

Influence of Thermal Treatment on Black Currant (*Ribes nigrum* L.) Juice Aroma

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The influence of thermal treatment on black currant juice aroma was investigated in temperature and time ranges relevant for black currant juice concentration processes, namely, 45, 60, 75, and 90 °C. Forty-nine aroma compounds were quantified, and the thermal treatment resulted in concentration increases of most terpenes, aldehydes, furans, and phenols, whereas the concentration of esters slightly decreased. Higher temperatures and longer exposure times had larger effects on the aroma compounds. Odor triangle tests showed no sensory difference between pasteurized juice and juice heated at 60 °C, whereas juice heated at 90 °C differed significantly from pasteurized juice. It is concluded that a 90 °C thermal treatment of black currant juice, which is in the temperature range used for conventional evaporation of black currant juice, has an effect on the aroma and sensory properties.

KEYWORDS: Aroma; black currant juice; thermal treatment; dynamic headspace collection

INTRODUCTION

Black currants are almost exclusively grown in Europe (1) and are mainly processed as juice, syrup, or jam (2). The processing of the berries usually requires the application of heat, which causes changes in the aroma and sensory characteristics of the fruit. The industrial production of black currant berries to juice involves enzyme treatment, pressing, clarification, and filtration as well as several heating steps. Each processing step alters to some extent the aroma profile, mainly by a decrease in the concentration of aroma components (3). More than 120 aroma compounds have been identified in black currant juice, in which terpenes, esters, and alcohols are the main groups of aroma compounds (4–7).

von Sydow and co-workers studied the influence of heat on the aroma of black currant products and found that heating black currant juice or mash to 70, 85, or 100 °C for 30 min increased the levels of benzene derivatives, dimethyl sulfide, and aldehydes and caused large rearrangements in the monoterpene complex. Larger changes in the composition of the volatiles were observed at higher temperatures than at lower (8, 9). Heating of black currants leads to an increase of odor qualities such as cooked odor and a decrease of odors such as fruity and floral (10).

Short-time heating has been shown to cause minor or no aroma and sensory changes. Heating of black currant juice to 80 °C for 4 min did not lead to significant changes in the content of volatile compounds (4). Pasteurization of black currant nectar at 88 °C for 27 s caused only minor changes in the concentration levels of 2 of 52 compounds, and no significant differences between pasteurized and nonpasteurized nectar were found in a sensory evaluation (5).

Fruit juices are often concentrated to reduce volume and stabilize the product for storage and transport. The conventional

method of concentrating fruit juices is by evaporation of water and recovery of the aroma in a distillate, which is subsequently added to the concentrate for reconstitution. During falling film evaporation concentration processes temperatures of 90–105 °C are applied with a residence time of ~5–10 min (11, 12). The aroma of concentrated juice is distinctly different from that of fresh black currant juice. An overall loss of some esters, alcohols, carbonyls, and terpenes occurs during the concentration, whereas certain volatiles are recovered in larger amounts than in the base juice. This is the case for furan and benzene derivatives, indicative of heat treatment, and aliphatic and terpene alcohols that might have existed in glycosidically or otherwise bound forms (6, 7). Partial least-squares regression has been successful in modeling the perceived sensory flavor intensity of black currant drinks from aroma data on concentrate composition (13).

Recently, gentler membrane process technologies for distillation and concentration of fruit juices have been introduced (14). One such process is vacuum membrane distillation, which require less or no heat admission as the process is conducted in the 10–60 °C range (15, 16).

The aim of the present study was to investigate thermally induced changes in the composition of aroma compounds from black currant juice by using temperatures and holding times that are relevant for conventional and novel black currant juice concentration processes. Several temperature and holding time levels have been investigated, and a large range of aroma compounds are quantified, with emphasis on characterization of the changes in the concentration of compounds that are important for the aroma of black currants.

MATERIALS AND METHODS

Materials. A commercial black currant juice of the variety Ben Lemond was obtained from an industrial plant. The juice preparation included crushing, heating, enzyme treatment (50 °C/maximum 6 h), pressing, pasteurization (98 °C/30 s), clarification (45 °C/maximum 6 h), and filtration. The juice was stored at –18 °C and defrosted

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overnight at 5 °C before use. °Brix of the juice was 12, and the pH was 3.0. The aroma standards used for quantification were obtained as follows: ethyl propanoate, methyl butanoate, ethyl butanoate, ethyl 3-methylbutanoate, butyl acetate, methyl hexanoate, ethyl hexanoate, eugenol, furfural, ethyl benzoate, and benzyl alcohol (Merck, Darmstadt, Germany); α -terpinene, rose oxide, linalool oxide, camphor, cuminaldehyde, methyl 2-furoate, and *p*-cymene (Fluka, Buchs, Switzerland); 4-methylphenol (Supelco, Bellefonte, PA); terpinolene and 4-terpineol (Roth, Karlsruhe, Germany); hexyl acetate (K&K Laboratories, Plainview, NY); β -damascenone (Firmenich, La Plaine, Switzerland); benzaldehyde (Riedel-de Hen, Seelze, Germany); and the remaining compounds were from Sigma-Aldrich (Copenhagen, Denmark).

Heating of Juice. Two hundred grams of black currant juice was weighed into a 500 mL blue-cap flask equipped with a screw cap. Heating was performed in a closed system to avoid evaporation. To obtain the desired temperatures of 45, 60, 75, and 90 °C, samples were heated in a microwave oven (Samsung Classic Collection microwave oven-b30) for 57, 80, 110, and 130 s, respectively. To facilitate heat distribution within samples, each sample was shaken halfway through the heating time. Samples were then transferred to a preheated water bath and, under magnetic stirring, kept at the desired temperatures for 2.5, 5, 10, 30, and 60 min, respectively. One sample, labeled "0", was not further heated after heating in the microwave oven. The control sample, henceforth termed the pasteurized juice, was not subject to any heating, apart from the juice preparation described under Materials.

