous year accumulated temperature from May to July did not have to carry the negative effect of accumulated temperature in May, and its own negative effect was thus decreased and could better describe the weather condition in question. The regression coefficient of accumulated temperature in May changed from -2.14 (p = 0.05) in the univariate model to -1.88 (p = 0.03) in the trivariate model (in 10^{o}C units). The negative effect on yield of accumulated temperature in May in the trivariate model ranged from -6.96% (-1.88 x 3.70) at the minimum observation to -36.00% at the maximum observation.

When accumulated temperature in July (p=0.05) was included in the quadrivariate model as the third added variable, the R^2 value increased by 8.6%. The four weather conditions together thus explained 73.3% of the variation in yield in our data. The inclusion of the third added variable enhanced the negative effect of the starting variable from -2.11 to -2.28 (in 10^{o}C units) due to the positive correlation of these two variables and their opposite effects on yield. The starting variable before also carried the positive effect of July accumulated temperature through the correlations of these two variables on the data. Inclusion of accumulated temperature in July also increases the regression coefficient of May from -1.88 in the trivariate model to -2.02 in the quadrivariate model (in 10^{o}C units). When the accumulated temperature in May does not have to carry the weight of the partial influence of warm summer it allows the negative effect of warmness in spring to rise in influence on its own and the negative regression coefficient of accumulated temperature is strengthened. Quadrivariate analysis also revealed the positive effect of accumulated temperature in July (regression coefficient 1.42, p = 0.05, in 10^{o}C units), although it was not significant in the univariate analysis (regression coefficient 0.77, p = 0.47, in 10^{o}C units).

When assessing the effects of different weather conditions on the quadrivariate model (Table 3), the value ranges among years also provide useful information on each weather condition. The previous year accumulated temperature ranged from 55.68 to 82.44 (in 10°C units), representing a difference of 26.76 between the most extreme years. When it was multiplied by the -2.28 regression coefficient for this particular weather condition, we discovered a 61% difference in yield between the most favorable and the most unfavorable year. Previous year October rainfall ranged from 0.61 to 9.40 cm. Multiplying the difference with the regression coefficient (-4.69) indicates that this variable had the potential to decrease yield by 41%. Accumulated temperature in May ranged from 3.70 to 19.15 (in 10°C units), resulting in a 31% effect on yield from the most favorable to unfavorable seasons. The only variable with a positive influence on yield was the accumulated temperature in July. It ranged from 27.12 to 44.44 (in 10°C units), resulting in a potential positive effect of 25% on the yield. It thus appears that arctic bramble is very vulnerable to the negative effects of weather, and these results provide an explanation for the rarity of good yields.

Discussion

This analysis indicates that a high accumulated temperature in the previous summer has a negative effect on the fruit yield of arctic bramble. Under these conditions, the plants are more likely to suffer from drought. A negative effect of drought on the following year's yield has been reported in raspberry (*Rubus idaeus*) (Morales et al. 2013). Arctic bramble develops flower initials in the apical buds during the previous summer from mid-July to early August (Zeller 1964). Flowers are also initiated from axillary buds during the growing season of the harvesting year (Palonen et al. 2012) (Figure 2). It has been proposed that perennial species must allocate resources between the competing functions of pollen and ovule production and the storage of nutrients for survival and growth during the following season (Primack 1979). Our results corroborate this. Further studies are needed to test the theory that under high accumulated temperature conditions, arctic bramble prioritizes yield production over apical bud and initial flower formation for the following year. Jean and Lapointe (2001) reported that cloudberry yield might be dependent on the use of stored carbohydrates in the rhizome, as carbon limitation is an important causal factor in fruit abortion. The previous year high accumulated temperature might influence the arctic bramble yield both by affecting the amount of stored carbohydrates and thus fruit abortion rates, and by affecting the number of floral primordia in axillary buds.

