

Determination of Odor Active Aroma Compounds in Freshly Cut Leek (*Allium ampeloprasum* Var. Bulga) and in Long-Term Stored Frozen Unblanched and Blanched Leek Slices by Gas Chromatography Olfactometry Analysis

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The odor active compounds in freshly cut leek slices and in blanched and unblanched leek slices stored for 12 months were investigated by a detection frequency method. Fifteen judges were evaluating the three samples randomized. The most important aroma compounds in the freshly cut leek slices were dipropyl disulfide, methyl propenyl disulfide, pentanal, decanal, and propyl propenyl disulfide in order of priority. When stored frozen and unblanched for 12 months, the aroma composition changed and the most important compounds became pentanal, decanal, 2,5-dimethyl furan, unknown compound I, and dipropyl disulfide. Blanching before freezing prevented to some degree these changes but also reduced the perceived intensity of the aroma compounds. The most important aroma compounds in the blanched sample were dipropyl disulfide, unknown compound I, pentanal, 2,5-dimethyl furan, and propyl propenyl disulfide.

KEYWORDS: Leek; GC-O; aroma compounds; frozen storage; blanching

INTRODUCTION

The production of volatile compounds in freshly cut leek and other *Allium* species has given rise to many publications during the past decades, but few papers (1–4) deal with the GC-O analysis on leeks; consequently, the evaluation of the odor active compounds still remains relatively unsolved.

According to the literature, numerous sulfur-containing volatile compounds dominate the aroma profile of fresh leek. Sulfurous volatiles originate from the alliinase (EC 4.4.1.4) catalyzed decomposition of the odorless nonvolatile precursors *S*-alk(en)ylcysteine sulfoxides (5, 6). The products, sulfenic acids, are highly reactive (7) and combine quickly to form thiosulfonates. Thiosulfonates are responsible for the odor of freshly cut leeks (7, 8), but as they are relatively unstable (5, 9), they rearrange to form polysulfides and thiosulfonates. As thiosulfonates are transformed to the corresponding monosulfide, the final products of the reaction are a combination of mono- and polysulfides with all of the possible combinations of the existing alk(en)yl radicals.

Products from the lipoxygenase (LOX) pathway are also found to be important for the leek aroma (7, 9, 10). LOX (EC 1.13.11.12) catalyzes the formation of hydroperoxy derivatives of polyunsaturated fatty acids with a *cis,cis*-pentadiene moiety (11, 12) under the consumption of dioxygen. Volatile aldehydes are produced by the action of hydroperoxide lyase upon the

formed hydroperoxides (11–13). All of these aldehydes, both saturated and nonsaturated, can be further metabolized by alcohol dehydrogenase (EC 1.1.1.1) to the corresponding alcohols (12). This formation of mainly aldehydes and alcohols may contribute to the aroma of freshly cut leeks, but it is not very pronounced in the fresh leek because of the pungency of thiosulfonates and thiopropanal-*S*-oxide (9). Previous investigations of unblanched frozen leek slices (1, 10) have shown though that when leek slices are stored frozen for a longer period, the production of aldehydes probably has an influence on the aroma profile as well, both because of the increasing amount of these compounds and because of the diminishing content of sulfur compounds (1, 10). Normally, manufacturing of frozen vegetables includes a blanching step to destroy the catalytic activity of enzymes and prevent this off-flavor formation. Leeks, however, are often processed without blanching, mainly because this has an undesirable effect on the texture. Consequently, enzymatic activity is still possible during frozen storage and in the thawing process.

Four papers have been found describing GC-O analysis on leek aroma. One paper is concerned with the determination of important aroma compounds from steam-distilled leek by means of GC-O (3); components contributing to the specific leek flavor were 1-propanethiol and 4 polysulfides. Another paper by the same authors (4) deals with GC-O analysis on headspace condensation extract of cut leeks collected for 24 h at 30 °C. This showed that besides the above-mentioned compounds five other polysulfides were important for the leek aroma. GC-O investigations on rehydrated dried leeks (2) also found that

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sulfur-containing components are the main odor active compounds in rehydrated leeks. A study (1) on GC-O analysis of unblanched leeks frozen for 3 months found that there is no key component in leeks but that both sulfur compounds and aldehydes contribute to the aroma.

