Influence of Variety and Growing Location on the Development of Off-Flavor in Precooked Vacuum-Packed Potatoes

Kirsten Jensen,*,† Mikael Agerlin Petersen,† Leif Poll,† and Per Bruun Brockhoff‡

Department of Dairy and Food Science/Centre for Advanced Food Studies and Department of Mathematics and Physics, The Royal Veterinary and Agricultural University, DK-1871 FC, Denmark

Development of potato off-flavor (POF) was examined in precooked vacuum-packed potatoes by GC and sensory analyses. The experiments comprised four varieties grown at two locations. Aroma compounds shown to be potential contributors to POF were determined quantitatively, and their relative importance was interpreted by aroma values based on odor detection threshold values determined in water. There were statistically significant differences in the content of POF compounds between the growing locations and among some of the varieties. The results from the sensory analyses concurred roughly with the GC analyses. (*E*,*E*)-2,4-Nonadienal and (*E*,*E*)-2,4-decadienal were shown to be the most potent of the POF compounds examined, in addition with hexanal, (*E*)-2-octenal, and (*E*)-2-nonenal. Lowering the development of POF in precooked vacuum-packed potatoes should be possible by optimizing the environmental conditions and breeding for suitable varieties.

Keywords: *Potato; off-flavor; precooked; catering; threshold values*

INTRODUCTION

Stored boiled potatoes rapidly develop an off-flavor (POF) that can be described as cardboard-like. This is a serious problem in food service systems where the use of precooked vacuum-packed potatoes is widespread.

It has been known for several decades that the small fat fraction in potatoes can be responsible for oxidative off-flavor in dried potato products (Buttery et al., 1961; Hallberg and Lingnert, 1991). These reactions are, however, due to autoxidation while the processes leading to POF in boiled potatoes most probably are lipoxygenase-catalyzed reactions (Petersen et al., 1998). Investigations have been carried out to determine the influences of variety and growing conditions on the lipoxygenase activity, resulting however, with considerable differences in the findings (Galliard and Matthew, 1973; Pun et al., 1980; Lojkowska and Holubowska, 1989). Other investigations focused on the development of off-flavor by analyzing the influence of packing materials (Thybo and Christiansen, 1996; Petersen and Trolle, 1996). To our knowledge, the influence of variety and growing conditions on the development of POF has not been investigated. If significant differences in POF intensity exist, proper selection of variety and growing conditions could be used for minimizing POF development in boiled potato products.

The aim of the present study was therefore to compare the tendency of POF development in four potato varieties grown at two locations. The concentration of POF compounds (eight aldehydes pointed out by Petersen et al., 1998) was determined in the potatoes by GC analysis, and the examination was supplemented by a sensory evaluation of the POF intensity. To enable a better interpretation of the GC data, odor thresholds of the compounds in question were determined as well.

The investigations were carried out in collaboration with Flensted A/S, Skovlund, Denmark, who commercially produces vacuum-packed precooked potatoes.

* Address correspondence to Kirsten Jensen, Department of Dairy and Food Science, The Royal Veterinary and Agricultural University, Rolighedsvej 30, DK-1871 FC, Denmark (telephone d.d.(+45)35283435; fax (+45)35283265; e-mail kje@kvl.dk).

† Department of Dairy and Food Science/Centre for Advanced Food Studies.

‡ Department of Mathematics and Physics.

MATERIALS AND METHODS

Experimental Design. The experiment was carried out in three parts: (i) identification and quantitative determinations of POF compounds in precooked vacuum-packed potatoes by GC-analysis, (ii) examination of the POF intensity in the potatoes using a sensory panel, and (iii) determination of odor detection threshold values of POF compounds in water. For three of the POF compounds, threshold values were determined in mashed potatoes as well.

