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Effects of Latitude and Weather Conditions on Contents of Sugars, Fruit Acids, and Ascorbic Acid in Black Currant (*Ribes nigrum* L.) Juice

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The genetic background determined the composition of black currants and the compositional response to weather conditions. The variety Melalahti had higher values for glucose and sugar/acid ratio and lower contents of fructose, citric acid, quinic acid, and vitamin C than the varieties Mortti and Ola ($p < 0.05$). In comparison to black currants grown in northern Finland (latitude 66°34′ N), the berries grown in southern Finland (latitude 60°23′ N) had higher contents of fructose, glucose, sucrose, and citric acid (by 8.8, 6.1, 10.0, and 11.7%, respectively) and lower contents of malic acid, quinic acid, and vitamin C (by 31.1, 23.9, and 12.6%) ($p < 0.05$). Fructose, glucose, and citric acid in Melalahti were not influenced by the weather, whereas their concentrations in Mortti and Ola correlated positively with the average temperature in February (Pearson's correlation coefficients = 0.53−0.79, $p < 0.01$) and July (Pearson's correlation coefficients = 0.63−0.87, $p < 0.01$) and negatively with the percentage of the days with a relative humidity of 10−30% from the start of the growth season until the day of harvest (Pearson's correlation coefficients = from −0.47 to −0.76, $p < 0.01$). Positive correlations existed between fructose and glucose (Pearson's correlation coefficients = 0.95−0.96, $p < 0.01$), citric acid and fructose (Pearson's correlation coefficients = 0.57−0.75, $p < 0.01$), as well as between citric acid and glucose (Pearson's correlation coefficients = 0.56−0.70, $p < 0.01$) in the three varieties because of the closely related metabolic pathways.

KEYWORDS: Black currant; fruit acids; latitude; *Ribes nigrum*; sugars; vitamin C; weather conditions

INTRODUCTION

Black currant is commonly grown for juice, jam, and syrup production in northern Europe, where it is highly valued for its flavor and nutrient content. The sensory properties of black currant are of special importance for the consumers. Contents of sugars, fruit acids, and the sugar/acid ratio are among the primary quality factors of fruits and fruit juices (*1*, *2*). Berries with pleasant sensory characteristics often have high contents of sugars and relatively low contents of acids (*2*, *3*). Genotype is one of the key factors affecting the sensory and biochemical characteristics of black currant (*4*, *5*).

Metabolism of sugars and acids is closely related to the photosynthesis and respiration of the plant. Vitamin C is derived from the hexose pool and is thus related to the carbohydrate metabolism pathways (*6*, *7*). Factors affecting these bioprocesses, such as water, light, temperature, and soil nutrients, often have an effect on the contents of sugars, acids, and vitamin C in fruits and berries (*8*−*10*). Latitude is always associated with climatic properties. Temperature, day length, UV irradiation, and total precipitation may vary according to the latitude. Thus, both latitude and weather conditions are of special importance for fruit quality.

Although little has been reported about the correlation between latitude and the composition of fruits, the effects of weather conditions on some plant species have been studied. For example, accumulation of malic acid in grapes is favored at fairly low temperatures (20−25 °C) (*11*). Citric acid production in peach is reduced by high temperatures during the last weeks before harvest but increased by high temperatures before this period (*12*). Likewise, high temperature increases the concentrations of glucose and fructose but decreases the content of sucrose in purple passionfruit (*13*). A relation between the temperature sum in the late harvest season and the fruit quality of orange has also been reported (*14*). The rate of photosynthesis and the activity of sucrose phosphate synthase are reduced by

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drought conditions to some extent in mulberry varieties (*15*). Saltwater irrigation and limited water supply increase the concentration of sucrose in kiwifruit and orange (*16, 17*) and decrease the concentration of ascorbic acid in cherry tomato (*18*). Partial root drying reduces the fruit size but increases the content of total soluble solids in tomato (*19*). Exclusion of light inhibits the degradation of malic acid, increases the concentration of dioxygenated anthocyanins, and reduces the content of flavonols in grape. In contrast, exposure to sunlight increases the contents of anthocyanins and phenolics in grape skin (*20*−*23*).

Until now, little is known about the overall impact of latitude and weather conditions on the composition of black currants. Because black currant is mainly grown under contract farming for commercial juice processing, it is particularly important for the processors that the essential composition and the sensory properties of the juice remain relatively constant (*4*). Therefore, the less the currant variety is affected by weather conditions, the more suitable it is for commercial processing. In the present study, sugars, fruit acids, and vitamin C in three Finnish commercial varieties of black currant grown at two different latitudes were analyzed over a 3 year period. Vitamin C was determined in the form of ascorbic acid. This is the first investigation into the effects of growth latitude and weather conditions on these components. Correlations among the components were also studied.

MATERIALS AND METHODS

Samples. Black currants (*Ribes nigrum* L.) of three different varieties, Mortti, Ola, and Melalahti, were cultivated in Piikkiö, southern Finland (latitude 60°23′ N, longitude 22°33′ E, altitude 5−15 m), and Apukka, northern Finland (latitude 66°34′ N, longitude 26°01′ E, altitude 100−105 m), by MTT Agrifood Research Finland. All of the bushes were planted in four field blocks (each block consisted of three bushes) in May 2002, and no irrigation was applied during the study period. All of the cultivation blocks, both in the south and the north, were set up in an identical way. A ditch, 10 cm deep and 20 cm wide, was plowed through every block. The ditches were filled with white *Sphagnum* peat (pH 6) mixed with 8 kg of dolomite lime and 1.5 kg/m^3 NPK basic fertilizer. The seedlings were planted, and the peat was covered with the local fine sand soil. The berries were picked optimally ripe as defined by experienced horticulturists based on color, flavor, and structure of the berries. Four lots were harvested separately from the four field blocks in both Piikkiö and Apukka in three consecutive years. The berries of the variety Mortti were harvested on August 15th, 18th, and 1st in Piikkiö and on August 31st, 14th, and 23rd in Apukka in 2005, 2006, and 2007, respectively. The berries of the variety Ola were harvested on August 19th, 11th, and 2nd in Piikkiö and on August 31st, 16th, and 23rd in Apukka in 2005, 2006, and 2007, respectively. The berries of the variety Melalahti were harvested on August 22nd, 11th, and 2nd in Piikkiö and on August 22nd, 10th, and 23rd in Apukka in 2005, 2006, and 2007, respectively. The berries were frozen and stored at −20 °C immediately after harvesting and were analyzed within 1 year. A paired-sample *t* test showed that there was no significant difference ($p > 0.05$) between the black currant samples analyzed after harvesting and the samples stored at −20 °C for 1 year. Therefore, the compounds in black currant juice studied are stable at −20 °C for 1 year.

Information on Weather Conditions. Data recorded at the weather station in Piikkiö Yltöinen (latitude 60°23′ N, longitude 22°33′ E, altitude 6 m) and Rovaniemi Airport (latitude 66°33′ N, longitude 25°50′ E, altitude 195 m) for the years 2005−2007 were provided by the Finnish Meteorological Institute (Erik Palménin aukio, FI-00560 Helsinki, Finland). The weather variables and their abbreviations used in the study are shown in **Table 1**.

Reference Compounds. D-Fructose, D-quinic acid, and L-ascorbic acid were purchased from Sigma Chemical Co. (St. Louis, MO). D-Glucose and internal standard D-sorbitol (for sugars) were purchased from Fluka (Buchs, Switzerland). Malic acid and internal standard L-tartaric acid (for acids) were purchased from Merck (Darmstedt, Germany). Sucrose and citric acid were purchased from J. T. Baker (Deventer, Holland).

Sample Preparation. Two methods of sample preparation were applied for samples collected in different years. The comparison of the methods was conducted with the sample collected from block 2 of Mortti in Apukka in 2005.