Immediately after heating at the desired temperature, samples were cooled in an ice-water bath and stored at 5 °C overnight. For aroma analyses each time and temperature combination was performed in triplicate. For sensory analyses the juice was heated prior to each of four triangle test sessions.

Dynamic Headspace Collection. Seventy-five grams of black currant juice was weighed into a 250 mL glass flask equipped with a purge head. One milliliter of internal standard (50 μ L/L 4-methyl-1-pentanol, Aldrich, Steinheim, Germany) was added. Sample temperature was equilibrated in a 30 °C water bath for 10 min. Under magnetic stirring (200 rpm) the sample was then purged with nitrogen (100 mL/min) for 45 min. The volatiles were collected into traps containing 250 mg of Tenax TA (mesh size = 60/80, Buchem bv, Apeldoorn, The Netherlands).

Quantification. Quantifications for dynamic headspace collection were carried out on commercially available aroma compounds constituting >0.1% of the total peak area of the black currant juice GC chromatogram. A tap water model solution resembling black currant juice (glucose concentration = 48 g/L, fructose concentration = 61 g/L, citric acid monohydrate concentration = 39 g/L, 14 °Brix) was used. The aroma compounds to be quantified were divided into two series. For each series, 100 mg/L of aroma standard stock solutions in ethanol was diluted with the model solution to concentrations of 0.1 and 0.5 mg/L. During data processing linear calibration curves of each aroma standard were based on entries of 0, 0.1, and 0.5 mg/L. Due to their high concentrations in the juice, methyl butanoate and 2-methyl-1-propanol were analyzed at an additional concentration level of 1.0 mg/L, and 2-methyl-1-butanol was analyzed also at 5.0 mg/L. Dynamic headspace collection was performed in triplicate, under the same conditions as applied to the juice samples.

Gas Chromatography–Mass Spectrometry (GC-MS). The collected volatiles from the juice and the model solution were thermally desorbed using an automated thermal desorber (ATD 400, Perkin-Elmer), and separation and identification of aroma compounds were carried out on a Hewlett-Packard (Palo Alto, CA) G1800A S GC-MS system equipped with a J&W Scientific DB-Wax column (30 m \times 0.25 mm \times 0.25 μ m). Settings were the same as described in ref 17. Identifications were carried out by probability-based matching with mass spectra in the G1035A Wiley library (Hewlett-Packard) and comparisons with mass spectra and retention indices (RI) of the authentic reference standards. Linear retention indices were calculated after analysis under the same conditions of an *n*-alkane series (C9–C24). Peak area calculations were based on single ions, and peak areas of aroma compounds were divided by peak area of the internal standard.

Principal Component Analysis (PCA). To study the main variation in the material, multivariate data analysis was applied. In principal

Table 1. Concentration of Aroma Compounds in Pasteurized and Heated Black Currant Juice

compound	retention index	concn ^a (μ g/L)	
		pasteurized juice	juice heated at 90 °C for 60 min
alcohols			
2-methyl-1-propanol	1078	618 \pm 31	477 \pm 97
2- and 3-methyl-1-butanol ^b	1200	3404 \pm 78	2992 \pm 161
1-hexanol	1344	72 \pm 0.87	61 \pm 3.5
<i>cis</i> -3-hexenol	1371	36 \pm 0.61	32 \pm 1.4
<i>trans</i> -2-hexen-1-ol	1392	26 \pm 0.79	26 \pm 1.9
1-octanol	1545	2.9 \pm 0.29	3.3 \pm 0.29
carbonyls			
<i>trans</i> -2-methyl-2-butenal	1069	6.4 \pm 0.03	12 \pm 1.3
octanal	1273	0.30 \pm 0.14	1.7 \pm 0.97
nonanal	1375	2.5 \pm 0.44	16 \pm 5.0
(<i>E</i>)-3-penten-2-one	1108	5.5 \pm 0.20	48 \pm 4.9
6-methyl-5-hepten-2-one	1320	0.63 \pm 0.02	0.70 \pm 0.05
esters			
methyl 2-methylpropanoate	910	1.7 \pm 0.01	1.4 \pm 0.07
ethyl propanoate	939	3.8 \pm 0.04	3.0 \pm 0.30
methyl butanoate	976	1007 \pm 11	1053 \pm 75
methyl 2-methylbutanoate	1000	1.1 \pm 0.03	0.86 \pm 0.11
2-methylpropyl acetate	1002	2.2 \pm 0.04	1.5 \pm 0.20
ethyl butanoate	1023	222 \pm 2.4	194 \pm 21
ethyl 3-methylbutanoate	1049	0.17 \pm 0.004	0.14 \pm 0.02
butyl acetate	1052	2.0 \pm 0.05	1.5 \pm 0.14
2-methylbutyl acetate	1111	2.2 \pm 0.04	1.5 \pm 0.20
methyl hexanoate	1176	17 \pm 0.22	12 \pm 1.5
ethyl hexanoate	1223	4.5 \pm 0.01	3.0 \pm 0.55
hexyl acetate	1261	0.48 \pm 0.01	0.38 \pm 0.10
methyl octanoate	1374	0.56 \pm 0.01	0.35 \pm 0.05
terpenoids			
α -terpinene	1165	3.1 \pm 0.67	33 \pm 8.0
limonene	1190	0.61 \pm 0.15	5.1 \pm 0.71
γ -terpinene	1229	0.84 \pm 0.16	15 \pm 3.4
<i>p</i> -cymene	1251	1.6 \pm 0.04	9.1 \pm 2.0
terpinolene	1265	0.35 \pm 0.06	8.4 \pm 1.9
rose oxide	1339	0.47 \pm 0.01	0.47 \pm 0.06
<i>cis</i> -linalool oxide	1425	22 \pm 0.53	64 \pm 6.3
camphor	1490	0.18 \pm 0.02	0.48 \pm 0.05
linalool	1530	18 \pm 0.62	8.7 \pm 0.17
4-terpineol	1585	385 \pm 9.1	300 \pm 6.8
β -cyclocitral	1599	4.3 \pm 0.06	10 \pm 1.4
α -terpineol	1679	65 \pm 2.0	124 \pm 7.1
cumin aldehyde	1760	0.0 \pm 0.0	1.4 \pm 0.19
phenols			
4-methylphenol	2059	0.0 \pm 0.0	11 \pm 1.9
eugenol	2146	2.8 \pm 0.12	13 \pm 2.1
carvacrol	2189	1.6 \pm 0.32	4.8 \pm 0.89
furans			
furfural	1439	6.0 \pm 0.35	1077 \pm 147
2-acetyl-furan	1479	11 \pm 1.3	107 \pm 8.4
methyl 2-furoate	1553	3.3 \pm 0.09	24 \pm 3.4
others			
2-methoxy-3-isopropyl-pyrazine	1413	0.05 \pm 0.002	0.41 \pm 0.05
benzaldehyde	1494	1.6 \pm 0.34	27 \pm 2.5
ethyl benzoate	1644	0.54 \pm 0.05	1.2 \pm 0.17
methyl salicylate	1753	1.6 \pm 0.18	5.4 \pm 0.53
β -damascenone	1802	1.2 \pm 0.04	8.3 \pm 0.19
benzyl alcohol	1837	42 \pm 6.2	55 \pm 0.99