Our finding on the negative effects of October rainfall on the next year's yield appears to agree with that of Bristow et al. (1989). The authors found that late fall flooding causes root damage and root rot in red raspberry, weakening photosynthesis and growth in the following summer. Cook and Papendick (1972) found that late fall rains can create optimal conditions for root pathogens. In arctic bramble, the late fall rainfall occurs after the development of apical buds, which already contain floral primordia. It might thus be that a very rainy fall damages apical buds directly, or indirectly by creating optimal conditions for different types of pathogens. It has also been reported that heavy irrigation late in the fall has a negative effect on the winter survival of red raspberry

(Hoppula and Salo 2006). Winter logging is likely to become a more frequent phenomenon in Finland due to climate change, and thus poses a further threat to arctic bramble yield (Jylhä et al. 2004).

Our results on the positive effects of night frosts in May, and low accumulated temperature, are novel. The spring weather plays a multidimensional role in the yield production of arctic bramble. Frosts in successive nights have been reported to cause severe yield losses (Saastamoinen 1930; Ryynänen 1973). Cooler temperatures in early season have been speculated to create more favorable conditions for flowering, due to delays in the development of flowers, but until now this has not been shown. Another possibility is that the abortion or damage to the buds and flowers early in the flowering period induces a more abundant second flowering at the end of June and at the beginning of July, which is the second flowering peak in arctic bramble. However, this is not a probable explanation as energy would be wasted for flowers to be damaged by frost, and flower formation does not seem to be a bottleneck in arctic bramble yield production. An assumption is that a late start for the season improves the yield by assuring warm weather during the flowering period, and the colonies of pollinating insects in nature have had time to grow sufficiently to facilitate optimal pollination. It is probable that a late season favors better yields and more effective pollination, as the occurrence of frosts and cold weather are then more unlikely during the main flowering period. However, it is arguable whether night frosts would have a detrimental effect on the yield in a plant such as arctic bramble, which can produce new flowers in June to replace the damaged or aborted ones.

We found that high accumulated temperature in July has a positive effect on yield. Previously arctic bramble fruits have been reported to dry up under hot weather conditions (Saastamoinen 1930). Morales et al. (2013) also reported that drought affected fruit quality in raspberry; a larger proportion of malformed fruits developed under drought, and the fruits were smaller. We have observed a high proportion of malformed arctic bramble fruits not developing into full aggregate fruits, but we were not able to identify any single reason for the findings (Kostamo et al. 2015). Artificial elevation of the relative air humidity has been shown to affect arctic bramble yield positively under hot summer conditions (Hiirsalmi 1975). Ryynänen (1973) reported the best yield in 1963, which was cool but not rainy. The accumulated temperature could have an optimum value, after which a positive effect turns negative. It is likely that under limited resources the plants focus on yield instead of the rhizome for storage or apical bud for the formation of flowers, which in arctic bramble occurs concurrently with the ripening of the berries (Zeller 1964). Apical buds reveal their first flowers in the spring. The previous year high accumulated temperature might also influence yield through the resources available for flower formation and not only the number and size of flowers developed in the previous mid-July to August.

These results indicate that the positive effect on the yield of the accumulated temperature in July turns to a negative effect on the next year's yield, based on the weather variable 'accumulated temperature in previous year from May to July'. It seems to be a built-in characteristic of arctic bramble to have yield fluctuations because a weather condition can have a positive effect on the yield in the same season and a negative effect on the next season.

No data were available for this analysis on daily light integral. Palonen et al. (2012) found that the number of flowers per plant increases when arctic bramble plants are exposed to higher daily light integral and long days (24 h). Arctic bramble produces fewer leaves between the flowers in higher than in lower light integral. Higher light integral promotes earlier flowering and increases the number of flowers also in *Eustoma grandiflorum* (Islam et al. 2005). Furthermore, Mattson and Erwin (2005) found in ten herbaceous plants that when irradiance increases, the number of leaves decreases before the first flowers develop. The influence of light conditions should be assessed in the future when arctic bramble yield is considered.