Identification and Quantification of POF Compounds in Potatoes. *Potatoes.* Four varieties of *Solanum tuberosum* L. were examined: Jutlandia, Bintje, Sava, and Dali. The potatoes were grown at The Danish Institute of Plant and Soil Science, Tylstrup Experimental Station, Jutland (Northwest Denmark), and at the Danish Potato Breeding Foundation, Vandel, Jutland (Southwest Denmark). Dali was only grown at Tylstrup. At Vandel the soil is loamy and sandy while at Tylstrup the soil is sandy. Specifications for the potatoes were as follows: size, 45−50 mm, dry matter (average); Vandel, all varieties 20−22%; Tylstrup, Sava and Bintje 20−22%, Jutlandia 18−20%, and Dali 16−18%.

Precooking. After three months of storage at 4−5 °C, the potatoes were processed by Flensted A/S. The potatoes were peeled by knife and kept in cold water for 20−120 min. They were then vacuum-packed in plastic bags (Danisco, Flexible; permeability O_2, 25.0 $cm^3/m^2/24$ h/atm (23 °C, 0% RH); permeability H_2O(g), 5.5 $g/m^2/24$ h (38 °C, 90% RH)). The vacuum was 95%. After the potatoes were boiled in the bags for 70 min by steam, they were cooled to 10 °C during a period of 3 h and finally stored at 4−5 °C.

Isolation of Aroma Compounds. The potatoes were examined in duplicate on day 12, 13, and 14 after production. From each 3 kg vacuum package of precooked potatoes, 175 g of potatoes

10.1021/jf9807115 CCC: $18.00
Published on Web 02/13/1999

were homogenized in 525 g of tap water using an Ultra Turax. To obtain a more representative sample, the potatoes were roughly mashed in the plastic bag before weighing. One milliliter of internal standard (4-methyl-1-pentanol (Aldrich, 97%), 50 μL/kg) and 1 mL of Antifoam B, 10% (Sigma), were added to the suspension. The aroma compounds were isolated by a modified Likens−Nickerson method (micro-steam distillation−extraction apparatus, Chrompack). The suspension was placed in a 1 L flask, preheated in a microwave oven (4 min at 900 W), and connected to the distillation unit. Distillation−extraction was continued for 30 min, with 6 mL of diethyl ether/pentane (1:1) being used as the solvent. The solvent fraction was dried with 1 g of anhydrous sodium sulfate and concentrated to 50 mg by blowing nitrogen over the surface.

Separation and Quantification of POF Compounds. Separation of the volatiles in the extracts was carried out by gas chromatography using Hewlett-Packard 5890A GC equipped with a J&M Scientific DB-wax column (30 m $\times$ 0.25 mm i.d., 0.25 μm film thickness). The experimental conditions for the GC analysis was as follows: carrier gas, helium; flow, 1.0 mL/min; split ratio, 1:10; pressure, 65 kPa (constant); detector, FID; temperature, 250 °C; injection volume, 2 μL; injector temperature, 250 °C; oven program, 10 min at 40 °C, increased to 240 °C at 6 °C/min, constant at 240 °C for 25 min. The data were collected on a HP 3365 Series II Chem Station.

The aroma compounds found to be important for POF were quantified and identified by reference samples. The identification was verified by GC−MS (Hewlett-Packard G1800A GCD System). The same type of column and the same GC settings as described above were used with the exception that the split ratio was 15:1. The mass selective detector was on the electron ionization mode, and the *m/z* (mass/charge) ratio ranged between 10 and 425. Identification was carried out by probability-based matching with mass spectra in the G1033A NIST PBM library (Hewlett-Packard, Palo Alto, CA) and by matching with mass spectra obtained in the laboratory from reference compounds.

The quantification was done by adding POF compounds to fresh boiled potatoes in amounts corresponding to that found in boiled, stored potatoes (hexanal, 500 nL/kg; other, 100 nL/kg). The relation between the peak area obtained and the amount added the potatoes was used to estimate the concentration in the test samples of potatoes. The recovery of the POF compounds from the potato tissue was tested in triplicate, in addition with blind samples.