^a Concentrations are given as average \pm standard deviation ($n = 3$). ^b Quantified on basis of 2-methyl-1-butanol standard.

component analyses average response values over aroma replicates were used, and variables were mean centered and scaled to unit variance prior to analysis. The calibration models were validated by full cross validation and results presented as validation variation. Analyses were performed using the Unscrambler (Windows version 7.6 software package, Camo a/s Trondheim, Norway).

Sensory Evaluation. Triangle tests were used to evaluate odor differences between the heat-treated and the original pasteurized black currant juice samples. Twenty-eight untrained judges were selected from staff and students of the department. The thermal treatments to be tested were selected on the basis of preliminary test sessions and on temperature relevance for the juice concentration processes. Juice

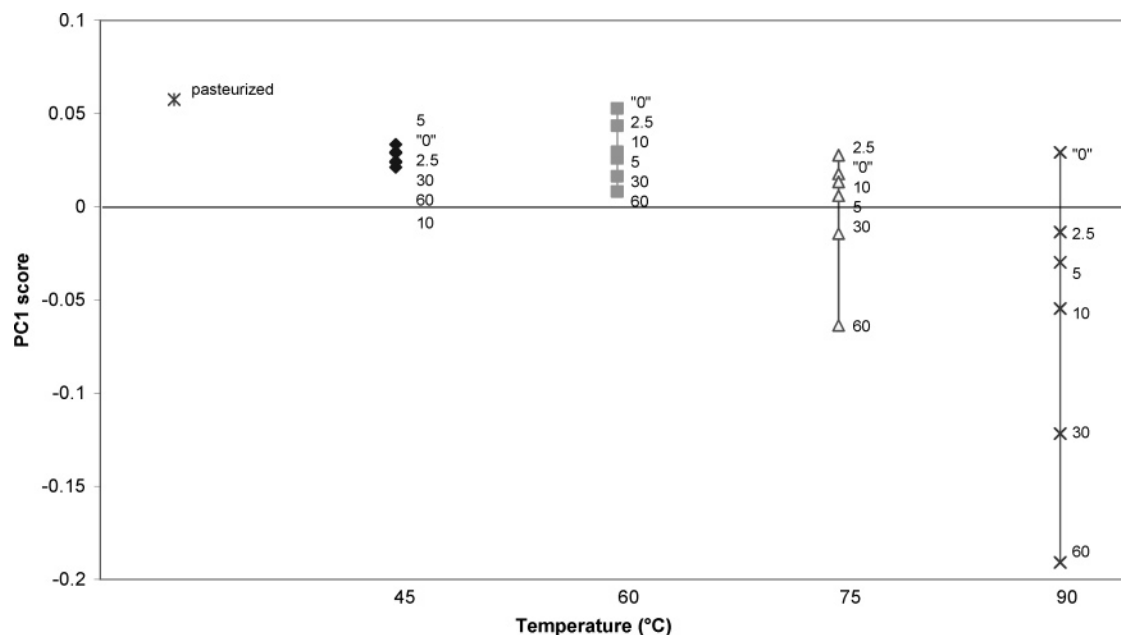


Figure 1. Changes in score values of PC1 during heating of black currant juice: "O" = heated in microwave oven. The numbers 2.5–60 refer to heating times in minutes.

samples heated at 60 °C for 30 and 60 min and at 90 °C for 2.5, 5, 10, 30, and 60 min °C were evaluated against the pasteurized juice. Samples (35 g) were evaluated in 110 mL clear plastic beakers with lids, which were allowed to equilibrate for 1 h before testing. The triangle tests were completely randomized with respect to odd sample and order of presentation within and between judges. The subjects were informed about the principle and task of the test and instructed in the procedure for the evaluation. Within each test, judges were instructed to select the odd sample after smelling the three samples in a given order. The triangle tests were performed during four sessions with seven judges participating, and each judge evaluated the seven tests within the same session. Water was provided to avoid dryness in the throat and to rinse between samples. Assessors were given the opportunity to make comments on the test sheet.