Samples Collected in 2005 and 2006. Quadruplicate extracts of sugars and acids of each sample lot were prepared according to a method previously used in this laboratory (*2*). About 50 g of berries were taken in duplicate, thawed, and crushed manually 50 times with a potato masher. The slurry was centrifuged at 4420*g* for 10 min. After centrifugation, the juice was separated and the volume was determined. A portion of 0.5 mL of juice was taken in duplicate, and 0.5 mL of internal standard sorbitol (0.5 g/100 mL), 0.5 mL of internal standard tartaric acid (1.0 g/100 mL), and 0.3 mL of 0.1 M NaOH were added. The solution was diluted with MilliQ water to a final volume of 10 mL. The remnant of the juice was combined, and the pH of the juice was measured using an Inolab pH level 1 meter (Wissenschaftlich Technische Werkstätten, Weilheim, Germany), and the content of soluble solids was determined with a refractometer (0−32 °Brix, Atago, Tokyo, Japan). A sample of 1 mL dilution was fractionated using a dual solid-phase extraction procedure, where the anthocyanins were absorbed in the upper nonpolar cyclohexyl Isolute CH (EC) column (100 mg/mL) (International Sorbent Technology, Hengoed, U.K.), and the acids were trapped in the lower anion-exchange Isolute SAX column (International Sorbent Technology). Sugars and fruit acids were eluted from the SAX column with 2 mL of water and 1 mL of 15 M formic acid, respectively. Ascorbic acid was eluted together with acids. Both fractions were diluted to a final volume of 3 mL, from which a sample of 1 mL was taken and evaporated to dryness under nitrogen stream at 40 °C and kept in a desiccator over P_2O_5 overnight. Trimethylsilyl (TMS) derivatives of sugars and acids were prepared by adding 600 μL of Tri-Sil (Pierce, Rockford, IL) reagent in each fraction, shaking vigorously with a Vortex (Vortex-Genie, Springfield, MA) for 5 min, and incubating at 60 °C for 30 min. The sample was then cooled to room temperature.

Samples Collected in 2007. Quadruplicate extractions of sugars and acids of each sample lot were performed without fractionation as described earlier (*24*). About 7 g of berries were weighed accurately in duplicate, thawed at room temperature for 15 min, and pressed manually 30 times with a potato masher. The slurry was centrifuged at 4360*g* for 10 min. The juice was separated, and the volume was determined. A portion of 0.25 mL of the juice was taken in duplicate, and 0.25 mL of internal standard sorbitol (0.5 g/100 mL) and 0.25 mL of internal standard tartaric acid (1.0 g/100 mL) were added. The juice was then diluted with MilliQ water to a final volume of 5 mL. The remnant of the juice was combined, and the pH and soluble solids were determined. The diluted juice was filtered (0.45 μm). An aliquot of 300 μL of the filtrate was evaporated to dryness under nitrogen stream at 40 °C and kept in a desiccator over P_2O_5 overnight. TMS derivatives were prepared in the same way as described in the previous section.

Gas Chromatographic Analysis. *Samples Collected in 2005 and 2006.* The TMS-derivatized samples were analyzed with a Perkin-Elmer Auto System gas chromatograph (GC) equipped with a flame ionization detector (FID). The analyses were carried out with a methyl silicone Supelco Simplicity-1 fused silica column (30 m × 0.25 mm i.d. × 0.25 μm d_f) (Bellefonte, PA). A sample of 1 μL was injected with an autosampler (Perkin-Elmer, Norwalk, CT) into a split injector (split ratio of 1:25). The flow rate of the carrier gas helium was 1.3 mL/min. The temperature of the injector was 210 °C, and the temperature of the detector was 290 °C. The column temperature program for the sugar fraction was set as 2 min at 200 °C, raised to 240 °C at a rate of 10 °C/min, raised to the final temperature of 285 °C at a rate of 30 °C/min, and held at 285 °C for 5 min. The appearance of three fructose peaks and two glucose peaks in chromatogram are due to their different isomeric forms. The retention times of fructose peaks are 3.64, 3.68, and 3.81 min; the retention times of glucose peaks are 4.28 and 4.99 min; the retention time of sorbitol is 4.80 min; and the retention time of sucrose is 9.71 min. For the acid fraction, the temperature was programmed as 2 min at 150 °C, followed by a rise to 275 °C at a rate

Table 1. Weather Variables and Their Abbreviations Used in the Study

abbreviations	weather variables	abbreviations	weather variables
Tjan	average temperature in January (°C)	HUgh	average of relative humidity at mid-day from the start of the growth season until the day of harvest (%)
Tfeb	average temperature in February (°C)	HUm	average of relative humidity at mid-day in last month before harvest (%)
Tmar	average temperature in March (°C)	DHu0to10gh	percentage of days with relative humidity of 0−10% from the start of the growth season until the day of harvest (%)
Tapr	average temperature in April (°C)	DHu10to20gh	percentage of days with relative humidity of 10−20% from the start of the growth season until the day of harvest (%)
Tmay	average temperature in May (°C)	DHu20to30gh	percentage of days with relative humidity of 20−30% from the start of the growth season until the day of harvest (%)
Tjun	average temperature in June (°C)	DHu30to40gh	percentage of days with relative humidity of 30−40% from the start of the growth season until the day of harvest (%)
Tjul	average temperature in July (°C)	DHu40to50gh	percentage of days with relative humidity of 40−50% from the start of the growth season until the day of harvest (%)
Taug	average temperature in August (°C)	DHu50to60gh	percentage of days with relative humidity of 50−60% from the start of the growth season until the day of harvest (%)
Dg	the lengh of the growth season (day)	DHu60to70gh	percentage of days with relative humidity of 60−70% from the start of the growth season until the day of harvest (%)
SUMTg	temperature sum exceeding 5 °C during the growth season (°C)	DHu70to80gh	percentage of days with relative humidity of 70−80% from the start of the growth season until the day of harvest (%)
SUMTm	temperature sum exceeding 5 °C during the last month before harvest (°C)	DHu80to90gh	percentage of days with relative humidity of 80−90% from the start of the growth season until the day of harvest (%)
HDgh	hot days (temperature >25 °C) from the start of the growth season until the day of harvest (day)	DHu90to100gh	percentage of days with relative humidity of 90−100% from the start of the growth season until the day of harvest (%)
HDm	hot days (temperature >25 °C) in the last month before harvest (day)	DHu0to10m	percentage of days with relative humidity of 0−10% in last month before harvest (%)
Tm	average temperature in the last month before harvest (°C)	DHu10to20m	percentage of days with relative humidity of 10−20% in last month before harvest (%)
Tw	average temperature in the last week before harvest (°C)	DHu20to30m	percentage of days with relative humidity of 20−30% in last month before harvest (%)
TDm	mean daily temperature difference in the last month before harvest (°C)	DHu30to40m	percentage of days with relative humidity of 30−40% in last month before harvest (%)
LoTm	average of daily lowest temperature in the last month before harvest (°C)	DHu40to50m	percentage of days with relative humidity of 40−50% in last month before harvest (%)
HiTm	average of daily highest temperature in the last month before harvest (°C)	DHu50to60m	percentage of days with relative humidity of 50−60% in last month before harvest (%)
SUMRgh	radiation from the start of the growth season until the day of harvest (kJ/m^2)	DHu60to70m	percentage of days with relative humidity of 60−70% in last month before harvest (%)
SUMRm	radiation during the last month before harvest (kJ/m^2)	DHu70to80m	percentage of days with relative humidity of 70−80% in last month before harvest (%)
SUMRw	radiation during the last week before harvest (kJ/m^2)	DHu80to90m	percentage of days with relative humidity of 80−90% in last month before harvest (%)
SUMPgh	precipitation from the start of the growth season until the day of harvest (mm)	DHu90to100m	percentage of days with relative humidity of 90−100% in last month before harvest (%)
SUMPm	precipitation in the last month before harvest (mm)		

of 20 °C/min, and held at 275 °C for 5 min. The retention time of malic acid is 3.73 min; the retention time of tartaric acid is 4.88 min; the retention time of citric acid is 6.07 min; the retention time of quinic acid is 6.62 min; and the retention time of ascorbic acid is 7.11 min. Analytes were identified by co-injection of the reference compounds and by comparing the mass spectra of the analytes to those of the reference compounds.

Samples Collected in 2007. TMS derivatives of the dried juice samples were analyzed with a Hewlett-Packard 5890 Series II GC (Hewlett-Packard Co., Palo Alto, CA) equipped with a FID and a Hewlett-Packard 7673 autosampler. The analyses were carried out with a Supelco Simplicity-1 fused silica column, as defined earlier. A sample of 1 μL was injected into a split/splitless injector. The flow rate of the carrier gas helium was 1.4 mL/min. The temperature of the injector was 210 °C, and the temperature of the detector was 290 °C. The column temperature was programmed as 2 min at 150 °C, raised to 210 °C at a rate of 4 °C/min, raised to the final temperature of 275 °C at a rate of 40 °C/min, and held at 275 °C for 5 min. The retention time of malic acid is 3.27 min; the retention time of tartaric acid is 5.36 min; the retention time of citric acid is 8.57 min; the retention times of three fructose peaks are 8.80, 8.94, and 9.06 min; the retention time of quinic acid is 9.82 min; the retention times of two glucose peaks are 10.41 and 12.52 min; the retention time of ascorbic acid is 11.12 min; the retention time of sorbitol is 11.70 min; and the retention time of sucrose is 20.13 min.