The purpose of the present study was to evaluate both the odor active compounds in freshly cut leeks and the impact of the alteration of the aroma profile that occurs during frozen storage for 12 months of both blanched and unblanched samples.

MATERIALS AND METHODS

Plant Material. Leeks (*Allium ampeloprasum* var. Bulga) were harvested fully matured at Funen, Denmark, in October 2001 and immediately used for the experiment.

Chemicals. 1-Propanethiol, methyl propyl disulfide, dipropyl disulfide, dimethyl trisulfide, 2,5-dimethylthiophene, butanal, pentanal, hexanal, octanal, nonanal, decanal, (*E*)-2-hexenal, (*E*)-2-heptenal, (*E*)-2-octenal, 2-methyl-(*E*)-2-pentenal, (*E,E*)-2,4-heptadienal, 1-octen-3-ol, 1-octen-3-one, propanoic acid, and 4-methyl-1-pentanol were bought commercially from Sigma-Aldrich, Copenhagen, Denmark.

Sample Preparation. *Fresh Samples.* The white part of the leek stem was cleaned and cut into 15 mm slices immediately before the headspace collection of aroma compounds.

Unblanched Frozen Samples. The white part of the leek stem was cleaned and cut into 15 mm slices and frozen immediately in a blast freezer at $-20\text{ }^{\circ}\text{C}$ for 10 min, so that the center temperature reached $-20\text{ }^{\circ}\text{C}$.

Blanched Frozen Samples. The white part of the leek stem was cleaned and cut into 15 mm slices (500 g) and immediately immersed in a pot with lid containing 1 L of boiling water; blanching time, 225 s. After the they were blanched, the leek slices were dripped off for 15 s, cooled in crushed ice for 15 min, and frozen in a blast freezer at $-20\text{ }^{\circ}\text{C}$ for 10 min, so that the center temperature reached $-20\text{ }^{\circ}\text{C}$.

The frozen samples (unblanched and blanched) were packed in airtight glass jars with atmospheric air as the headspace and kept at $-20\text{ }^{\circ}\text{C}$ in the dark until analysis.

Experimental Design. Fresh slices were analyzed at harvest time, and subsequently, unblanched samples and blanched samples were analyzed after 12 months of storage. Each sample was analyzed for content of aroma compounds (for identification) in three replicates and GC-O analysis with 15 judges using the detection frequency method described by refs 14–16.

Dynamic Headspace Collection of Aroma Compounds. Aroma compounds were isolated by dynamic headspace with nitrogen (purity = 99.8%) as the purge gas. Fresh or frozen leek slices (50 g) were crushed with 200 mL of tap water and 4 mL of internal standard (50 ppm of 4-methyl-1-pentanol in tap water) for 120 s in a Waring commercial blender. After the mixture had been transferred to a 1 L glass flask by adding another 150 mL of tap water, it was left for 10 min at $30\text{ }^{\circ}\text{C}$ with agitation (200 rpm) to equilibrate the temperature before purging. Aroma compounds were trapped on 250 mg of Tenax GR (mesh size = 60/80, Buchem bv, Apeldoorn, The Netherlands) for 45 min with a nitrogen flow of 75 mL/min and agitation (200 rpm).

GC-MS Analysis. Desorption of aroma compounds was done thermally by an ATD 400 automatic thermal desorption system (Perkin-Elmer, Bucks, England). The desorption temperature of the trap to the cold trap (contains 30 mg of tenax GR; temperature, $5\text{ }^{\circ}\text{C}$) was $250\text{ }^{\circ}\text{C}$ for 15 min with a helium flow of 60 mL/min. The desorption temperature of the cold trap was $300\text{ }^{\circ}\text{C}$ for 4 min with a helium flow of 31 mL/min and an outlet split ratio of 1:30. The temperature of the transfer line to the chromatograph was $175\text{ }^{\circ}\text{C}$. Separation was performed by a GC-MS (HP G1800 A GCD system) with the following conditions: column, DB Wax from J&W Scientific, CA ($30\text{ m} \times 0.25\text{ mm i.d.} \times 0.25\text{ }\mu\text{m}$ film thickness); carrier gas, helium; start flow, 1 mL/min; split ratio, none; column pressure, 48 kPa (constant); oven program, $45\text{ }^{\circ}\text{C}$ for 10 min, $3\text{ }^{\circ}\text{C}/\text{min}$ to $240\text{ }^{\circ}\text{C}$, constant at $240\text{ }^{\circ}\text{C}$ for 30 min; temperature of the interface to the MS, $250\text{ }^{\circ}\text{C}$. The mass selective detector was operated in the electron ionization mode (ionization energy, 70 eV), and the m/z (mass/charge) ratio ranged