A closer analysis of our results indicated that the data were not suitable for determining, which weather parameters have an effect on pollination. The weather during the flowering period most likely influences the yield, as arctic bramble is self-sterile and needs insect pollination for fruit production (Ryynänen 1973, Tammisola 1988). To explore the influence of weather during the flowering period would require the yield data from a specific location and the weather data from that particular microclimate at the height of the plants. Also, the plants should be optimally pollinated, so as to exclude the absence of pollinators from affecting the results. This is because it has been found in strawberry that the fruit weight increases with the number of visits by pollinating insects up to 20 visits, and fruit abortion rates are affected by the number of visits up to six visits (Free 1993). It has also been reported that in arctic bramble the best yields in natural habitats are found where pollination is secured by seven or more different genotypes of arctic bramble (Tammisola 1988). However, as the microclimatic factors affect pollinator activity and thus pollination, our data were not suitable for assessing pollination effects.

The information about harvesting period was also not optimal for our analysis. Yield data should have been recorded daily or weekly and weather conditions should correspond to the same microclimate. The harvesting period in arctic bramble can be two months long. In rainy weather, the fruits spoil easily and the harvesting period in the same season can include diverse weather conditions.

The yield data used in this study are the most reliable ones that exist on arctic bramble, spanning a 20-year period. We acknowledge that the data are not derived from exact field studies, but are from the records of the main industrial end-user of arctic bramble. Although the fruits have been picked from a rather limited area in Finland, the weather conditions obviously have some local variation. Obtaining significant findings from such data strengthens their validity. The phenomena found in this study are strong because the yield data was based on yield gathered from different natural habitats. Different habitats caused added dispersion to the yield data compared to a data from controlled field study. This added dispersion could not hide the phenomena's found in this study.

We found that single weather parameters are best analyzed in their natural context in interaction with other parameters, and not as individual entities. Despite the uncertainties in estimating yield, the results are clear and valid for assessing the annual fluctuations observed in arctic bramble. The weather records are from the most important harvesting area and thus, are also considered appropriate. Although we were unable to analyze factors affecting arctic bramble pollination and harvesting period, this study offers novel information, which may have wider implications than just for the arctic bramble. Rather than optimizing yield in one year, it is evidently crucial to aim for constantly good average yields, as the same weather condition can have positive effects on the same year's yield and a negative effect on the next year's yield. Cultivation practices should be developed to eliminate the possible negative effects of different weather characteristics and to enhance the positive ones. Cultivation in polytunnels would offer the possibility to exclude rainfall in autumn and the possibility to ensure higher accumulated temperature in summer months. Both of these were found to have a positive effect on yield in our study. Drip irrigation might prevent the negative effect we found that high accumulated temperature in previous summer had on yield. The use of straw or other mulches should be investigated in delaying the spring growth to get the beneficial effect of low accumulated May weather found in this study.

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Table 1. Conversion of original data into yearly weather conditions

Weather conditions
length of snow cover in the previous winter
monthly accumulated temperature from May to July
total accumulated temperature from May to July
total accumulated temperature in the previous year from May to July
monthly accumulated temperature in the previous year from May to July
number of days above 10°C in May and 14°C in May and 10°C in June and 14°C in June, all months separately
monthly rainfall from May to October
monthly rainfall in the previous year from May to October
rainfall from June to July and June to August and May to August and May to September
days with less than 1 mm rainfall monthly from May to July
days with no rainfall from June to July
days with less than 1 mm rainfall from June to July
days with less than 1 mm rainfall in the previous year, monthly from May to July
days with the daily minimum temperature below 0°C during the flowering period (a)
days with the daily minimum temperature below -2°C during the flowering period (a)
days with the daily minimum temperature below 0°C in May
days with the daily minimum temperature below -2°C in May
days with the daily minimum temperature below 0°C in June
days with the daily minimum temperature below -2°C in June

a) Flowering period = days from the 85°C accumulated temperature till the end of June

Table 2. Weather conditions as overall means during the observation period, with standard deviations as well as minimum and maximum values.