Sensory Analysis of Potatoes. A panel consisting of eight assessors was trained in evaluating the intensity of POF by sniffing samples of freshly boiled and stored potatoes, respectively. Immediately after the original packing with precooked potatoes was opened, samples were taken out for GC and sensory analyses. For the sensory analysis the potatoes were repacked by vacuum one by one. One hour before the sensory evaluation, the samples were tempered to room temperature. The assessors themselves cut the bags open, aerated the potatoes, and sniffed a few times. Then a score was given for the POF intensity, on a 10 cm unstructured line scale. Freshly boiled, vacuum-packed potatoes (Bintje, Tylstrup) were used as the reference sample (intensity 0). The intensity scores (cm) were determined by measuring the distance from 0 to the mark placed by the assessor on the line scale.

Odor Detection Threshold Determinations of POF Compounds. The compounds used in the threshold test were pentanal (Sigma), hexanal (Sigma), (*E*)-2-pentenal (Aldrich, 97%), (*E*)-2-hexenal (Aldrich, 99%), (*E*)-2-octenal (Aldrich, 94%), (*E*)-2-nonenal (Aldrich, 93%), (*E*,*E*)-2,4-heptadienal (Aldrich, 88%), (*E*,*E*)-2,4-nonadienal (Aldrich, 85%), and (*E*,*E*)-2,4-decadienal (Aldrich). The compounds were used without further purification, but to ensure that there were no impurities whose odor would dominate over that of the principal component, each commercial sample was checked by GC−olfactometry (GCO)/GC−FID and GC−MS. GCO/FID analyses were carried out on a Hewlett-Packard 5890 GC equipped with an SGE olfactory detector outlet ODO-1. The same type of column and the same GC settings were used as described for the GC−FID analysis of potatoes. Immediately after the GC−FID analysis of ether solutions of the compounds, the column was moved from the FID detector to the olfactory outlet. The solutions were injected again, and GCO determinations were carried out by two of the authors.

Sample Preparation, Aqueous Solutions. To dissolve partially hydrophobic substances, 20 μL of the aroma compounds used in the test solutions was mixed with 5 mL of 96% ethanol (ISO/DIS.2 13301, 1998). The odor threshold for ethanol was determined to verify that the concentration used had no influence on the threshold determinations of the POF compounds. Subsequent dilutions were prepared with odorless tap water. The test solutions and blank samples (tap water) were presented in volumes of 70 mL in 270 mL odorless plastic cups with lids (mod. Larsen and Poll, 1992).

Sample Preparation, Mashed Potatoes. Potatoes were boiled with skin, since earlier laboratory studies showed that skins prevented the development of POF (Petersen, 1998). Mashed potatoes were prepared from 1800 g of peeled potatoes mixed with 500 g of tap water. The test samples consisted of 50 g of mashed potatoes, spiked with 5 mL of aqueous solution of hexanal, (*E*)-2-octenal, and (*E*,*E*)-2,4-decadienal, respectively. Preparation of the aqueous solutions was started from 100 μL of aroma compounds mixed with 5 mL of 96% ethanol. The blank samples consisted of 50 g of mashed potatoes and the added 5 mL of tap water.

Measuring Detection Thresholds. Determinations were conducted using a three-alternative forced choice (3-AFC) procedure (ASTM, E 679, 1991; ISO/DIS.2 13301, 1998). A panel of 12 semitrained assessors (employees of the department) participated in the tests. The assessors began with presentations in which the concentration in the test sample was well above the expected threshold value. The concentration level was then decreased in decades until the threshold was demarcated. At first the presentations were tested in replicate. To achieve a sufficient precision of the threshold estimates, further samples were tested around the threshold value, and for some of the aroma compounds scale steps were halved.