Gas Chromatographic−Mass Spectrometric (GC−MS) Analysis. TMS derivatives of sugars, acids, and reference compounds were analyzed with a Shimadzu QP 5000 MSD GC−MS (Kyoto, Japan). The column used was DB-1MS (30 m × 0.25 mm i.d. × 0.25 μm d_f) (J&W Scientific, Agilent, Folsom, CA). A sample of 0.5 μL was injected manually into a split (1:24) injector. The flow rate of the carrier gas helium was 1.3 mL/min. The temperature of the injector and the column temperature program were the same as in the corresponding GC−FID analysis.

Statistical Analysis. Statistical analyses were performed using SPSS 16.0.1 (SPSS, Inc., Chicago, IL). The results obtained with two analytical procedures were compared using a paired-sample *t* test. An independent-sample *t* test was used to investigate the difference between black currants grown at two latitudes. Differences in the composition between black currant varieties and black currants grown under different weather conditions were investigated by a one-way analysis of variance (ANOVA) and the nonparametric Kruskal−Wallis test. Tukey's honestly significant difference (HSD) test for the population with equal variances and Tamhane's test for that with unequal variances were employed to carry out the multiple comparisons of the black currant varieties and the composition of each variety grown under different

Table 2. Soluble Solids (°Brix), pH, and Juice Yield of Black Currants[a]

variety	year	location[b]	°Brix	pH	juice yield (mL/100 g)
Mortti	2005	S (n = 4)	13.4 ± 0.6 a	2.87 ± 0.01 a	41.3 ± 3.2 d
		N (n = 4)	16.0 ± 0.5 c	3.00 ± 0.03 d	36.5 ± 1.9 c
	2006	S (n = 1)	16.3 ± 0.0 c	2.99 ± 0.00 d	40.7 ± 0.0 d
		N (n = 4)	15.3 ± 0.4 b	2.94 ± 0.02 c	25.2 ± 3.2 a
	2007	S (n = 4)	13.7 ± 1.3 a	2.92 ± 0.02 b	28.6 ± 2.6 b
		N (n = 4)	13.4 ± 0.6 a	3.05 ± 0.02 e	23.4 ± 0.7 a
Ola	2005	S (n = 4)	14.9 ± 1.1 GH	2.89 ± 0.07 FG	39.4 ± 5.0 I
		N (n = 4)	15.4 ± 0.7 HI	2.98 ± 0.02 H	39.0 ± 2.9 I
	2006	S (n = 1)	17.3 ± 0.0 J	2.87 ± 0.00 F	26.4 ± 0.0 G
		N (n = 4)	15.9 ± 0.8 I	2.93 ± 0.04 G	25.1 ± 4.3 FG
	2007	S (n = 4)	14.3 ± 0.5 G	2.93 ± 0.01 G	30.2 ± 2.7 H
		N (n = 4)	13.1 ± 0.9 F	3.00 ± 0.05 H	23.8 ± 1.6 F
Melalahti	2005	S (n = 4)	13.6 ± 0.6 p	2.82 ± 0.03 p	37.5 ± 1.2 r
		N (n = 4)	15.0 ± 0.2 q	2.88 ± 0.01 q	42.7 ± 2.1 t
	2006	S (n = 1)	18.8 ± 0.0 s	2.88 ± 0.00 q	39.8 ± 0.0 s
		N (n = 4)	15.9 ± 0.7 r	2.82 ± 0.01 p	30.8 ± 2.6 q
	2007	S (n = 4)	15.8 ± 0.5 r	2.89 ± 0.03 q	38.4 ± 2.3 rs
		N (n = 4)	15.1 ± 1.0 qr	2.97 ± 0.01 r	24.3 ± 2.3 p
Mortti	2005−2007	S + N (n = 21)	14.4 ± 1.3 W	2.96 ± 0.07 X	31.5 ± 7.5 W
Ola		S + N (n = 21)	14.9 ± 1.3 X	2.94 ± 0.06 X	31.3 ± 7.4 W
Melalahti		S + N (n = 21)	15.2 ± 1.3 X	2.88 ± 0.06 W	35.0 ± 6.8 X
total	2005−2007	S (n = 27)	14.6 ± 1.5 y	2.89 ± 0.05 y	35.9 ± 5.7 z
		N (n = 36)	15.0 ± 1.2 z	2.95 ± 0.07 z	30.1 ± 7.5 y

[a] Significant differences (p < 0.05) between samples grown under different weather conditions are marked as a−e in variety Mortti, F−J in variety Ola, and p−t in variety Melalahti. Significant differences (p < 0.05) between black currant varieties and latitudes are marked as W and X, and y and z, respectively. Values (means ± standard deviation) with different letters within a column are significantly different at the 5% level. [b] S, southern Finland; N, northern Finland.

weather conditions at p < 0.05. A one-way ANOVA was used to investigate the variances in weather variables and to choose the weather variables for further analysis of correlation between weather conditions and the composition of black currant. Differences reaching a confidence level of p < 0.05 were considered as statistically significant. To study the effects of weather conditions on the compositional parameters of black currant berries, principal component analysis (PCA) and Pearson's correlation coefficients analysis were carried out. The varimax rotation method was applied to maximize the differences among variables in the PCA analysis.

RESULTS

Compositional Analysis. The mean values and standard deviations of the yield, soluble solids (°Brix), and the pH of the juice are shown in **Table 2**. The juice yield varied considerably among the samples, from 23.4 to 42.7 mL/100 g of berries. The content of soluble solids in juice varied from 13.1 to 18.8 °Brix, and the pH varied from 2.82 to 3.05. The average values and standard deviations of sugars, the sugar/°Brix ratio, and sugar/acid ratio are given in **Table 3**. Fructose (39.2−53.7% of total sugar in different samples) and glucose (34.9−45.1%) were the most abundant sugars in black currant juice. Sucrose accounted for 7.8−19.9% of the total sugar in the juice of different samples. The sugar/°Brix ratio ranged from 0.44 to 0.66, and the sugar/acid ratio ranged from 1.95 to 3.36. The mean contents and standard deviations of the acids are available in **Table 4**. Citric acid (85.1−95.4% of total acid in different samples) was the most abundant acid in black currant juice. Malic and quinic acids accounted for 2.6−7.3 and 0.4−1.2%, respectively, of the acids in the juice in different samples.

Comparison of Varieties. Significant differences in the composition were found among the three varieties investigated. The values of fructose (**Table 3**), citric acid, quinic acid, ascorbic acid, total acid (**Table 4**), and pH (**Table 2**) were significantly lower in Melalahti than in the other two varieties. In contrast, Melalahti had the highest values of glucose and juice yield and the highest sugar/acid ratio, regardless of the year or place of growth (**Tables 2** and **3**). However, Mortti and Ola had similar compositions, except for soluble solids.

Effect of Latitude on Composition. In the three varieties investigated, the values of sugars, °Brix, sugar/°Brix ratio, and sugar/acid ratio were higher in 2005 but lower in 2006 and 2007 in samples from northern Finland (henceforth the north) as compared to those from southern Finland (henceforth the south) (**Tables 2** and **3**). The greatest differences between the latitudes appeared in 2006, with the contents of fructose, glucose, sucrose, and total sugar being 0.98−2.17, 1.16−1.65, 0.51−0.76, and 2.90−4.13 g/100 mL, respectively, lower in berry juice of different varieties grown in the north compared to those grown in the south (**Table 3**). The content of ascorbic acid seemed to be higher in 2005 and 2007 but lower in 2006 in samples from the north than in those from the south (**Table 4**). Citric acid, total acid, and juice yield showed higher values in berries from the south than in those from the north, except for Melalahti in 2005 (**Tables 2** and **4**). In contrast, the contents of malic acid and quinic acid were higher in the berries grown in the north when compared to those grown in the south in all of the years studied (**Table 4**). When the data is combined for all varieties and years, it appears that the berries grown in the south displayed significantly higher values of citric acid (11.7% higher than those grown in the north), total acid (7.6%) (**Table 4**), fructose (8.8%), glucose (6.1%), sucrose (10.0%), and total sugar (7.9%), as well as a significantly higher sugar/°Brix ratio (10.8%) (**Table 3**) and juice yield (19.2%) (**Table 2**) but significantly lower values of malic acid (31.1% lower than those grown in the north), quinic acid (23.9%), and ascorbic acid (12.6%) (**Table 4**), soluble solids (2.6%), and pH (2.1%) (**Table 2**) compared to berries grown in the north.