between 10 and 425. Identification was done by probability-based matching with mass spectra in the G1035A Wiley library (Hewlett-Packard). Identity was confirmed by checking with mass spectra and retention indices obtained in the laboratory from reference compounds for the following compounds: 1-propanethiol, methyl propyl disulfide, dipropyl disulfide, dimethyl trisulfide, 2,5-dimethyl thiophene, butanal, pentanal, hexanal, octanal, nonanal, decanal, (*E*)-2-hexenal, (*E*)-2-heptenal, (*E*)-2-octenal, 2-methyl-(*E*)-2-pentenal, (*E,E*)-2,4-heptadienal, 1-octen-3-ol, 1-octen-3-one, and propanoic acid. The retention time indices (RTI) of the volatile compounds were calculated with a mixture of hydrocarbons ($\text{C}_9\text{--C}_{26}$) as references according to the method of ref 17.

GC-O and GC-FID Analysis. Desorption of aroma compounds was done thermally by a Short Path Thermal Desorption from Scientific Instrument Services Inc. Ringoes, NJ. The desorption temperature of the trap was $250\text{ }^{\circ}\text{C}$ for 3 min with a helium flow of 60 mL/min. Separation was performed by a Hewlett-Packard 5890 GC with the following conditions: column, DB Wax from J&W Scientific ($30\text{ m} \times 0.25\text{ mm i.d.} \times 0.25\text{ }\mu\text{m}$ film thickness); carrier gas, helium; start flow, 1 mL/min; split ratio, 1:20; column pressure, 88 kPa (constant); oven program, $45\text{ }^{\circ}\text{C}$ for 10 min, $3\text{ }^{\circ}\text{C}/\text{min}$ to $240\text{ }^{\circ}\text{C}$, constant at $240\text{ }^{\circ}\text{C}$ for 30 min; detector temperature, $250\text{ }^{\circ}\text{C}$; air flow, 345 mL/min; hydrogen flow, 35 mL/min.

For the GC-O analysis, the FID detector was detached and the total flow was led to an olfactory detector outlet ODO-1 from SGE, Ringwood, Victoria, Australia. The flow from the olfactory outlet was combined with humidified air (150 mL/min) to avoid nasal dehydration. Fifteen untrained judges evaluated all three samples, and each sniffing session continued for 45 min. The judges were instructed to note start and finish time of the odor and a description of the odor. The odor descriptions were not checked by reference compounds. The judges were sniffing the samples randomized, and each judge was only sniffing one sample per day to avoid lassitude. The sniffing procedure was performed in a temperature-controlled room ($20\text{ }^{\circ}\text{C}$).

Computation of Aromagrams. The 15 individual aromagrams of one sample were added up to one aromagram. The NIF value was calculated as the number of judges in percentage detecting the odor at the peak as described by refs 14 and 16, and the SNIF value was calculated as the summed minutes that one peak lasted.

Identification of the Aromagrams. Identification of the detected odors was done by comparison of leek chromatograms obtained from GC-FID and GC-MS and by analyzing a known mixture of 12 aroma compounds by GC-FID, GC-MS, and GC-O and interpolating between compounds. The odor descriptions generated by the judges were not used for identification of the compound.

RESULTS AND DISCUSSION

Table 1 lists the odors that were detected during the GC-O analyses, and **Table 2** lists the 15 most important compounds in each of the three samples as evaluated by the largest NIF value and SNIF value (14). The judges were asked to define both a start and a finish time, but in some cases, there was no intermission between two odors; only the character of the odor changed. In that case, the judge was asked to state the same time as the finish time for the first odor and the start time for the next odor. For the fresh leek slices, this resulted in a level of four judges (26.7%) sniffing something all of the time starting approximately halfway through the sniffing time, and for that reason, a noise level of four judges was chosen. Many of the odors were very persistent late in the chromatogram, and it was hard for the judges to determine when the odor was over.