Statistical Analysis. *Content of Aroma Compounds.* Analysis of variance on the quantitative content of the aroma compounds in question was carried out using the GLM procedure in SAS, version 6.12. The effects of *growing location* and *variety* were tested. Sample means were compared by Duncan's multiple range test (Duncan Grouping). A significance level of 5% was applied.

Sensory Analysis. For the sensory data, the mixed model analysis of variance was used (SAS, version 6.12). Effects of *growing location*, *testing day*, and *variety* were fixed. Effects of *assessor* and the interaction *growing location*testing day*variety*assessor* were considered random. Sample means for each combination of growing location and variety were compared by Duncan Grouping.

Threshold Determinations. For each compound a curve was fitted to the observed relative frequence as a function of the logarithm (with base 10) of the stimulus concentrations. A normal probability distribution function restricted to span from 1/3 to 1 was used (Brockhoff and Müller, 1997). This is an example of a so-called generalized linear model (McCullagh and Nelder, 1989), with the probit function of the chance-corrected probabilities as the "link function". Using the procedure GENMOD of SAS (SAS technical report, 1993), the curves were fitted by maximum likelihood methods.

Special care must be taken when the data has replications on each individual assessor. To correct for possible heterogeneities among assessors, data were corrected for "over-dispersion" whenever present in the data. This was done by using the "pscale" option of the SAS GENMOD procedure whenever the "pscale" was larger than 1. In Brockhoff and Müller (1997) this approach was shown to provide feasible results in sensory threshold experiments.

The threshold was determined from the curve as the concentration point giving a response probability of 2/3, i.e., minus the intercept parameter divided by the slope parameter. From the GENMOD procedure the covariance matrix of the two parameter estimates is obtained, and standard statistical methodology then provides the standard error of the threshold.

Table 1. Odor Detection Thresholds of POF Compounds Examined in Water and Mashed Potatoes, Together with Thresholds from the Literature[a]

aroma compd	odor threshold (nL/kg), water	odor threshold (nL/kg), mashed potatoes	lit. odor threshold (nL/kg), water
pentanal	22 (35)		13−124[b]
hexanal	2.5 (5.9)	47 (93)	6−28[b]
(*E*)-2-pentenal	310 (400)		
(*E*)-2-hexenal	96 (130)		20−372[b]
(*E*)-2-octenal	0.34 (1.0)	600 (1200)	4−5[b]
(*E*)-2-nonenal	0.23 (0.44)		0.1−1[b]
(*E*,*E*)-2,4-heptadienal	56 (100)		
(*E*,*E*)-2,4-nonadienal	0.0017 (0.0041)		104[c]
(*E*,*E*)-2,4 decadienal	0.045 (0.093)	63[d]	0.08[b]

[a] The results are expressed in mean values with the corresponding upper limit of the confidence interval (2 times the standard error of the threshold, corresponding approximately to a 95% confidence interval). [b] van Gemert and Nettenbreijer, 1977. [c] Belitz and Grosch, 1987. [d] For this compound a curve was not estimable in mashed potatoes.

RESULTS AND DISCUSSION

Threshold Values of POF Compounds. Odor detection thresholds of the POF compounds determined in water and mashed potatoes are shown in Table 1. The results are expressed as mean values with the corresponding upper limit of the confidence interval. In general, the threshold values obtained in water were found to be in accordance with those determined in previous studies (van Gemert and Nettenbreijer, 1977). However, for (*E*,*E*)-2,4-nonadienal, a considerable difference was found from the value shown by Belitz and Grosch (1987). For (*E*,*E*)-2,4-decadienal in mashed potatoes a curve was not estimable. Therefore, a linear regression on probit-transformed change-corrected probabilities was used to obtain the threshold.