Effects of Weather Conditions on Composition. Significant differences (p < 0.01) were found in the compositional parameters of black currant berries when analyzed through different weather parameters. ANOVA treatments of the weather parameters excluded from the correlation studies the parameters without significant variances (p > 0.05) between different years and locations. Such parameters included the length of the growth season (Dg), temperature sum exceeding 5 °C during the growth season (SUMTg), hot days (temperature >25 °C) from the start of the growth season until the day of harvest (HDgh), and in the last month before harvest (HDm), radiation from the start of the growth season until the day of harvest (SUMRgh), the percentage of the days with a relative humidity of 0−10% from the start of the growth season until the day of harvest (DHu0to10gh), and the percentage of the days with a relative humidity of 0−10, 10−20, and 20−30% in the last month before harvest (DHu0to10m, DHu10to20m, and DHu20to30m). For the same reason, the percentage of the days with a relative humidity of 30−40% in the last month before harvest (DHu30to40m) was not included in the analysis of the variety Ola.

The PCA plotting and Pearson's correlation coefficients analysis were used to investigate the correlation between the compositional parameters and weather conditions as well as the correlation between the metabolites. The PCA plots of weather conditions and the compositional parameters of the varieties Mortti, Ola, and Melalahti are shown in **Figure 1**. Pearson's correlation coefficients between the compositional parameters and correlated weather conditions in each variety are given in **Table 5**. The weather variables and their abbreviations are listed

Table 3. Values of Sugars, Sugar/°Brix Ratio, and Sugar/Acid Ratio in Black Currant Juice[a]

variety	year	location[b]	frutose (g/100 mL)	glucose (g/100 mL)	sucrose (g/100 mL)	total sugar (g/100 mL)	sugar/°Brix	sugar/acid
Mortti	2005	S (n = 16)	4.47 ± 0.27 cd	3.20 ± 0.26 b	0.65 ± 0.19 a	8.32 ± 0.50 c	0.62 ± 0.01 c	2.08 ± 0.15 ab
		N (n = 16)	5.25 ± 0.95 d	3.84 ± 0.55 c	1.44 ± 0.23 de	10.53 ± 1.69 d	0.66 ± 0.09 bc	2.65 ± 0.29 c
	2006	S (n = 4)	4.42 ± 0.04 c	3.84 ± 0.07 c	1.61 ± 0.02 e	9.87 ± 0.10 d	0.61 ± 0.01 bc	2.27 ± 0.09 b
		N (n = 16)	3.29 ± 0.24 b	2.68 ± 0.23 a	1.00 ± 0.10 b	6.97 ± 0.53 ab	0.45 ± 0.03 a	2.13 ± 0.15 ab
	2007	S (n = 16)	3.67 ± 0.57 b	2.81 ± 0.42 ab	1.43 ± 0.16 d	7.91 ± 1.10 bc	0.58 ± 0.05 b	1.95 ± 0.27 a
		N (n = 16)	2.96 ± 0.31 a	2.41 ± 0.27 a	1.21 ± 0.17 c	6.57 ± 0.70 a	0.49 ± 0.06 a	2.04 ± 0.12 ab
Ola	2005	S (n = 16)	4.77 ± 0.30 H	3.37 ± 0.27 G	0.92 ± 0.23 F	9.06 ± 0.47 H	0.61 ± 0.03 H	2.26 ± 0.23 GH
		N (n = 16)	4.83 ± 0.29 H	3.62 ± 0.31 G	1.11 ± 0.32 F	9.56 ± 0.34 I	0.62 ± 0.02 H	2.40 ± 0.12 H
	2006	S (n = 4)	5.49 ± 0.07 I	4.14 ± 0.03 H	1.65 ± 0.02 G	11.28 ± 0.11 J	0.65 ± 0.01 I	3.07 ± 0.14 I
		N (n = 16)	3.32 ± 0.24 G	2.69 ± 0.26 F	1.14 ± 0.19 F	7.15 ± 0.63 F	0.45 ± 0.02 F	2.07 ± 0.24 FG
	2007	S (n = 16)	3.57 ± 0.30 G	2.76 ± 0.29 F	1.57 ± 0.15 G	7.91 ± 0.71 G	0.55 ± 0.05 G	2.18 ± 0.17 G
		N (n = 16)	2.82 ± 0.52 F	2.35 ± 0.45 F	1.06 ± 0.16 F	6.23 ± 1.11 F	0.47 ± 0.07 F	1.97 ± 0.19 F
Melalahti	2005	S (n = 16)	3.07 ± 0.51 p	3.02 ± 0.48 p	0.62 ± 0.07 p	6.70 ± 1.05 p	0.49 ± 0.09 pq	2.43 ± 0.18 p
		N (n = 16)	3.92 ± 0.18 r	3.91 ± 0.19 qr	0.99 ± 0.11 q	8.83 ± 0.46 r	0.59 ± 0.03 s	2.66 ± 0.16 q
	2006	S (n = 4)	4.17 ± 0.05 s	4.76 ± 0.03 s	1.62 ± 0.02 r	10.56 ± 0.06 s	0.56 ± 0.00 qr	3.36 ± 0.10 s
		N (n = 16)	3.19 ± 0.28 p	3.11 ± 0.30 p	0.86 ± 0.12 q	7.06 ± 0.69 pq	0.44 ± 0.05 p	2.48 ± 0.16 pq
	2007	S (n = 16)	3.73 ± 0.33 qr	4.07 ± 0.36 r	1.70 ± 0.24 r	9.50 ± 0.88 r	0.60 ± 0.06 rs	3.03 ± 0.27 r
		N (n = 16)	3.35 ± 0.37 pq	3.55 ± 0.41 q	1.02 ± 0.16 q	7.93 ± 0.84 q	0.53 ± 0.07 q	2.67 ± 0.50 pqr
Mortti	2005−2007	S + N (n = 84)	3.95 ± 0.97 X	3.03 ± 0.63 W	1.17 ± 0.35 W	8.15 ± 1.71 W	0.56 ± 0.09 W	2.17 ± 0.32 W
Ola		S + N (n = 84)	3.94 ± 0.92 X	3.02 ± 0.61 W	1.18 ± 0.32 W	8.14 ± 1.54 W	0.55 ± 0.08 W	2.22 ± 0.30 W
Melalahti		S + N (n = 84)	3.47 ± 0.50 W	3.59 ± 0.60 X	1.07 ± 0.40 W	8.12 ± 1.40 W	0.53 ± 0.08 W	2.69 ± 0.37 X
total	2005−2007	S (n = 108)	3.97 ± 0.73 z	3.32 ± 0.64 z	1.20 ± 0.47 z	8.49 ± 1.37 z	0.58 ± 0.06 z	2.38 ± 0.46 y
		N (n = 144)	3.65 ± 0.91 y	3.13 ± 0.68 y	1.09 ± 0.24 y	7.87 ± 1.62 y	0.52 ± 0.09 y	2.34 ± 0.36 y

[a] Significant differences ($p < 0.05$) between samples grown under different weather conditions are marked as a−e in variety Mortti, F−J in variety Ola, and p−s in variety Melalahti. Significant differences ($p < 0.05$) between black currant varieties and latitudes are marked as W and X, and y and z, respectively. Values (means ± standard deviation) with different letters within a column are significantly different at the 5% level. [b] S, southern Finland; N, northern Finland.