	Unit	Mean		Sd	Min	Max
Accumulated temperature in previous year in May	°C	97.4	±	40.6	37.0	163.5
Accumulated temperature in previous year in June	°C	248.6	±	42.1	150.0	318.1
Accumulated temperature in previous year in July	°C	339.4	±	44.5	271.2	444.4
Accumulated temperature in previous year from May to July	°C	685.4	±	72.0*	556.8	824.4
Rainfall in previous year in June	mm	48.6	±	31.5	6.5	111.8
Rainfall in previous year in July	mm	77.5	±	41.1	24.3	191.1
Rainfall in previous year in August	mm	62.4	±	34.5	11.1	138.4
Rainfall in previous year in September	mm	48.8	±	29.1	15.5	108.3
Rainfall in previous year in October	mm	50.1	±	25.1	6.1	94.0
Rainfall in previous year from May to August	mm	234.7	±	82.6	90.9	439.3
Length of snow cover in the previous winter	weeks	22.4	±	3.1	17.9	28.1
Night frost days during the flowering period a)	number of	5.4	±	3.1	0.0	12.0
Night frost days in May	number of	16.3	±	5.3*	6.0	27.0
Night frost days in June	number of	5.1	±	2.2	1.0	9.0
Night freeze days during the flowering period a)	number of	1.3	±	1.6	0.0	6.0
Night freeze days in May	number of	11.7	±	5.0*	5.0	25.0
Night freeze days in June	number of	1.3	±	1.0	0.0	3.0
Accumulated temperature in May	°C	102.1	±	44.8*	37.0	191.5
Accumulated temperature in June	°C	246.8	±	41.8	150.0	318.1
Accumulated temperature in July	°C	343.5	±	47.0	271.2	444.4
Accumulated temperature from May to July	°C	692.4	±	76.7	556.8	825.3
Rainfall in May	mm	40.8	±	23.7	14.6	47.9
Rainfall in June	mm	47.9	±	30.8	6.5	111.8
Rainfall in July	mm	76.6	±	40.2	24.3	191.1
Rainfall in August	mm	66.0	±	31.3	11.1	138.4
Rainfall in June and July	mm	124.5	±	57.2	38.9	283.1
Rainfall from June to August	mm	190.5	±	78.3	50.0	389.7
Rainfall from May to August	mm	223.0	±	96.0	90.9	439.3
Days with less than 1 mm rainfall in May	number of	22.9	±	3.1	18.0	29.0
Days with less than 1 mm rainfall in June	number of	21.6	±	4.3	13.0	29.0
Days with less than 1 mm rainfall in July	number of	20.7	±	4.2	14.0	28.0

a) flowering period accumulated temperature from 85°C to the end of June

*) significant correlation of parameter to yield at $P<0.05$ in univariate regression model

Table 3. The process of building a quadrivariate model of yield using elaboration approach displayed by the effects (regression coefficients) of four weather conditions on the lifecycle of arctic bramble. All weather conditions were analyzed individually and in a series of three additional regression models. The regression coefficients were measured as yield (%) per one unit (10°C) increase in temperature or one unit (cm) increase in rainfall. For example, regression coefficient -2.34 indicates a 2.34 % decrease in the yield if accumulated temperature in previous year May to July increases by 10°C. Significant interactions between yield and models at $P < 0.05$ or $P < 0.01$ are indicated by (*) or (**), respectively.

Regression coefficients of the four weather conditions with yield as a response (Coefficients of determination, R^2)						
Cumulative order of the variables into the models			Univariate models	Bivariate model (51.6%)	Trivariate model (64.7%)	Quadrivariate model (73.3%)
Starting variable	Previous year	Accumulated temperature in May-July (per 10°C)	-1.62 * (28.5 %)	-2.34**	-2.11**	-2.28**
First added variable		Rainfall in October (cm)	-1.91 (4.0 %)	-5.14*	-5.26**	-4.69**
Second added variable	Harvesting year	Accumulated temperature in May (per 10°C)	-2.14 * (20.0 %)		-1.88 *	-2.02*
Third added variable		Accumulated temperature in July (per 10°C)	0.77 (2.9 %)			1.42 *

Figure 1. High accumulated temperature in the previous year lowers the yield potential for the perennial arctic bramble.

Figure 2. Effects of different weather conditions on arctic bramble yield production under the conditions prevailing during the data collection for this study, combined with information from the available literature.

† Palonen et al. 2012

‡ Ryynänen 1973

§ Saastamoinen 1930; Ervi et al. 1955; Ryynänen 1973

¶ Ryynänen 1973

≠ Saastamoinen 1930; Ryynänen 1973

£ Saastamoinen 1930