Table 1 shows that thresholds in mashed potatoes were much higher than in water, particularly for (*E*)-2-octenal and (*E*,*E*)-2,4-decadienal where the threshold values were 1000-fold higher. This phenomenon may be due to the formation of inclusion complexes with potato starch to varying degrees. Osman-Ismail and Solms (1973) reported that potato starch rapidly formed inclusion compounds with flavor substances (e.g., decanal) and that the molecular dimensions of the flavor substances definitely affected the formation and composition of these compounds. Although the content of lipids in potatoes is only 0.07−0.13% of fresh weight (Thybo and Christiansen, 1996), partitioning into endogenous lipids may be another reason for elevated threshold values in potato tissue. The addition of 1% vegetable oil into water has been shown to decrease the volatility of nonpolar compounds markedly. For homologous aliphatic aldehydes, the effect was found to be more noticeable as the carbon number increased (Buttery et al., 1973; Schirle-Keller et al., 1994). These results can explain why the threshold value of the more polar compound hexanal was less affected by the potato tissue than (*E*)-2-octenal and (*E*,*E*)-2,4-decadienal. Since the main part of the compounds in question are of nonpolar nature, considerably higher threshold values must be expected for these in potatoes.

Some of the compounds used for the threshold determination showed a minor contamination with the corresponding acids (<5%, GC−MS). These were, however, not detected by GCO. In general for the unsaturated compounds, minor impurities were detected by GCO besides the odor of the principal component. For (*E*,*E*)-2,4-nonadienal and (*E*,*E*)-2,4-decadienal, GC−MS showed that this phenomenon most probably was due to cis/trans-isomerism. For the rest of the unsaturated compounds, it was not possible to identify the impurities. However, when samples were diluted until only one odor was detectable during GCO, the corresponding results from the GC−FID analysis showed that this odor was conferred by the principal component. Therefore, the stimuli in the test samples, in the sensory presentations near the threshold concentration, was concluded to be unaffected by the impurities.

The threshold value for ethanol was determined to be above 100 mg/kg. This means that the ethanol concentration did not exceed its threshold in the test samples.

Content of POF Compounds in Potatoes. Table 2 shows the mean values (nL/kg) of POF compounds in the precooked vacuum-packed potatoes, calculated from the six replicates. Unfortunately, (*E*)-2-hexenal and a component in Antifoam B coeluted, and therefore, it was not possible to determine the content of this compound.

The variation in the content of the individual POF compounds was analyzed between growing locations and varieties. For each of the POF compounds examined, the overall test for the effect of growing location showed a significantly higher content in potatoes grown at Tylstrup (*P*-value < 0.0001). As could be expected, a comparison of the same variety between the locations of growing by Duncan Grouping shows significant differences for all the POF compounds. The most striking difference between Vandel and Tylstrup is the soil type. Other factors, however, such as watering, fertilization, period of growing, and handling on harvest and storage may also have an influence on the content of aroma compounds found at Vandel and Tylstrup, respectively. For practical reasons, it was not possible to

Table 2. Effect of Growing Location and Variety on the Content of POF Compounds (nL/kg) in Precooked Vacuum-Packed Potatoes[a]

	Tylstrup				Vandel		
aroma compd	Jutlandia	Bintje	Sava	Dali	Jutlandia	Bintje	Sava
pentanal	260 (a)	140 (b)	110 (bc)	150 (b)	70 (cd)	70 (cd)	50 (d)
hexanal	3300 (a)	2000 (b)	1600 (b)	1800 (b)	900 (c)	860 (c)	650 (c)
(*E*)-2-pentenal	180 (a)	130 (b)	130 (bc)	90 (de)	110 (cd)	70 (e)	80 (de)
(*E*)-2-octenal	190 (a)	130 (b)	130 (b)	110 (b)	75 (c)	71 (c)	66 (c)
(*E*)-2-nonenal	40 (a)	24 (b)	23 (b)	24 (b)	16 (c)	15 (c)	13 (c)
(*E*,*E*)-2,4-heptadienal	140 (a)	91 (b)	96 (b)	67 (c)	93 (b)	63 (c)	67 (c)
(*E*,*E*)-2,4-nonadienal	72 (a)	45 (b)	42 (b)	40 (b)	27 (c)	22 (c)	18 (c)
(*E*,*E*)-2,4-decadienal	1200 (a)	580 (bc)	500 (cd)	620 (b)	350 (ef)	380 (de)	250 (f)

[a] Mean values are compared across growing location and variety for each compound by Duncan Grouping. Means with the same letter are not significantly different ($\alpha = 0.05$).