RESULTS AND DISCUSSION

Aroma Changes during Thermal Treatment of Black Currant Juice. The changes in aroma components of black currant juice heated at 45, 60, 75, and 90 °C, respectively, were determined by GC-MS. Concentrations of aroma compounds in the pasteurized and the most extensively heated (90 °C for 60 min) black currant juice are shown in **Table 1**. The concentrations found in pasteurized juice are in the same range as those reported for black currant nectar by Iversen et al. (5), except for 4-terpineol and α -terpineol, for which 100-fold higher levels were found in the present study. The extensive heating decreased the concentration of most esters and gave minor or no decreases in the alcohol concentrations. The concentrations of terpenoids increased with the thermal treatment, except those of linalool and 4-terpineol, which decreased. Aldehyde, furan, phenol, and other compound concentrations increased, many considerably.

Large standard deviations between triplicates were observed for the terpene hydrocarbons α -terpinene, limonene, γ -terpinene, and terpinolene, due to degradation on the Tenax adsorbent material, and for the aldehydes octanal and nonanal due to Tenax artifact formation (18). Other compounds could not be quantified, such as cineole, phellandrene, and (+)-3-carene, which were insoluble in the model solution, whereas dimethyl sulfide, diacetyl, methyl acetate, and 2-methyl-3-buten-2-ol was not quantified due to breakthrough on the adsorbent traps. Separation of diacetyl and 2-pentanone was not possible due to coelution.

The average concentrations of the 49 aroma compounds in black currant juice samples (25 in all) heated at the different temperatures (45, 60, 75, and 90 °C) and times were subjected to PCA. A single principal component (PC) explained 52% of the total variation (validated), indicating the temperature effect, whereas the following individual PCs revealed limited variation in the data, although a minor effect of heating time was observed in PC2 (not shown). Sample scores, giving information about the relative importance of each sample, are shown in **Figure 1**. A decrease of sample score value with heating time was generally observed within each temperature group except at 45 °C, where the sample scores were only slightly different (**Figure 1**). The sample scores show that pasteurized juice, all samples heated at 45 and 60 °C, samples heated at 75 °C for "0", 2.5, 5, and 10 min, as well as the 90 °C "0" sample are correlated to each other, having positive PC1 values (**Figure 1**). These samples will in the following be designated the "low processed group". The samples heated at 75 °C for 30 and 60 min and at 90 °C for 2.5, 5, 10, 30, and 60 min are correlated, having negative PC1 values, the two latter samples being the most extreme. These samples will be designated the "high processed group".

The concentration of the majority of the compounds changed relative to the original pasteurized juice during the thermal treatment, which is revealed by the loading variables of PCA that give information about the variables causing the differences between samples (**Figure 2**). All esters are correlated, except methyl butanoate, which influences the model least (**Figure 2A**). The esters are positively correlated to the low processed group, which indicates that the concentrations of esters decrease by the thermal treatment. The terpenoids are correlated to each other and are positively correlated to the high processed group; that is, their concentrations increase by thermal treatment (**Figure 2B**). Exceptions, however, are linalool, 4-terpineol, and rose oxide, which are correlated to each other and are positively correlated to the low processed group, and hence they decrease by thermal treatment. Most of the alcohols are correlated and are positively correlated to the low processed group, and hence decrease during thermal treatment, which is opposite from the development of aldehydes and ketones (**Figure 2C**). Furan