Table 4. Contents of Acids in Black Currant Juice[a]

variety	year	location[b]	malic acid (g/100 mL)	citric acid (g/100 mL)	quinic acid (g/100 mL)	ascorbic acid (g/100 mL)	total acid (g/100 mL)
Mortti	2005	S (n = 16)	0.10 ± 0.02 a	3.74 ± 0.16 c	0.02 ± 0.01 a	0.14 ± 0.03 a	4.01 ± 0.13 b
		N (n = 16)	0.27 ± 0.03 d	3.40 ± 0.30 b	0.04 ± 0.01 c	0.25 ± 0.08 b	3.96 ± 0.39 b
	2006	S (n = 4)	0.17 ± 0.01 bc	3.95 ± 0.12 c	0.02 ± 0.00 ab	0.22 ± 0.02 b	4.36 ± 0.14 b
		N (n = 16)	0.18 ± 0.01 c	2.92 ± 0.13 a	0.03 ± 0.00 a	0.15 ± 0.02 a	3.28 ± 0.14 a
	2007	S (n = 16)	0.15 ± 0.02 b	3.71 ± 0.39 bc	0.03 ± 0.00 a	0.19 ± 0.02 b	4.08 ± 0.40 b
		N (n = 16)	0.24 ± 0.04 d	2.76 ± 0.34 a	0.03 ± 0.00 c	0.21 ± 0.02 b	3.24 ± 0.40 a
Ola	2005	S (n = 16)	0.17 ± 0.03 FG	3.70 ± 0.27 H	0.02 ± 0.01 F	0.13 ± 0.05 F	4.03 ± 0.25 H
		N (n = 16)	0.24 ± 0.05 I	3.50 ± 0.12 H	0.04 ± 0.01 G	0.21 ± 0.08 FG	3.99 ± 0.17 H
	2006	S (n = 4)	0.17 ± 0.01 FG	3.31 ± 0.16 GH	0.03 ± 0.00 F	0.17 ± 0.01 F	3.68 ± 0.15 GH
		N (n = 16)	0.19 ± 0.01 GH	3.10 ± 0.29 G	0.03 ± 0.00 F	0.16 ± 0.02 F	3.48 ± 0.28 FG
	2007	S (n = 16)	0.17 ± 0.02 F	3.24 ± 0.14 G	0.03 ± 0.00 F	0.19 ± 0.02 G	3.62 ± 0.16 G
		N (n = 16)	0.23 ± 0.04 HI	2.68 ± 0.33 F	0.04 ± 0.01 G	0.21 ± 0.04 G	3.15 ± 0.40 F
Melalahti	2005	S (n = 16)	0.13 ± 0.04 q	2.59 ± 0.40 p	0.01 ± 0.00 p	0.04 ± 0.01 p	2.77 ± 0.44 pq
		N (n = 16)	0.19 ± 0.04 rs	3.08 ± 0.15 q	0.02 ± 0.00 q	0.04 ± 0.01 p	3.33 ± 0.19 r
	2006	S (n = 4)	0.07 ± 0.01 p	3.00 ± 0.10 q	0.01 ± 0.00 p	0.06 ± 0.00 q	3.15 ± 0.11 pr
		N (n = 16)	0.17 ± 0.01 r	2.62 ± 0.16 p	0.02 ± 0.00 q	0.04 ± 0.01 p	2.85 ± 0.17 p
	2007	S (n = 16)	0.17 ± 0.04 qr	2.86 ± 0.26 pq	0.03 ± 0.00 r	0.10 ± 0.02 r	3.15 ± 0.30 qr
		N (n = 16)	0.22 ± 0.04 s	2.68 ± 0.47 pq	0.04 ± 0.00 s	0.11 ± 0.01 r	3.04 ± 0.51 pr
Mortti	2005−2007	S + N (n = 84)	0.19 ± 0.06 WX	3.34 ± 0.50 X	0.03 ± 0.01 X	0.19 ± 0.06 X	3.74 ± 0.50 X
Ola		S + N (n = 84)	0.20 ± 0.04 X	3.25 ± 0.42 X	0.03 ± 0.01 X	0.18 ± 0.05 X	3.65 ± 0.41 X
Melalahti		S + N (n = 84)	0.17 ± 0.05 W	2.78 ± 0.35 W	0.02 ± 0.01 W	0.06 ± 0.03 W	3.03 ± 0.39 W
total	2005−2007	S (n = 108)	0.15 ± 0.04 y	3.32 ± 0.52 z	0.02 ± 0.01 y	0.13 ± 0.06 y	3.62 ± 0.57 z
		N (n = 144)	0.21 ± 0.05 z	2.97 ± 0.41 y	0.03 ± 0.01 z	0.15 ± 0.08 z	3.37 ± 0.48 y

[a] Significant differences ($p < 0.05$) between samples grown under different weather conditions are marked as a−d in variety Mortti, F−I in variety Ola, and p−s in variety Melalahti. Significant differences ($p < 0.05$) between black currant varieties and latitudes are marked as W and X, and y and z, respectively. Values (means ± standard deviation) with different letters within a column are significantly different at the 5% level. [b] S, southern Finland; N, northern Finland.

in **Table 1**. Examples of correlations between the content of metabolites and weather conditions in the black currant varieties are available in **Figure 2**.

In the PCA plots, the first three principal components (PCs) explained 78.76, 77.79, and 63.47% of the variance of the weather condition and composition data of Mortti, Ola, and Melalahti, respectively. The compositional parameters located close to each other in the PCA plots behave in a manner mutually similar in response to weather conditions. The closer a weather parameter and a compositional parameter are to each other in the arrangement of the plots, the stronger the positive correlation between the parameters. The parameters that are located centro-symmetrically at a distance from each other correlate negatively.

The PC1 (29.65% of Mortti, 30.45% of Ola, and 28.01% of Melalahti) explained the variation of humidity and the contribution of precipitation and radiation to humidity. The sugar/°Brix ratio in Melalahti was only explained by PC1 and showed positive correlations with all of the high humidity variables (relative humidity > 50%) and negative correlations with low humidity variables (relative humidity < 50%). The sugar/°Brix ratios in Mortti and Ola also showed similar correlations with humidity as in Melalahti. Furthermore, they were represented