Table 3. Aroma Values of POF Compounds (on a log 10 scale) Determined in Vacuum-Packed Precooked Potatoes[a]

	Tylstrup				Vandel		
aroma compd	Jutlandia	Bintje	Sava	Dali	Jutlandia	Bintje	Sava
pentanal	1.1	0.8	0.7	0.83	0.5	0.5	0.36
hexanal	3.1 (1.8)	2.9 (1.6)	2.8 (1.5)	2.9 (1.6)	2.5 (1.3)	2.5 (1.3)	2.4 (1.1)
(*E*)-2-pentenal	−0.24	−0.38	−0.38	−0.54	−0.45	−0.65	−0.59
(*E*)-2-octenal	2.7 (−0.5)	2.6 (−0.66)	2.6 (−0.66)	2.5 (−0.74)	2.3 (−0.9)	2.3 (−0.93)	2.3 (−0.96)
(*E*)-2-nonenal	2.2	2.0	2.0	2.0	1.8	1.8	1.8
(*E*,*E*)-2,4-heptadienal	0.40	0.21	0.23	0.078	0.22	0.0051	0.0078
(*E*,*E*)-2,4-nonadienal	4.6	4.4	4.4	4.4	4.2	4.1	4.0
(*E*,*E*)-2,4-decadienal	4.4 (1.3)	4.1 (0.96)	4.0 (0.9)	4.1 (0.99)	4.0 (0.74)	3.9 (0.78)	3.7 (0.6)

[a] The values in the parentheses were calculated on the basis of the threshold values determined in mashed potatoes.

Table 4. Results from the Sensory Evaluation of the POF Intensity in Precooked Vacuum-Packed Potatoes[a]

	Tylstrup				Vandel		
	Jutlandia	Bintje	Sava	Dali	Jutlandia	Bintje	Sava
mean score	6.2 (a)	5.6 (ab)	5.6 (ab)	4.9 (b)	5.2 (b)	5.6 (ab)	4.8 (b)

[a] Mean values of the scores (cm), are compared for each variety by Duncan Grouping ($\alpha = 0.05$).

obtain identical conditions for these factors on the two locations, neither were the climatic data directly comparable.

Jutlandia, grown at Tylstrup, was found to possess a significantly higher amount of all the POF compounds in question. Within growing locations, significant differences were found among the other varieties in the content of (*E*)-2-pentenal, (*E*,*E*)-2,4-heptadienal, and (*E*,*E*)-2,4-decadienal.

From the quantitative data shown in Table 2 and the threshold values listed in Table 1, it was possible to calculate the aroma values of the POF compounds (Rothe and Thomas, 1963). This value gives an indication of the importance of the volatiles. Table 3 shows the aroma values of the POF compounds on a log 10 scale, in water and mashed potatoes, respectively. (*E*,*E*)-2,4-nonadienal and (*E*,*E*)-2,4-decadienal possessed maximum aroma value in all of the determinations, and therefore, they are assumed to be the most potent of the POF compounds examined. Additionally, hexanal, (*E*)-2-octenal, and (*E*)-2-nonenal have log aroma values substantially higher than 0 and may, therefore, be contributors to POF. When the aroma value calculations were based on the thresholds values determined in mashed potatoes, the aroma values were still relatively high for hexanal, while values for (*E*)-2-octenal and (*E*,*E*)-2,4-decadienal were less than 0 and around 1, respectively. The interpretation of the relative importance of the individual POF compounds is therefore highly influenced by the choice of matrix during determination of thresholds. However, the pattern of variation between the aroma values of the individual POF compounds, across growing location and variety, will not be influenced.