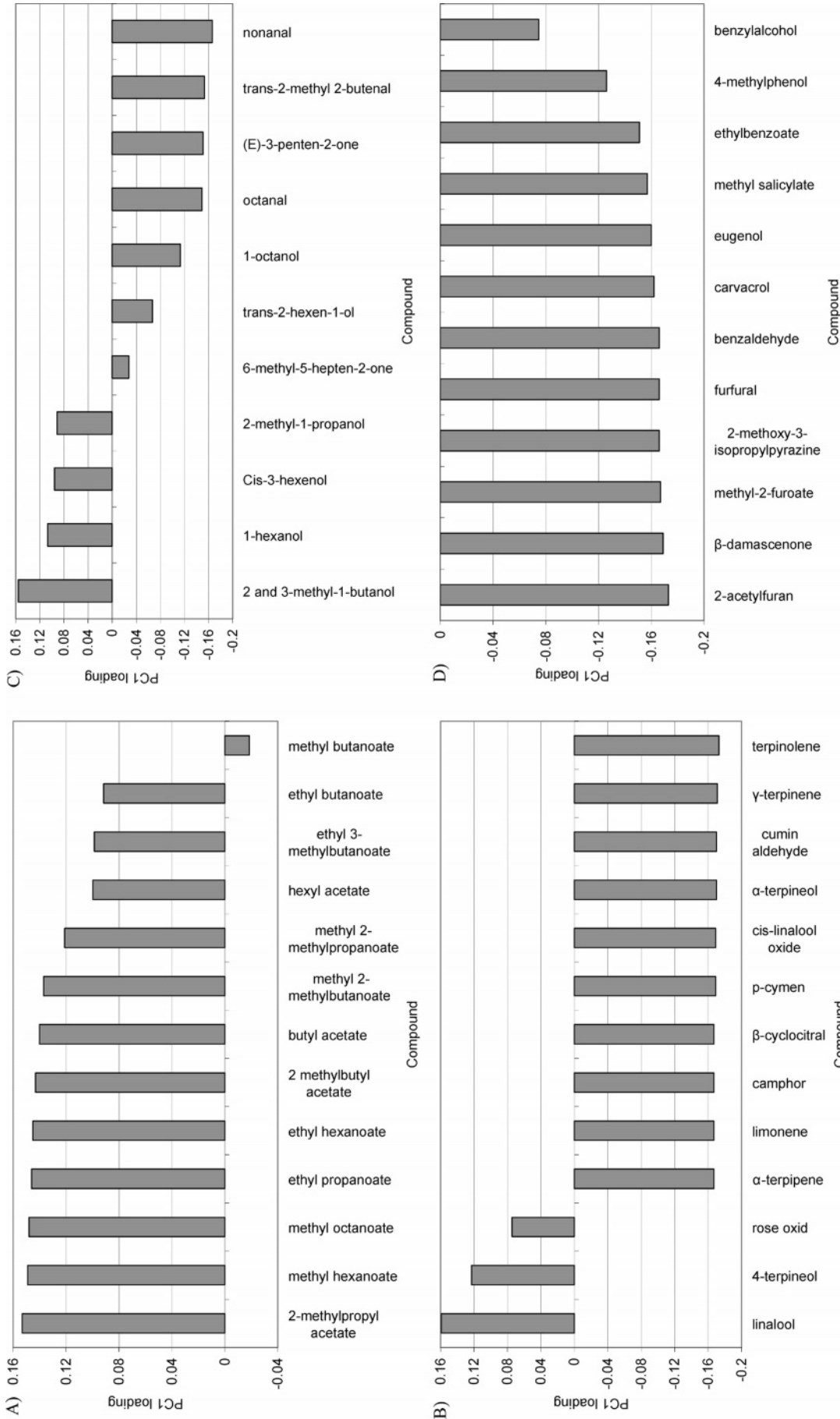


Figure 2. PC1 variable loadings for heating of black currant juice: (A) esters; (B) terpenoids; (C) alcohols and carbonyls; (D) others.

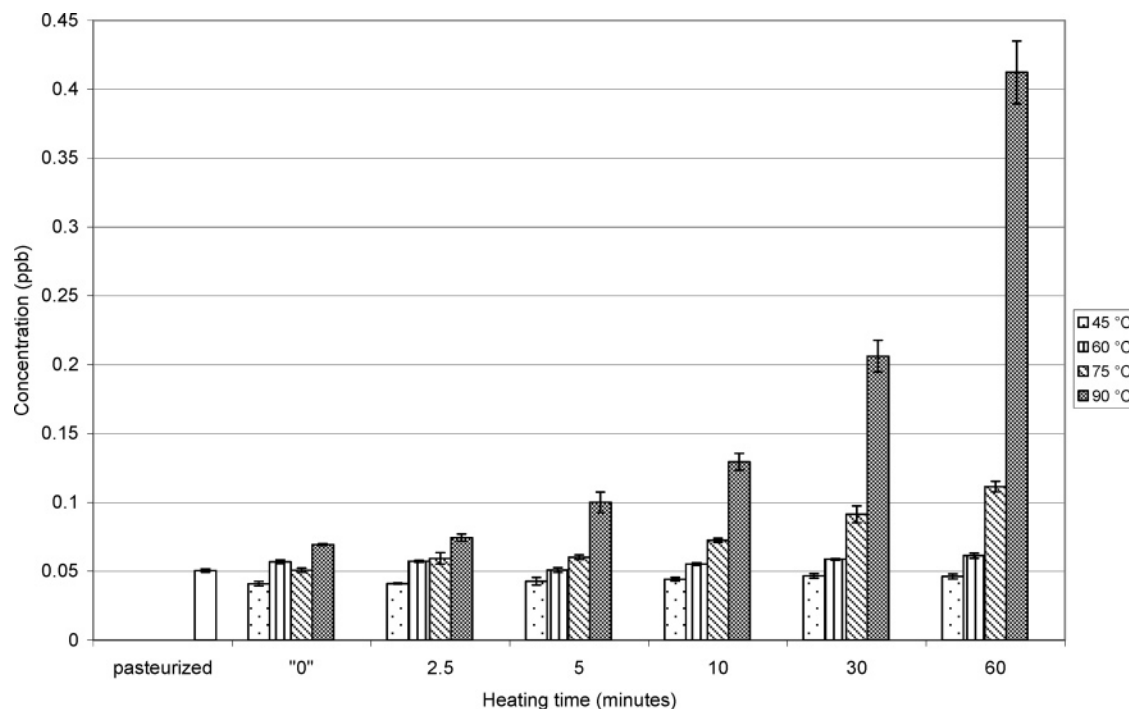


Figure 3. Changes in concentration of 2-methoxy-3-isopropylpyrazine during thermal treatment of black currant juice. Error bars represent standard deviations.