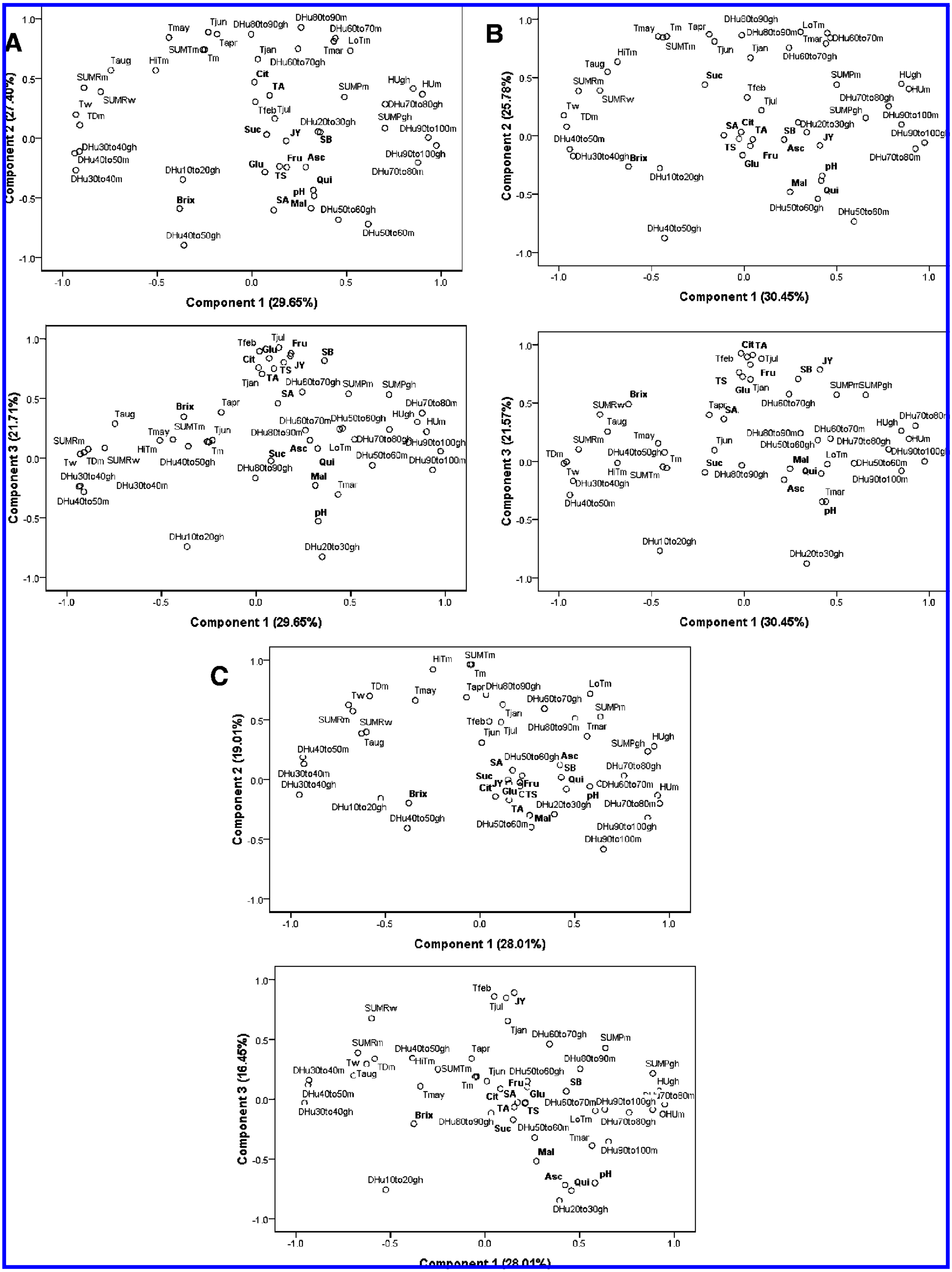

Figure 1. Differences in PCA plots between the compositional parameters of the black currant variety (A) Mortti, (B) Ola, and (C) Melalahti based on their responses to weather conditions. Fru, fructose; Glu, glucose; Suc, sucrose; Mal, malic acid; Cit, citric acid; Qui, quinic acid; Asc, ascorbic acid; SA, sugars/acids ratio; SB, sugars/°Brix ratio; TA, total acid; TS, total sugar; JY, juice yield; for the abbreviations of weather variables, refer to **Table 1**.

Table 5. Correlations and Pearson's Correlation Coefficients between Weather Conditions and Compositional Parameters of Black Currant Varieties

		correlated weather variables (Perason's correlation coefficient)[a]	
component	variety	positive correlation	negative correlation
fructose	Mortti	Tfeb (0.61**), Tjul (0.69**)	DHu10to20gh (−0.63**), DHu20to30gh (−0.55**)
	Ola	Tfeb (0.78**), Tjul (0.87**)	DHu10to20gh (−0.58**), DHu20to30gh (−0.71**)
	Melalahti		
glucose	Mortti	Tfeb (0.53**), Tjul (0.63**)	DHu10to20gh (−0.49**), DHu20to30gh (−0.50**)
	Ola	Tfeb (0.64**), Tjul (0.74**)	DHu10to20gh (−0.47**), DHu20to30gh (−0.60**)
	Melalahti		
citric acid	Mortti	Tfeb (0.77**), Tjul (0.75**)	DHu10to20gh (−0.68**), DHu20to30gh (−0.53**)
	Ola	Tfeb (0.79**), Tjul (0.78**)	DHu10to20gh (−0.66**), DHu20to30gh (−0.76**)
	Melalahti		
total sugar	Mortti	Tfeb (0.49**), Tjul (0.58**)	DHu10to20gh (−0.54**), DHu20to30gh (−0.41**)
	Ola	Tfeb (0.72**), Tjul (0.80**)	DHu10to20gh (−0.55**), DHu20to30gh (−0.63**)
	Melalahti		
total acid	Mortti	Tfeb (0.67**), Tjul (0.68**)	DHu10to20gh (−0.66**), DHu20to30gh (−0.43**)
	Ola	Tfeb (0.72**), Tjul (0.73**)	DHu10to20gh (−0.65**), DHu20to30gh (−0.67**)
	Melalahti		
sucrose	Mortti		
	Ola	Tjun (0.65**)	DHu40to50gh (−0.40**)
	Melalahti	Tjun (0.76**)	DHu40to50gh (−0.71**)
malic acid	Mortti	DHu50to60gh (0.61**), DHu50to60m (0.82**)	temperature variables especially Tmay (−0.81**), SUMRm (−0.64**), SUMRw (−0.62**)
	Ola	DHu50to60gh (0.43**), DHu50to60m (0.61**)	temperatue variables especially Tmay (−0.65**), SUMRm (−0.52**), SUMRw (−0.57**)
	Melalahti	DHu20to30gh (0.60**)	temperature variables especially Tmay (−0.52**), SUMRm (−0.67**), SUMRw (−0.70**)
quinic acid	Mortti	DHu50to60gh (0.48**), DHu50to60m (0.67**)	temperature variables especially Tmay (−0.64**), SUMRm (−0.57**), SUMRw (−0.48**)
	Ola	DHu50to60gh (0.52**), DHu50to60m (0.67**)	temperature variables especially Tmay (−0.66**), SUMRm (−0.64**), SUMRw (−0.68**)
	Melalahti	DHu20to30gh (0.86**)	SUMRm (−0.62**), SUMRw (−0.78**)
ascorbic acid	Mortti		SUMRm (−0.47**), SUMRw (−0.50**)
	Ola		SUMRm (−0.32**), SUMRw (−0.46**)
	Melalahti	Tmar (0.81**), DHu20to30gh (0.79**)	SUMRm (−0.45**), SUMRw (−0.64**), DHu40to50gh (−0.76**)
sugar/°Brix	Mortti	high humidity especially DHu70to80m (0.63**), Tfeb (0.63**), Tjul (0.69**)	low humidity especially DHu10to20gh (−0.71**)
	Ola	high humidity especially DHu70to80m (0.54**), Tfeb (0.71**), Tjul (0.79**)	low humidity especially DHu10to20gh (−0.67**)
	Melalahti	high humidity especially DHu70to80gh (0.65**), DHu60to70m (0.60**)	low humidity especially DHu30to40gh (−0.55**), DHu30to40m (−0.60**)
sugar/acid	Mortti	DHu50to60gh (0.61**), DHu50to60m (0.58**)	temperature variables especilly Tmay (−0.57**)
	Ola		
	Melalahti		
pH	Mortti	DHu20to30gh (0.75**), DHu50to60m (0.73**)	temperature variable except Tmar, SUMRm (−0.62**), SUMRw (−0.71**)
	Ola	DHu20to30gh (0.55**), DHu50to60m (0.53**)	temperature variable except Tmar, SUMRm (−0.60**), SUMRw (−0.70**)
	Melalahti	DHu20to30gh (0.89**), DHu50to60m (0.40**)	temperature variable except Tmar, SUMRm (−0.73**), SUMRw (−0.84**)
°Brix	Mortti		Tmar (−0.63**), DHu90to100m (−0.52**)
	Ola		Tmar (−0.61**), DHu90to100m (−0.66**)
	Melalahti		Pgh (−0.67**), Pm (−0.70**)
juice yield	Mortti	Tfeb (0.86**), Tjul (0.94**), DHu60to70gh (0.56**)	DHu10to20gh (−0.66**), DHu20to30gh (−0.76**)
	Ola	Tfeb (0.76**), Tjul (0.78**), DHu60to70gh (0.54**)	DHu10to20gh (−0.80**), DHu20to30gh (−0.64**)
	Melalahti	Tfeb (0.77**), Tjul (0.78**), DHu60to70gh (0.54**)	DHu10to20gh (−0.80**), DHu20to30gh (−0.63**)

[a] For the abbreviations of weather variables, refer to **Table 1**. (*) $p < 0.05$ and (**) $p < 0.01$.

by PC3 and correlated positively with the average temperature in February (Tfeb) and July (Tjul) (correlation coefficients, $r = 0.63-0.79$, $p < 0.01$) (**Table 5**).

The PC2 (27.40% of Mortti, 25.78% of Ola, and 19.01% of Melalahti) represented the temperature parameters and separated the compositional parameters by the response of their concentration to temperature. Malic acid in all of the varieties and quinic acid in Mortti and Ola correlated negatively with all of the temperature parameters, especially with the average temperature in May (Tmay) (r = from −0.52 to −0.81, $p < 0.01$) (**Table 5**).