The reason for differences found in the development of POF compounds among the varieties could be related to both substrate concentration (unsaturated fatty acids) and enzyme activity (lipase, lipoxygenase, and fatty acid hydroperoxide lyases). Pun et al. (1980) conducted studies on the influence of lipid-degrading enzyme activity. In general, it was found that lipase activity was highly dependent upon variety but not on growing conditions, while lipoxygenase activity was less clearly defined and tended to vary greatly both within and between varieties (Gatfield and Woelk, 1971; Galliard and Matthew, 1973; Berkeley and Galliard, 1974). No consistent trends in variety specificity or relation to soil type could be found for any of the enzymes in these studies.

Sensory Evaluation of the Intensity of POF. Table 4 presents the results from the sensory evaluation of the POF intensity in precooked vacuum-packed potatoes. In accordance with the GC data, there was a significantly higher intensity of POF in potatoes grown at Tylstrup (P-value = 0.0038). Jutlandia grown at Tylstrup possessed the highest intensity of POF, and the difference found between Jutlandia grown at Tylstrup and Vandel was statistically significant. The same tendency was seen for Sava. These results were in accordance with the GC data shown in Table 2 and the aroma values listed in Table 3 as well. In contrast to Jutlandia and Sava, the POF intensity in Bintje was unaffected by the growing location. Thus, the environmental conditions make different influences on the ability of the varieties to develop POF. We are not able to show a clear connection between the content of POF compounds in Bintje and the sensory scores. This incoherence suggests that other compounds, probably in combination with the POF compounds in question, affect the POF intensity. Thus, compounds with more pleasant odors could suppress the POF intensity by a masking effect.

Looking at the results from the chemical and the sensory analysis in all, it is obvious that considerable differences in the concentration of the POF compounds examined are necessary before a change will be recognized by a sensory evaluation.

CONCLUSION

The present study shows that the growing location is of great importance for development of POF in precooked vacuum-packed potatoes. This result must be explained by the environmental conditions, through the period of growing, harvest, and storage. Therefore, to envelop the important factors concerning the growing management, further investigations are needed.

Five of the POF compounds examined possessed aroma values at levels in which an influence on the total odor of precooked vacuum-packed potatoes must be expected. (*E*,*E*)-2,4-nonadienal and (*E*,*E*)-2,4-decadienal were shown to be the most potent, followed by hexanal, (*E*)-2-octenal, and (*E*)-2-nonenal. However, since the connection between the GC data and the sensory evaluation of Bintje was equivocal, we suggest that additional compounds, probably by masking effects, cause influence on the intensity of POF.

In conclusion, this study has shown that both growers and breeders can contribute to reduce the undesirable development of POF. By optimizing the conditions for growing, harvest, and storage and breeding for suitable varieties with low levels of enzyme activity and unsaturated fatty acids we will be able to reduce the problem substantially.

ABBREVIATIONS USED

POF, potato off-flavor.

ACKNOWLEDGMENT

We thank Jette Skaarup Jensen for technical assistance.

LITERATURE CITED

ASTM Designation: E 679. Standard practice for determination of odor and taste thresholds by a forced-choice ascending concentration series method of limits. 1991; pp 1−5.

Belitz, H.-D.; Grosch, W. Lipids. In *Food chemistry*; Springer-Verlag: Berlin, Germany, 1987; pp 128−200.

Berkeley, H. D.; Galliard, T. Lipids of potato tubers. IV. Effect of growth and storage on the lipid-degrading enzymes of the potato tuber. *J. Sci. Food Agric.* **1974**, *25*, 869−873.

Brockhoff, P. M.; Müller, H. G. Random effect threshold models for dose−response relations with repeated measurements. *J. Royal Stat. Soc. Ser B.* **1997**, *59*, 431−446.