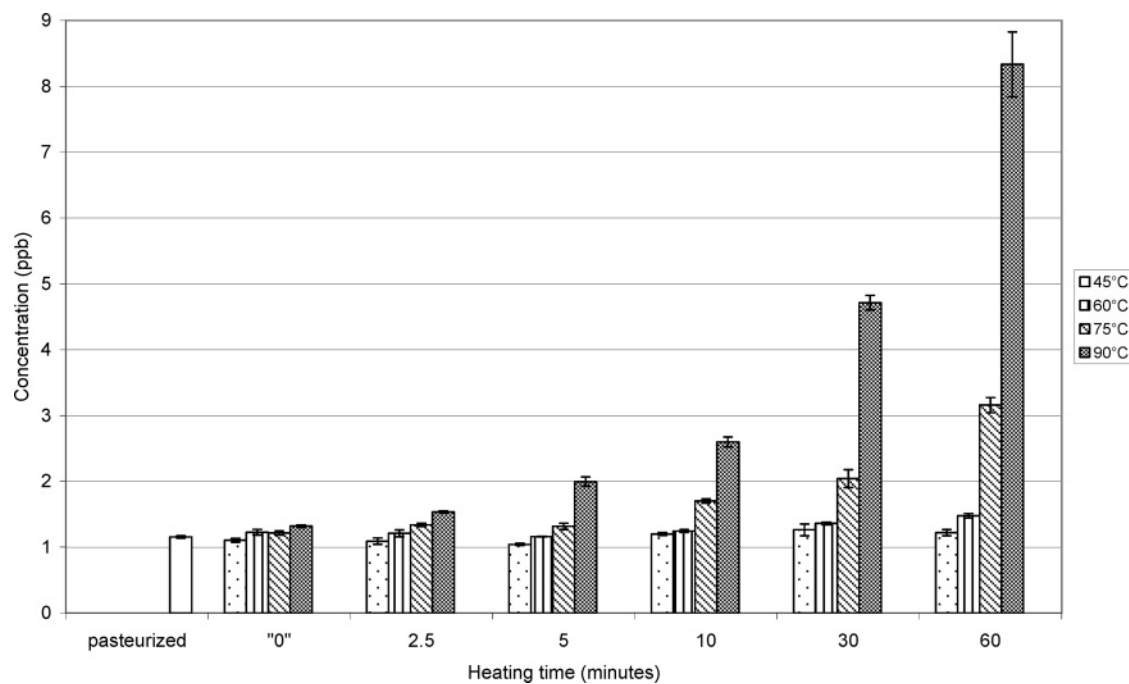


Figure 4. Changes in concentration of β -damascenone during thermal treatment of black currant juice. Error bars represent standard deviations.

derivatives, phenolic, and other compounds (**Figure 2D**) are correlated and are positively correlated to the high processed group; that is, the concentrations increase with thermal treatment.

Some volatile compounds present in black currant juice have been identified by gas chromatography–olfactometry (GC-O) as being more important than others for the aroma. Methyl butanoate, ethyl butanoate, ethyl hexanoate, cineole, 3-methyl-1-butanol, 1-octen-3-one, 2-methoxy-3-isopropylpyrazine, linalool, 4-terpineol, and β -damascenone have been reported by three of four studies to be important for black currant berry and/or juice aroma (3, 5, 7, 17). Thermally induced changes in the concentrations of these compounds are therefore expected to influence the odor properties of the juice. The concentrations

of 2-methoxy-3-isopropylpyrazine [pea and bell pepper odor (17)] and β -damascenone [black currant juice, boiled fruit, flower odor (17)] were in the present study found to increase by heating at 75 and 90 °C, with longer heating times resulting in higher concentrations (**Figures 3** and **4**). Pyrazines are formed by Strecker degradation of amino acids (19), and thermal treatment of black currants and mango pulp has previously been shown to lead to an increase in the concentration of the carotenoid degradation product β -damascenone (3, 20).

The concentration of linalool [floral odor (21)] decreased at temperatures of 75 and 90 °C (**Figure 5**), and the concentration of 4-terpineol [green and moldy odor (17)] changed in a similar way, but less pronounced than for linalool (not shown). The

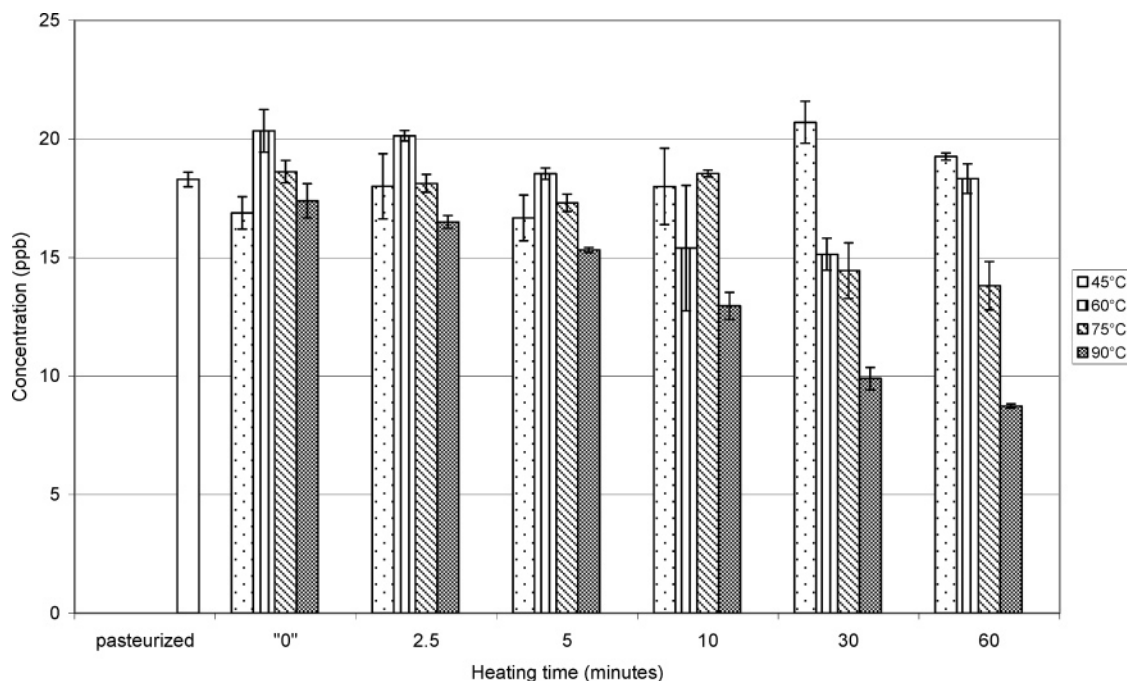


Figure 5. Changes in concentration of linalool during thermal treatment of black currant juice. Error bars represent standard deviations.