The PC3 (21.71% of Mortti, 21.57% of Ola, and 16.45% of Melalahti) separated the major metabolites from the minor metabolites. Juice yield was well-explained by PC3 in all three varieties and had positive correlations with Tfeb, Tjul (**Figure 2A**), and the percentage of the days with a relative humidity of 60−70% from the start of the growth season until the day of harvest (DHu60to70gh) and negative correlations with the percentage of the days with a relative humidity of 10−20 and 20−30% from the start of the growth season until the day of harvest (DHu10to20gh and DHu20to30gh) (**Figure 1** and **Table 5**).

The three PCs showed that fructose, glucose, and total sugar behaved quite identically in response to weather conditions. However, there was a clear difference between the varieties in the effect of weather conditions on the composition of black currant berries. In Melalahti, the major metabolites (fructose, glucose, and citric acid), total sugar, and total acid were not influenced by the weather conditions (**Figure 1C** and **Table 5**). These parameters, on the other hand, were highly explained by PC3 in both Mortti (**Figure 1A**) and Ola (**Figure 1B**) and showed positive correlations with Tfeb (**Figure 2B**) and Tjul

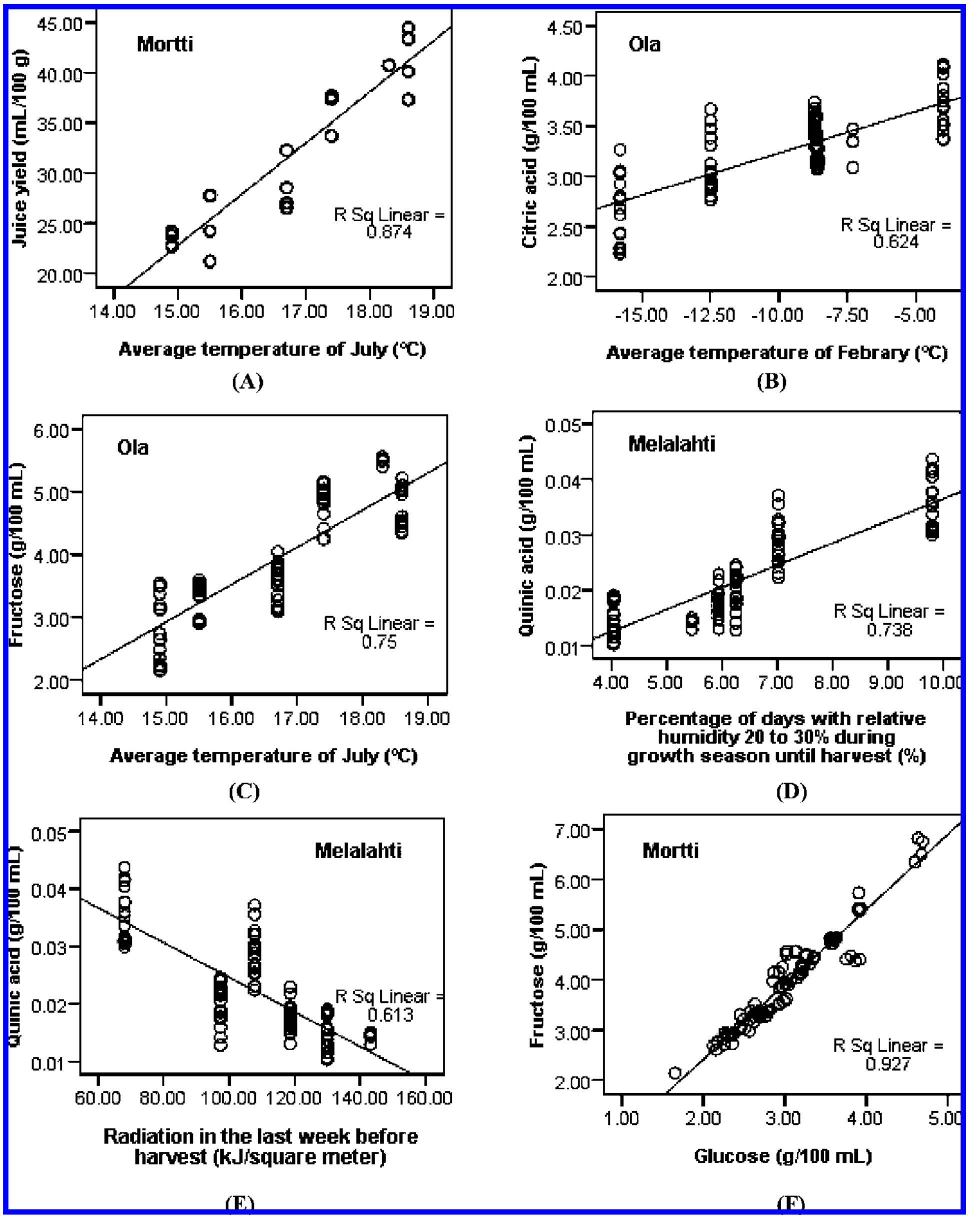

Figure 2. Correlations between (A) juice yield and average temperature in July in Mortti, (B) citric acid and the average temperature in February in Ola, (C) fructose and the average temperature in July in Ola, (D) quinic acid and the percentage of the days with a relative humidity of 20−30% from the start of the growth season until the day of harvest in Melalahti, (E) quinic acid and radiation during the last week before harvest in Melalahti, and (F) fructose and glucose in Mortti.

(**Figure 2C**) and negative correlations with DHu10to20gh and DHu20to30gh (**Table 5**).

The minor metabolites analyzed in this study for correlation with weather conditions (malic acid, quinic acid, and ascorbic acid) showed variation according to the variety of berry. The contents of malic acid and quinic acid in Mortti and Ola correlated positively with the percentage of the days with a relative humidity of 50−60% from the start of the growth season until the day of harvest (DHu50to60gh) and in the last month before harvest (DHu50to60m) and negatively with all of the temperature variables (**Table 5**). The content of ascorbic acid in these two varieties was not influenced by temperature and humidity. In comparison to Mortti and Ola, the concentration of malic acid, quinic acid, and ascorbic acid in Melalahti correlated positively with DHu20to30gh ($r = 0.60-0.86$, $p < 0.01$) (**Figure 2D** and **Table 5**). Furthermore, ascorbic acid in Melalahti had a positive correlation with the average temperature in March (Tmar) ($r = 0.81$, $p < 0.01$) and a negative correlation with the percentage of the days with a relative humidity of 40−50% from the start of the growth season until the day of harvest (DHu40to50gh) ($r = -0.76$, $p < 0.01$). However, there were negative correlations between malic acid, quinic acid, and ascorbic acid with the radiation during the last month before harvest (SUMRm) and during the last week before harvest (SUMRw) in all of the varieties (**Figure 2E** and **Table 5**).

Sucrose is vital to plants for providing carbon resources and initiating the hexose-based sugar signals (*25*). The content of sucrose was not influenced by weather conditions in Mortti, but in Ola and Melalahti, it was positively correlated with the average temperature in June (Tjun) ($r = 0.65$ and 0.76, respectively, $p < 0.01$) and negatively correlated with DHu40to50gh ($r = -0.40$ and -0.71, respectively, $p < 0.01$).

The content of soluble solids is commonly used to describe the sugar content in fruits and berries (*26*). °Brix in Mortti and Ola had negative correlations with Tmar and the percentage of the days with a relative humidity of 90–100% in the last month

Table 6. Correlated Compositional Parameters and Their Pearson's Correlation Coefficients of Black Currants[a]

variety	Fru × Glu	Fru × TS	Fru × S/B	Fru × S/A	Glu × TS	Glu × S/B	Glu × S/A	TS × S/B	S/B × S/A	TS × S/A	Suc × Fru	Suc × Glu	JY × Fru	JY × Glu	Y × Cit
Mortti	0.96**	0.97**	0.91**	0.74**	0.98**	0.86**	0.75**	0.90**	0.55**	0.78**	0.22*	0.31*	0.65**	0.57**	0.62**
Ola	0.96**	0.97**	0.88**	0.77**	0.97**	0.86**	0.81**	0.90**	0.72**	0.84**	−0.03	−0.01	0.67**	0.54**	0.70**
Melalahti	0.95**	0.94**	0.90**	0.48**	0.99**	0.88**	0.63**	0.87**	0.38**	0.65**	0.61**	0.78**	0.43**	0.33**	0.38**

variety	Fru × Cit	Glu × Cit	Fru × TA	Glu × TA	Cit × TA	Cit × TS	TA × TS	Asc × Suc	Qui × Mal	Asc × Mal	Asc × Qui	pH × Mal	pH × Qui	pH × Asc
Mortti	0.57**	0.56**	0.66**	0.66**	0.97**	0.54**	0.67**	0.74**	0.75**	0.67**	0.88**	0.80**	0.52**	0.50**
Ola	0.75**	0.70**	0.75**	0.70**	0.98**	0.71**	0.72**	0.48**	0.78**	0.50**	0.69**	0.58**	0.59**	0.45**
Melalahti	0.75**	0.65**	0.74**	0.66**	0.98**	0.63**	0.64**	0.64**	0.62**	0.45**	0.89**	0.47**	0.79**	0.78**

[a] Fru, fructose; Glu, glucose; Suc, sucrose; Mal, malic acid; Cit, citric acid; Qui, quinic acid; Asc, ascorbic acid, S/A, sugars/acids ratio; S/B, sugars/°Brix ratio; TA, total acid; TS, total sugar; JY, juice yield. (*) $p < 0.05$ and (**) $p < 0.01$.

before harvest (DHu90to100m), but in Melalahti, it only correlated negatively with the precipitation variables (**Table 5**).