Twelve out of 43 compounds in **Table 1** are listed as unknown. This is either because there was no peak present in the MS chromatogram matching the time or that the MS software could not give certain identifications; in some cases though (unknowns A, B, D, G, and I), the MS software gave an indication of sulfur compound.

Table 1. Odors Detected by GC-O Analysis of Fresh Leek Slices and Blanched and Unblanched Leek Slices Stored Frozen for 12 Months

identification	RTI ^a	description of odor	OM U		12M U		12M B	
			NIF ^b	SNIF ^c	NIF	SNIF	NIF	SNIF
total minutes				183.4		168.0		121.6
Sulfur Compounds								
1-propanethiol	843	fresh leek, fresh onion	60.0	4.9	40.0	2.7	40.0	2.7
methyl propyl disulfide	1217	rotten, fried onions, sour cabbage	60.0	5.0	53.3	2.2	40.0	1.6
methyl propenyl disulfide ^{d,e} no. 1	1250	fresh leek, strong chives	100.0	8.7	66.7	3.5	80.0	5.3
methyl propenyl disulfide ^{d,e} no. 2	1274	rotten water, rotten vegetables	80.0	4.6	46.7	1.6	46.7	1.7
methyl-2-propenyl disulfide ^d	1266	strong raw onion, leek	53.3	2.7	40.0	1.8		
dipropyl disulfide	1365	strong raw onion, sulfuric, fresh leek	100.0	9.5	93.3	7.7	100.0	9.0
propyl propenyl disulfide ^{d,e} no. 1	1393	fresh leek, bouillon	80.0	3.2	93.3	5.4	73.3	2.9
propyl propenyl disulfide ^{d,e} no. 2	1419	freshly cut leeks, strong, green	100.0	5.7	93.3	6.2	93.3	5.0
propyl-2-propenyl disulfide ^d	1410	heat treated leeks, leaves of leek	46.7	2.4	40.0	2.0		
dimethyl trisulfide	1356	solvent, rotten onion, tainted	93.3	3.4	73.3	1.9	73.3	2.0
diisopropyl trisulfide ^d	1646	sharp onion smell, chives	66.7	5.1	86.7	6.1	73.3	6.4
propyl propenyl trisulfide ^{d,e} no. 1	1743	sourish, solvent	86.7	4.5	93.3	3.0	73.3	5.5
propyl propenyl trisulfide ^{d,e} no. 2	1765	onion soup	66.7	4.3	60.0	3.0	33.3	1.2
2,5-dimethyl thiophene	1179	spring onions, fresh onion	33.3	2.4				
3,4- or 2,4-dimethyl thiophene ^d	1240	wood, dry smell, green, bookstore	80.0	4.9	53.3	2.5	33.3	2.3
total of sulfur compounds				71.3		49.6		45.6
Aldehydes								
butanal	877	rotten, fried onions	33.3	1.3	60.0	2.3		
pentanal	976	fried onions, burned, boiled leek	100.0	7.7	100.0	8.0	100.0	5.4
hexanal	1070	green, grass	86.7	5.7	86.7	5.2	53.3	3.0
octanal	1279	orange, rubber			60.0	3.8	53.3	1.6
nonanal	1382	paint, turpentine	40.0	2.5	53.3	2.2	40.0	0.7
decanal	1486	cooking smell, sweat, refuse pail	100.0	6.0	100.0	7.3	66.7	3.0
(E)-2-hexanal	1201	fresh onion	40.0	3.3	60.0	4.5	33.3	1.0
(E)-2-heptenal	1306	forest, sweat	73.3	5.2	53.3	3.5	46.7	3.2
(E)-2-octenal	1412	soap, old raw leek, compost	66.7	2.7	80.0	2.6	40.0	1.5
(E,E)-2,4-heptadienal	1474	chemical leek smell, fried onion	73.3	3.3	60.0	3.3	60.0	2.3
2-ethyl-(E)-2-butenal ^d	1139	green leaves, fresh grass	73.3	4.4	53.3	4.8		
2-methyl-(E)-2-pentenal	1153	cabbage, paint, pricking	66.7	4.8	46.7	1.9		
total of aldehydes				46.9		49.4		21.7
Miscellaneous								
2,5-dimethyl furan ^d	952	bouillon	100.0	4.5	100.0	5.5	100.0	4.1
1-octen-3-ol	1449	heat treated onion, burned	93.3	4.4	93.3	5.3	93.3	4.8
1-octen-3-one	1290	mushroom	73.3	2.4	80.0	3.4	73.3	3.3
propanoic acid	1528	ashtray, furniture depository	66.7	2.1	73.3	2.0	66.7	2.2
unknown A	1446	fried onion, unpleasant	66.7	1.9	60.0	2.1	33.3	1.1
unknown B	1468	fried onion, hazelnuts	93.3	7.9	93.3	7.6	80.0	6.9
unknown C	1495	fresh pricking onion, nettles, green	73.3	6.3	80.0	6.8	60.0	5.2
unknown D	1503	solvent, unpleasant	80.0	3.7	73.3	3.1	66.7	3.7
unknown E	1522	spring onion, red bell pepper	80.0	2.7	73.3	2.3	80.0	3.5
unknown F	1560	mild onion, sweet			73.3	6.5	46.7	2.2
unknown G	1566	sour-sweet sauce, mustard	80.0	9.6			53.3	3.3
unknown H	1595	roasted onions, hazelnuts			60.0	4.4	46.7	2.7
unknown I	1607	fresh, raw leek/onion	93.3	8.2	93.3	8.2	100.0	7.7
unknown J	1664	chemical, old onions	66.7	4.6	73.3	4.7	66.7	3.6
unknown K	1687	green, fresh			53.3	3.2		
unknown L	1702	sweetish leek, flower, green weeds	53.3	6.9	46.7	3.9		