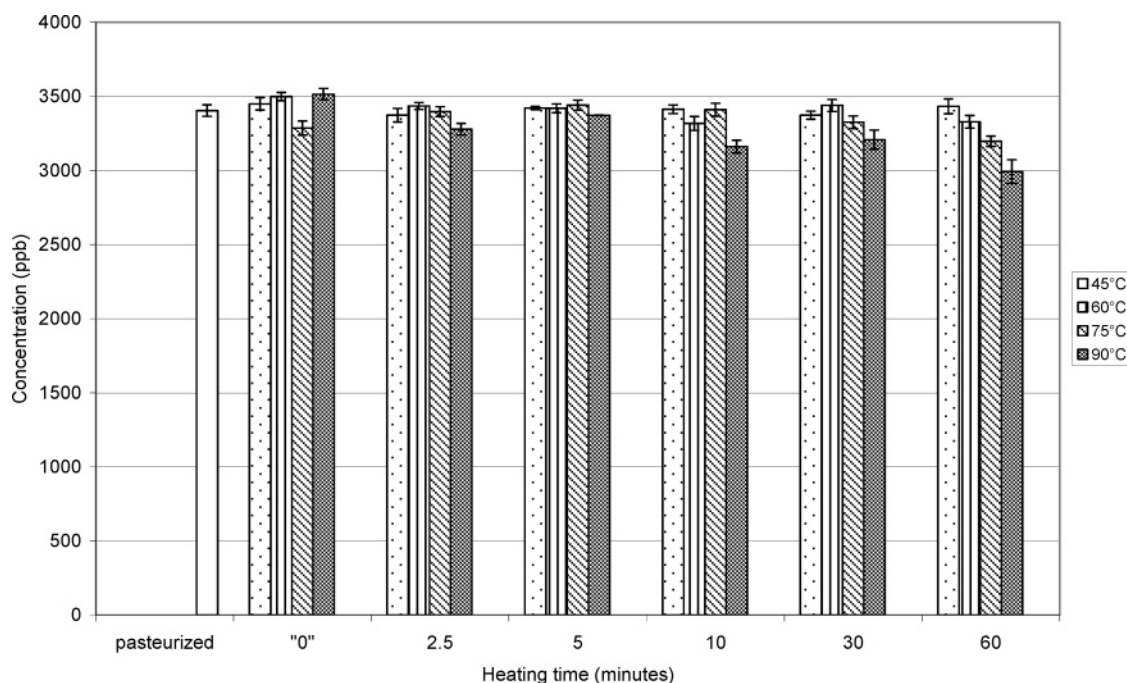


Figure 6. Changes in concentration of 2- and 3-methyl-1-butanol during thermal treatment of black currant juice. Error bars represent standard deviations.

concentration of the other terpenoids increased with the thermal treatment (Table 1). von Sydow et al. (9) also observed large rearrangements in the monoterpene complex of heated black currant mash. Heat treatment of orange juice has been shown to result in significant terpene hydrocarbon concentration increases (22), but in some studies no change or a decrease in the concentration of terpene hydrocarbons has been observed (9, 23, 24). Terpene hydrocarbons can be formed through acid hydrolysis of terpene alcohols (25), and *p*-cymene is formed by oxidation or acid-catalyzed rearrangements of monoterpenes (26, 27). Increases in the concentrations of α -terpineol have been observed upon heating of grape juice, orange juice, and mango pulp (20, 28, 29). Monoterpenes with hydroxy groups are in part present in plant material as glycosides that can hydrolyze due to low pH, accelerated by heat treatment (30),

and the presence of monoterpenic and aromatic glycosides has been identified in black currants (31). α -Terpineol is in addition a main conversion product of limonene and in particular linalool, these reactions being favored by low pH (32, 33). The observed decrease in linalool concentration can be due to its oxidation to linalool oxide, too, as observed in heated apricot juice (34).

Heat had a limited influence on 3-methyl-1-butanol [pungent odor (21)] (Figure 6) and ethyl hexanoate [fruity odor (21)] (Figure 7), and the concentration of these compounds decreased at temperatures of 75 and 90 °C. Methyl butanoate and ethyl butanoate [fruity odors (21)] behaved correspondingly to ethyl hexanoate, but less distinctly (not shown). Heat increases the rate of acid hydrolysis of esters to the carboxylic acid and alcohol, and the low pH of black currant juice favors many of the chemical reactions that take place during thermal treatment.

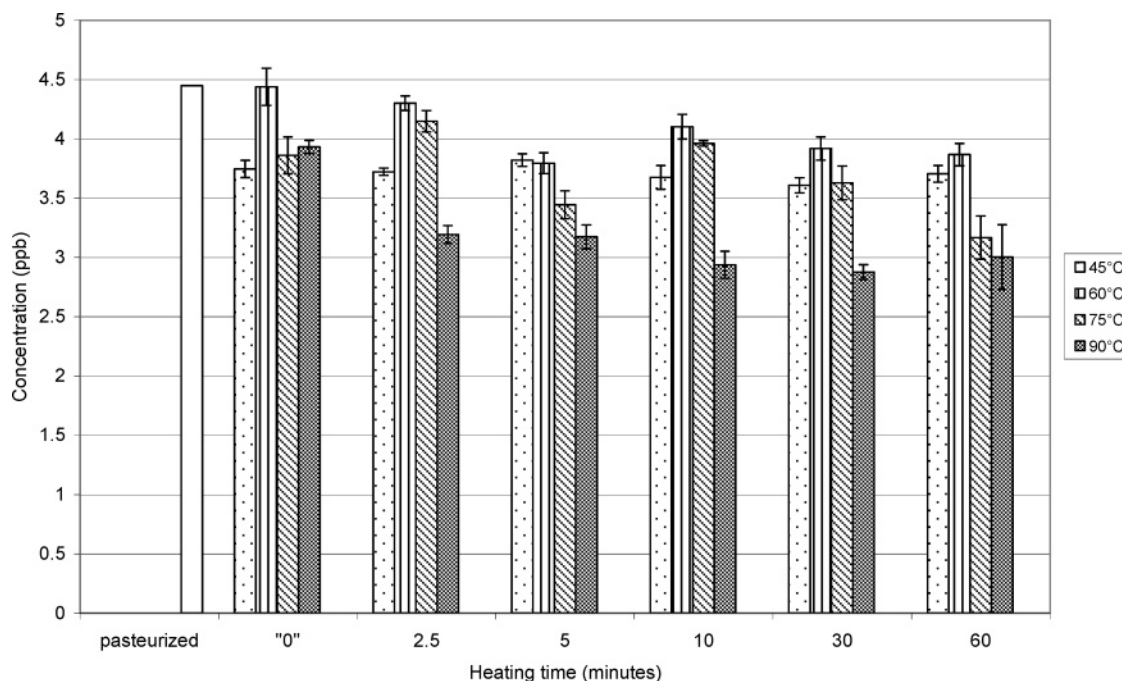


Figure 7. Changes in concentration of ethyl hexanoate during thermal treatment of black currant juice. Error bars represent standard deviations.