The sugar/acid ratio in Ola and Melalahti did not correlate with weather conditions (parts **B** and **C** of **Figure 1** and **Table 5**), whereas the corresponding value in Mortti correlated positively with DHu50to60gh and DHu50to60m ($r = 0.61$ and 0.58, respectively, $p < 0.01$) and negatively with all of the temperature variables (**Figure 1A** and **Table 5**).

The pH was represented by three PCs together and correlated negatively with the temperature variables, except for Tmar. The pH value also correlated positively with DHu20to30gh and DHu50to60m and negatively with SUMRm and SUMRw (**Figure 1** and **Table 5**). There was no difference among the varieties as to the effect of weather conditions on the juice yield and pH.

Correlation between Metabolites. Significant correlations among metabolites were found in the three varieties studied (**Table 6**). Fructose and glucose were highly correlated ($r = 0.95-0.96$, $p < 0.01$). The correlation between fructose and glucose in Mortti is shown in **Figure 2F**. As the main sugar components, fructose and glucose contributed significantly to total sugar, sugar/°Brix ratio, and sugar/acid ratio.

Citric acid was the main acid in black currant. The contents of citric acid and total acid in black currant juice correlated positively with the contents of fructose, glucose, and total sugar (**Table 6**). Ascorbic acid correlated positively with sucrose ($r = 0.48-0.74$, $p < 0.01$). The juice yield generally correlated positively with the main metabolites, fructose, glucose, and citric acid, but the correlation in Melalahti was somehow weaker than in the other two varieties (**Table 6**).

DISCUSSION

The two analytical procedures applied in this study gave identical qualitative and quantitative results ($p > 0.05$) for all of the components analyzed. The juice dilution method applied for the samples from 2007 is faster and easier than the juice fractionation method used for the samples from 2005 and 2006. This is in agreement with our findings reported earlier by Tiitinen et al. (*24*). The juice yield obtained by centrifugation in the current study was lower than the yield obtained by the conventional pressing technology (pressure extraction) used for industrial juice production. However, the difference in yield had no impact on the composition of the juice. Fructose and glucose were the two major sugars, while citric acid was the major acid present in the black currant juice.

Genetic background was an important factor determining the composition of black currant juice. Melalahti may taste sweeter and less sour than Mortti and Ola because of its lower contents of acids and higher sugar/acid ratio (*2*). Vitamin C consists of both ascorbic acid and dehydroascorbic acid, but the former contributed to 94% of the total vitamin C in black currant in the research conducted by Agar et al. (*27*). Therefore, vitamin C was determined in the form of ascorbic acid in this study, which ranged from 0.04 to 0.25 g/100 mL of juice. Del Castillo et al. have reported the content of ascorbic acid ranging from 0.08 to 0.40 g/100 mL of juice in 29 different black currant genotypes (*3*). The effect of genetic background on the sensory quality and composition has also been investigated in other black currant varieties (*4*, *5*, *28*). The effects of genotype on the contents of sugars and acids in strawberries and sea buckthorns have also been reported (*2*, *26*).

Latitude seemed to have a significant effect on the components of black currant juice. The values of sugars, °Brix, sugar/°Brix ratio, and sugar/acid ratio in the three varieties studied were higher in 2005 but lower in 2006 and 2007 in samples from the north than those from the south. The content of ascorbic acid seemed to be higher in 2005 and 2007 but lower in 2006 in black currant juice from the north than in those from the south. Thus, both the scale and direction of latitude impact varied greatly from year to year according to the weather conditions. Similar phenomena have been reported in strawberries by Kallio et al. (*26*). The annual variation of sugars and acids may be attributed to the fact that the effect of latitude is a combination of quite complex environmental factors.

Weather conditions were the most important factors influencing the composition of black currant and showed different effects on different black currant varieties. Dry weather decreased the juice yield and sugar/°Brix ratio in all of the varieties studied, but it decreased the contents of fructose, glucose, and citric acid in Mortti and Ola only. The contents of fructose and glucose in Melalahti were not influenced by weather conditions, but their concentrations in Mortti and Ola correlated positively with the average temperature in February and July, which could be explained by the increased rate of photosynthesis with the raised temperature (*29*). The genotype effects on photosynthetic characteristics and metabolic responses to weather conditions in the leaves of plants have been reported (*13*, *30*, *31*). In addition to the major sugars, the major acid (citric acid) and sugar/acid ratio in Melalahti stayed constant despite the varying weather conditions, which indicated that it has optimal characteristics as a stabile raw material for commercial juice processing (*4*). Malic acid in all of the three varieties correlated negatively with all of the temperature parameters and the radiation during the last month before harvest. The inhibition of catabolism of malic acid and the increase of its content caused by the exclusion of light have been reported also in grape (*20*, *21*). The negative correlation between the content of malic acid and temperature might be explained by the highly exothermic reaction of the biosynthesis of malic acid (*11*). In addition, the content of quinic acid in Mortti and Ola also decreased at high temperatures, but its concentration in Melalahti was not influenced. Giuntini et al. reported that the genotype of tomato affected the influence of UV-B radiation on the content of ascorbic acid (*32*). In the current study, ascorbic acid showed the same negative correlation with radiation in all three varieties but its correlation with other weather parameters differed among the varieties. Opposite of the findings of negative correlation between ascorbic acid and radiation in this study, ascorbic acid and total vitamin C (ascorbic plus dehydroascorbic acid) in other plants had a positive correlation with light intensity (*33*, *34*).

The interactional metabolism of sugars and acids in plants might explain the significant correlation among some metabolites in the black currants. Fructose and glucose are the major substrates in the hexose phosphate pool in plants and are converted to each other in carbon metabolism (*10*), and these two sugars showed a highly positive correlation in black currant juice in this study. Tiitinen et al. have reported a positive correlation between fructose and glucose as well as between glucose and ascorbic acid in sea buckthorn (*24*). Citric acid in black currant juice correlated positively with the sugar content. Ascorbic acid correlated positively with sucrose ($r = 0.48-0.74$, $p < 0.01$). Citric and malic acids are both metabolites in the citric acid cycle (*8*), whereas acetyl-CoA, which is a substrate in the cycle, is derived from hexose originating from sucrose. Ascorbic acid is derived from D-glucose converted from sucrose in plants (*35*). Although the metabolisms of these components are known, the correlations between these metabolites need more investigations in physiology and enzymology to explain the correlations found in the current study.

In conclusion, genotype, latitude, and weather conditions all have effects on the composition of black currant. Furthermore, genotype affects the compositional response to weather conditions. Generally, the black currants grown in southern Finland have higher contents of sugars and citric acid, whereas their contents of malic acid, quinic acid, and ascorbic acid are lower than those found in black currants grown in northern Finland. Among the three black currant varieties, Melalahti continues to be a satisfactory option for commercial processing purposes because of its lowest contents of acids and highest sugar/acid ratio. Moreover, the major components of the Melalahti variety displayed a relatively constant composition from year to year, which suggests that they are minimally influenced by environmental factors. Further investigations in plant physiology combined with enzymological studies are needed to elucidate the effect of genotype on the metabolism and composition of sugars and acids in black currant berries.

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Supporting Information Available: Tables of Pearson's correlation coefficients between weather conditions and compositional parameters and within compositional parameters of black currants. This material is available free of charge via the Internet at http://pubs.acs.org.

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