Buttery, R. G.; Hendel, C. E.; Boggs, M. M. Autoxidation of potato granules. Part I. Changes in fatty acids. *J. Agric. Food Chem.* **1961**, *9*, 245−252.

Buttery, R. G.; Guadagni, D. G.; Ling, L. C. Flavor compounds: volatilities in vegetable oil and oil−water mixtures. Estimation of odor thresholds. *J. Agric. Food Chem.* **1973**, *21*, 198−201.

Galliard, T.; Matthew, J. A. Lipids of potato tubers. II. Lipid-degrading enzymes in different varieties of potato tuber. *J. Sci. Food Agric.* **1973**, *24*, 623−627.

Gatfield, I. L.; Woelk, H. U. Lipoxidase and lipase in common potato *Solanum tuberosum*. *Lebensm.-Wiss. Technol.* **1971**, *4*, 129−130.

Hallberg, M. L.; Lingnert, H. Lipid oxidation of potato slices under conditions simulating the production of potato granules. *J. Am. Oil Chem. Soc.* **1991**, *68*, 167−170.

ISO/DIS.2. 13301. Sensory analysis − Methodology − General guidance for measuring odour, flavour, and taste detection thresholds by a three alternative forced-choice (3-AFC) procedure; 1998.

Larsen, M.; Poll, L. Odour thresholds of some important aroma compounds in strawberries. *Z. Lebensm. Unters.- Forsch.* **1992**, *195*, 536−539.

Lojkowska, E.; Holubowska, M. Changes of the lipid catabolism in potato tubers from cultivars differing in susceptibility to autolysis during the storage. *Potato Res.* **1989**, *32*, 463−470.

McCullagh, P.; Nelder, J. A. *Generalized linear models*; Chapman and Hall, London; 1989.

Osman-Ismail, F.; Solms, J. The formation of inclusion compounds of starches with flavor substances. *Lebensm.-Wiss. Technol.* **1973**, *6*, 147−150.

Petersen, M. A. The Royal Veterinary and Agricultural University, Denmark, unpublished results, 1998.

Petersen, M. A.; Trolle, E. T. Vitamin C retention and sensoric quality of potatoes and peas in a cook-chill system with packaging in modified atmosphere. *Hygiene and Nutrition in Foodservice and Catering* **1996**, *1*, 175−190.

Petersen, M. A.; Poll, L.; Melchior Larsen, L. Identification of compounds contributing to boiled potato off-flavour ("POF"). *Lebensm.-Wiss. Technol.* **1998**, in press.

Pun, W. H.; Khan, A. A.; Chung, I.; Haydar, M.; Hadziyev, D. Lipid distribution in potato tubers. *Potato Res.* **1980**, *23*, 57−74.

Rothe, M.; Thomas, B. Aromastoffe des Brotes. *Z. Lebensm. Unters. Forsch.* **1962−63,** *119*, 302−310.

SAS Institute Inc. *SAS/STAT Software: The GENMOD Procedure*, release 6.09; SAS technical report p-243; SAS Institute Inc.: Cary, NC; 1993.

Schirle-Keller, J. P.; Reineccius, G. A.; Hatchwell, L. C. Flavor interactions with fat replacers: effect of oil level. *J. Food Sci.* **1994**, *59*, 813−815, 875.

Thybo, A. K.; Christiansen, J. Quality of precooked vacuum-packed potatoes (*Solanum tuberosum* L.) in relation to cooking methods and oxygen permeability of the packing material. *J. Food Qual.* **1996**, *19*, 231−241.

van Gemert, L. J.; Nettenbreijer, A. H. *Compilation of odour threshold values in air and water*; National Institute for Water Supply, Voorburg, Netherlands. Central Institute for Nutrition and Food Research TNO, Zeist, Netherlands; 1977.

Received for review July 2, 1998. Accepted December 30, 1998. The support of The Danish Research and Development Programme for Food Technology through LMC, Centre for Advanced Food Studies, is acknowledged.

JF9807115