Table 2. Triangle Tests of Heated Black Currant Juice

heat treatment	no. of correct answers ^a (42)
60 °C for 30 min	13/28 ns
60 °C for 60 min	11/28 ns
90 °C for 2.5 min	17/28 **
90 °C for 5 min	13/28 ns
90 °C for 10 min	17/28 **
90 °C for 30 min	17/28 **
90 °C for 60 min	22/28 ***

^a All samples are tested against pasteurized juice. ns = nonsignificant, ** and *** indicate significance at $p < 0.01$ and $p < 0.001$, respectively.

The majority of the identified esters decreased during heating in the microwave oven, and at the lower temperatures they remained unchanged even during long heating times (Figure 7). Considering the very volatile nature of the esters, the observed loss might partly be due to evaporation during sample handling prior to analysis.

The concentration levels of benzaldehyde, benzyl alcohol, and furanic compounds in the black currant juice increased by heating as has also been observed with tomato juice, and heat-induced formation of furan derivatives is also reported in black currant mash, mango pulp, and orange juice (8, 9, 20, 29). In fruit products benzyl alcohol is known to be present as a glycosidic precursor (35, 36), which can be liberated by heat, and furans are derived from the thermal degradation and rearrangement of sugars and ascorbic acid (37, 38). The concentration of phenols increases due to either the thermal degradation of phenolic carboxylic acids or glycosidic release (39).

Triangle Tests of Heated Black Currant Juice. Juice samples heated at 60 °C for 30 and 60 min and at 90 °C for 2.5, 5, 10, 30, and 60 min were evaluated against the original pasteurized juice by triangle tests. The odor of black currant juice heated at 60 °C for 30 and 60 min did not significantly differ from that of the pasteurized juice, whereas the odor of juice heated at 90 °C for 2.5, 10, 30, and 60 min significantly differed from the odor of the pasteurized juice (Table 2). However, no significant effect of juice heated at 90 °C for 5

min was observed. A possible reason for this discrepancy can be the general strong odor of the juice that might "saturate" the judges' olfactory receptors, or that the sensory differences between the pasteurized sample and the heat-treated samples were minor.

Judges commented that samples heated at 60 °C for 30 and 60 min and at 90 °C for 2.5 and 5 min were very similar to the pasteurized sample and that any difference was difficult to detect. Odors of samples heated at 90 °C for 10, 30, and 60 min were characterized by the judges comments as boiled, sharp, off-flavored, earthy, burned, and less black currant. Results of the triangle tests are in agreement with those of the aroma analyses in which pasteurized juice and 60 °C samples were positively correlated and negatively correlated to samples heated at 90 °C for 2.5, 5, 10, 30, and 60 min (Figure 1).

Similar results have been reported by von Sydow et al. (10) on triangle tests of unheated black currants and berries heated at 70 °C for 15, 30, and 120 min and for 30 min at 55 and 100 °C. Significant differences among all samples were found, except between 55 °C/30 min and 70 °C/15 min. Odor quality assessment showed that heating led to an increase of odor qualities contributing undesirable aromas to fresh fruit such as cooked odor and sickly, whereas fruity and floral odors decreased. Some odor descriptors appeared in the heated but not in the unheated juice. Brennan et al. (40), on the other hand, reported that heating of black currant juice to 85 °C for 2 min significantly increased sweet and natural aroma and black currant and natural flavor.

Implications for Industrial Concentration of Black Currant Juice. Conventional methods for the concentration of black currant juice cause an increase in the levels of phenols, furans, and benzene derivatives (6, 7) as was also observed during the thermal treatments performed in the present study. Compared to the thermal treatments, the losses of esters and alcohols were larger during conventional concentration, and during conventional concentration most terpene compounds decreased in concentration (7), whereas thermal treatments resulted in an increase in levels of terpene compounds, except linalool and 4-terpineol. This suggests that aroma changes during conven-

tional concentration are not only thermally induced but can be due to other processing factors such as evaporation or loss through the vacuum pump of the evaporator unit. During 45 °C membrane distillations of black currant juice and a model solution, no changes in aroma composition were detected (41).

The heat treatments in the present study were carried out in a closed system to ensure that the observed effects were due to the thermal treatment and not caused by evaporation. The results obtained with the current model system are therefore expected to reflect the chemical changes that are induced by the heating alone, whereas other factors (mainly evaporation) are expected to increase the losses that are observed in specific industrial systems that operate under various conditions and are dependent on the manufacturer.

The results demonstrate that heating of black currant juice at 90 °C, which is within the temperature range used for conventional evaporation of black currant juice, has an effect on the aroma and sensory properties. On the other hand, heating of black currant juice at 60 °C for up to 1 h does not considerably change the aroma profile or the sensory character from that of pasteurized juice. Hence, application of temperatures of 60 °C and lower in, for example, membrane distillation is not expected to cause any heat-induced changes to black currant juice.

ABBREVIATIONS USED

PCA, principal component analysis; PC, principal component; GC-O, gas chromatography–olfactometry; GC-MS, gas chromatography–mass spectrometry; RI, retention index; SD, standard deviation.

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