^a Retention time index. ^b Number of judges in percentage detecting the odor at the peak. ^c Total of minutes the odor is detected by all judges. ^d Compound was identified by GC-MS data alone. ^e Z and E isomers.

Numerous strong odors were present in the freshly cut leek slices, and many of these were sulfur compounds. The most important compound in this sample was dipropyl disulfide (detected by 100% of the judges with a SNIF value of 9.5 min), which in prior investigations was found to be the most abundant aroma compound in fresh leeks (10), but also, methyl propenyl disulfide (no. 1; see **Table 1**) (SNIF value, 8.7 min) and propyl propenyl disulfide (no. 2) (SNIF value, 5.7 min) were detected by all judges. Several other sulfur compounds were detected by more than two-thirds of the judges [3,4- or 2,4-dimethyl thiophene, methyl propenyl disulfide (no. 2), dimethyl trisulfide, propyl propenyl disulfide (no. 1), diisopropyl trisulfide, and propyl propenyl trisulfide (nos. 1 and 2)] indicating that sulfur compounds are important for the leek aroma. This was also found in headspace condensate of fresh leeks (4) and in

rehydrated leeks (2). 1-Propanethiol, which other authors (2, 4) found to be important in leeks, was detected by 60% of the judges with a SNIF value of 4.9 min, which does not suggest any major importance as it was not among the 15 most important odors (**Table 2**). No thiosulfates were detected in the freshly cut leek slices; this is explained by the isolation method and the GC-MS method that most likely decomposes these compounds (7, 10).

The odor description of the sulfur compounds was mainly given as fresh leek or onion, but some of them were also described as unpleasant; methyl propyl disulfide was described as rotten or sour cabbage; methyl propenyl disulfide (no. 2) was described as rotten water or rotten vegetables; dimethyl trisulfide was described as rotten onion or tainted; and propyl propenyl trisulfide (no. 1) was described as sourish or solvent.

Table 2. Fifteen Most Important^a Odors Detected by GC-O Analysis of Fresh Leek Slices and Blanched and Unblanched Leek Slices Stored Frozen for 12 Months

no.	OM U			12M U			12M B		
	compound	NIF	SNIF	compound	NIF	SNIF	compound	NIF	SNIF
1	dipropyl disulfide	100.0	9.5	pentanal	100.0	8.0	dipropyl disulfide	100.0	9.0
2	methyl propenyl disulfide ^{b,c} no. 1	100.0	8.7	decanal	100.0	7.3	unknown I	100.0	7.7
3	pentanal	100.0	7.7	2,5-dimethyl furan ^b	100.0	5.5	pentanal	100.0	5.4
4	decanal	100.0	6.0	unknown I	93.3	8.2	2,5-dimethyl furan ^b	100.0	4.1
5	propyl propenyl disulfide ^{b,c} no. 2	100.0	5.7	dipropyl disulfide	93.3	7.7	propyl propenyl disulfide ^{b,c} no. 2	93.3	5.0
6	2,5-dimethyl furan ^b	100.0	4.5	unknown B	93.3	7.6	1-octen-3-ol	93.3	4.8
7	unknown I	93.3	8.2	propyl propenyl disulfide ^{b,c} no. 2	93.3	6.2	unknown B	80.0	6.9
8	unknown B	93.3	7.9	propyl propenyl disulfide ^{b,c} no. 1	93.3	5.4	methyl propenyl disulfide ^{b,c} no. 1	80.0	5.3
9	1-octen-3-ol	93.3	4.4	1-octen-3-ol	93.3	5.3	unknown E	80.0	3.5
10	dimethyl trisulfide	93.3	3.4	propyl propenyl trisulfide ^{b,c} no. 1	93.3	3.0	diisopropyl trisulfide ^b	73.3	6.4
11	hexanal	86.7	5.7	diisopropyl trisulfide ^b	86.7	6.1	propyl propenyl trisulfide ^{b,c} no. 1	73.3	5.5
12	propyl propenyl trisulfide ^{b,c} no. 1	86.7	4.5	hexanal	86.7	5.2	1-octen-3-one	73.3	3.3
13	unknown G	80.0	9.6	unknown C	80.0	6.8	propyl propenyl disulfide ^{b,c} no. 1	73.3	2.9
14	3,4- or 2,4-dimethyl thiophene ^b	80.0	4.9	1-octen-3-one	80.0	3.4	dimethyl trisulfide	73.3	2.0
15	methyl propenyl disulfide ^{b,c} no. 2	80.0	4.6	(<i>E</i>)-2-octenal	80.0	2.6	unknown D	66.7	3.7

^a The importance was evaluated by the NIF value and if equal the SNIF value. ^b Compound was identified by GC-MS data alone. ^c Z and E isomers.

These compounds were detected by 80–93.3% of the judges for 3.4–4.6 min, meaning that they are important contributors to the aroma profile of fresh leeks.

Apart from sulfur compounds, a lot of other compounds, mostly aldehydes, were detected. Eight of the 12 detected aldehydes, both saturated, nonsaturated, and branched, were detected by two-thirds or more judges, and the total minutes of detection was relatively high in some cases. The most important nonsulfur compounds in the freshly cut leek slices were pentanal (SNIF value, 7.7 min), decanal (SNIF value, 6.0 min), and 2,5-dimethyl furan (SNIF value, 4.5 min), which were all detected by 100% of the judges.

The odor descriptions of the nonsulfur compounds found in freshly cut leeks were mainly off-flavor notes. Some of the aldehydes were described as fried onions or leeks [butanal, pentanal, and (*E,E*)-2,4-heptadienal], but although butanal and pentanal are described as pungent by ref 18, these descriptions are probably due to odors lasting from a preeluting compound. (*E*)-2-Hexenal was described as fresh onion, and this compound was previously reported as being very important for the aroma of freshly cut leeks (7). In this study, (*E*)-2-hexenal was detected by 40% of the judges and the total minutes of detection were 3.3, which did not place this compound among the most important in the fresh leeks (**Table 2**).

When the leek slices had been stored frozen and unblanched for 12 months, most of the sulfur compounds decreased both in total minutes of detection and in number of judges agreeing on the odor. As no statistical analysis was possible, the following interpretation was done on the basis of simple comparison. The total minutes of detecting sulfur compounds decreases from 71.3 min in the freshly cut leeks to 49.6 min in the frozen stored leeks; see **Table 1**. Exceptions are propyl propenyl disulfide (nos. 1 and 2), diisopropyl-trisulfide, and propyl propenyl trisulfide (no. 1), which were at the same level as the fresh leeks or slightly increasing. Most aldehydes increased [butanal,

pentanal, (*E*)-2-hexenal, octanal, (*E*)-2-octenal, and decanal], two were unaffected by the frozen storage (hexanal and nonanal) and two decreased [(*E*)-2-heptenal and (*E,E*)-2,4-heptadienal]. 2-Methyl-(*E*)-2-pentenal, which is one of the breakdown products from the lachrymatory factor thiopropanal-*S*-oxide, was reduced during frozen storage, the total minutes of detection was more than halved, and the percent of judges detecting it decreased from 66.7 to 46.7%.

These results indicate that frozen storage has a strong influence on the aroma profile of the leek slices as mainly the sulfur compounds decreased in importance and the aldehydes increased. This is consistent with what Petersen et al. (1) found in their study on frozen leek slices. **Table 2** shows that the order of the 15 most important compounds evaluated on the basis of NIF and SNIF values changed so that pentanal moved from the third position to first. Dipropyl disulfide, which was no. 1 in the fresh leek slices, decreased from 100% and 9.5 min to 93.3% and 7.7 min in the unblanched frozen leek slices placing that compound in the fifth position. Furthermore, the sulfur compounds dimethyl trisulfide, 3,4- or 2,4-dimethyl thiophene, methyl propenyl disulfide (no. 2), and the two unknown compounds G and D, which most likely also are sulfur compounds, were replaced on the list by only one sulfur compound, diisopropyl trisulfide, and four other compounds, 1-octen-3-one, (*E*)-2-octenal, and unknowns C and F.

The blanching procedure did to some degree prevent this altering of the aroma profile during frozen storage, as many of the sulfur compounds still constituted an important part of the aroma. Dipropyl disulfide was detected by 100% of the judges with a SNIF value of 9.0 min, which was very close to what was found for the fresh leek slices and which left that compound in the first position. There were minor displacements in the order of the compounds in **Table 2** though. Decanal, which had a high impact in freshly cut leeks and in frozen unblanched leeks and hexanal, was not among the 15 most important compounds

in the blanched leeks. Also, two sulfur compounds [methyl propenyl disulfide (no. 2) and 3,4- or 2,4-dimethyl thiophene] were missing on the list but two others [propyl propenyl disulfide (no. 1) and diisopropyl trisulfide] were added.

The blanching process influenced the total minutes of detection though as the blanched samples resulted all together in a SNIF value of 121.6 min as compared to 183.4 min for the fresh and 168.0 min for the unblanched stored for 12 months, which indicates that the blanched leek slices have a lower odor intensity. This was also expressed in the fact that three sulfur compounds and five other compounds found in the fresh or the unblanched frozen leek slices were not sniffed at all in the blanched sample. Still, the total SNIF value of sulfur compounds (**Table 1**) in the blanched samples was in the same level as the stored unblanched leeks slices. The top 15 compounds shown in **Table 2** also indicate that there are most powerful compounds in the freshly cut leek slices and the unblanched frozen stored leek slices, as compound no. 15 in these two cases was detected by 80% of the judges whereas it was 66.7% for the blanched leek slices. This shows that the blanching procedure has a reducing effect on production of both sulfur compounds and aldehydes, probably because of both leaching of volatiles to the blanching water during the blanching process (19) and by preventing catalytic activity of enzymes during the frozen storage.

In conclusion, six compounds [dipropyl disulfide, methyl propenyl disulfide (no. 1), pentanal, decanal, propyl propenyl disulfide (no. 2), and 2,5-dimethyl furan] were detected by 100% of the judges in the freshly cut leeks and four more (two unknowns, 1-octen-3-ol, and dimethyl trisulfide) were detected by 93.3% of the judges, which signifies that no single key component was present in leek. When stored frozen and unblanched for 12 months, the aroma in the leek slices changed toward less sulfur compounds being important, as the total SNIF value of sulfur compounds altered from 71.3 min in freshly cut leeks to 49.6 min in the frozen samples. At the same time, aldehydes were in equal level (46.9 min in the freshly cut leeks and 49.4 in the frozen stored), which means that the aroma profile changed. Blanching prior to frozen storage prevented this alteration to some degree as the ratio between sulfur compounds and aldehydes was almost the same as in the freshly cut leeks, but the total level of perceptible odors decreased.

ABBREVIATIONS USED

GC-O, GC—olfactometry; NIF, nasal impact frequency; SNIF, surface of nasal impact frequency; OM U, freshly cut unblanched leek slices; 12M U, unblanched leek slices stored for 12 months; 12M B, blanched leek slices stored for 12 months.

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